AN ABSTRACT OF THE THESIS OF

GEORGE FOSSAS CORYELL for the degree of MASTER OF SCIENCE

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Title: STRATIGRAPHY, SEDIMENTATION, AND PETROLOGY OF THE TERTIARY ROCKS IN THE BEAR CREEK-WICKIUP MOUNTAIN-BIG CREEK AREA, CLATSOP COUNTY, OREGON

Abstract approved: Alan R. Niem

Alan R. Niem

Six Tertiary rock units are exposed in the Bear Creek-Wickiup Mountain-Big Creek area. They are: the late Oligocene to early Miocene Oswald West mudstones; the Big Creek sandstone member, the Pipeline member (a new unit), and the Silver Point mudstone member of the early to middle Miocene Astoria Formation; and the middle Miocene Depoe Bay and Cape Foulweather petrologic-type basalts. Quaternary alluvium locally overlies these units.

The Oswald West mudstones consist of over 2,000 feet of mudstones, tuffaceous siltstones, and subordinate very fine- to fine-grained sandstones which were deposited in a shallowing, open-marine, continental-shelf environment. The tuffaceous nature indicates considerable input from explosive dacitic and/or rhyolitic volcanism in the ancestral Cascade Range.

Regression subaerially exposed the thesis area during the middle early Miocene.

The Big Creek sandstone member unconformably overlies the Oswald West mudstones. It is a transgressive, fining-upward, 1,500-foot sequence of littoral and shallow-marine sandstones which were deposited on a subsiding, inner-continental shelf.

The overlying Pipeline member consists of 2,600 feet of very thickly bedded medium-grained arkosic sandstones complexly intertonguing with deep-marine mudstones. Sandstone intrusions into the mudstones are common. Fossils, lithologies, and geometry suggest the member is a submarine-canyon facies. The structureless sandstones were probably deposited by grain-flow and fluidized-flow mechanisms.

The Silver Point mudstone member consists of up to 1,600 feet of structureless to well-laminated hemipelagic mudstones deposited in a middle-continental shelf to upper-slope setting. The unit is lateral to, and overlies, the Pipeline member.

Aphanitic to fine-grained Depoe Bay Basalt intruded all the Tertiary sedimentary units. Local submarine volcanic centers formed over 400-foot sequences of pillow basalts, structureless to well-bedded hyaloclastites, and thick, structureless basaltic breccias, which are intruded by feeder dikes. Stratified, locally graded deposits are thought to be the result of turbulent, hot volcanic glass-water vapor mixtures transported by density currents. Minor subaerial flows and basalt conglomerates indicate that some volcanic centers built up above sea level. Locally derived pillow basalts and breccias appear to underlie Columbia Plateau-derived subaerial basalt flows of the Columbia River Group to the east of the thesis area.

The overlying, sparsely porphyritic Cape Foulweather Basalt is also of local submarine eruptive origin. Overall lithologies are similar to the Depoe Bay Basalt. A fan-like topographic expression and fossils suggest accumulation of stratified hyaloclastites on a submarine apron similar to those recognized surrounding some modern seamounts and basaltic islands.

Heavy minerals and sandstone petrology suggest both andesitic and regionally metamorphosed source areas, which are most likely the ancestral Cascades and areas to the east and north. A major river system, similar to the modern Columbia River drainage, is postulated to have been the main transporting agent of Oswald West and Astoria detritus to the thesis area. Some Big Creek sandstones were deposited or reworked by longshore currents.

The Pipeline sandstones are generally more feldspathic and have higher K-feldspar/plagioclase ratios than the Big Creek sandstones. The two sandstones can be differentiated mineralogically on a quartz-plagioclase-potassium feldspar ternary diagram, and texturally on a bivariant plot of deviation versus mean diameter.

The Depoe Bay and Cape Foulweather Basalts are chemically similar to the correlative units which occur on the Oregon Coast. In the thesis area, the two units are most easily differentiated by the consistently higher TiO_2 in the latter unit.

Post-Astoria deformation superimposed high-angle normal faults and gentle north-south folds on a regional northward dip.

Petroleum potential within the area is low, but projection of the Pipeline member offshore suggests the existence of ideal accumulation sites off the mouth of the modern Columbia River.

Stratigraphy, Sedimentation, and Petrology of the Tertiary Rocks in the Bear Creek-Wickiup Mountain-Big Creek Area, Clatsop County, Oregon

by

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I thank Mr. Bruce Clausen, Astoria City Engineer, and Mr. Jim Osborne, Caretaker, for their complete cooperation in allowing me to work in the Astoria Watershed. Thanks also to Mr. Bill Ellison, who gave permission to work on Crown Zellerbach Corporation property, and to Mr. Jim Lavely, who provided topographic and logging-road maps of the area. I am appreciative of Mr. Tom Olson, Mr. Dave Culver, and Mr. Russ McKinley of Boise-Cascade Corporation, for their helpfulness and cooperation during my work in the Big Creek drainage area.

Molluscan fossils were identified by Dr. Warren O. Addicott of the U.S. Geological Survey. Dr. C. Kent Chamberlain of the University of Nevada, Las Vegas, examined trace fossil samples, and Dr. Weldon W. Rau of the Washington State Department of Natural Resources identified microfossils.

One of the most helpful persons during the thesis work was my colleague, Mike Nelson. Mutual exchanges of information and numerous discussions of the stratigraphy of the Astoria Formation released many ideas that otherwise may have been trapped in my head. I hope I have aided him as much as he has helped me.

A very important factor in getting to where I am now is the ever-present moral and emotional support of my parents, Mr. and Mrs. George C. Coryell, and my wife, Linda Watson. Thank you to my uncle, Kirby Coryell, for sparking my interest in geology and giving me my first opportunity as a working geologist.

"It looked as though the time spans of scientific truths are in inverse function of the intensity of scientific effort."

R. M. Pirsig, 1974
Zen and the Art of Motorcycle Maintenance

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INTRODUCTION

Purposes of Investigation

A coherent picture of the geology of the northwestern Oregon Coast Range has not yet been completed. During the past few years Oregon State University geology students working under the guidance of Dr. Alan Niem have approached this problem utilizing detailed geologic mapping, along with systematic sedimentological and stratigraphic analysis. This thesis is a continuation of that effort.

The Bear Creek-Wickiup Mountain-Big Creek area is of interest for two major reasons. The first is that it contains two facies (previously undifferentiated) of the Astoria Formation which have not been analyzed in detail. The second is that the area may be the site of an interfingering of petrologically-similar, locally-derived and Columbia Plateau-derived basalts.

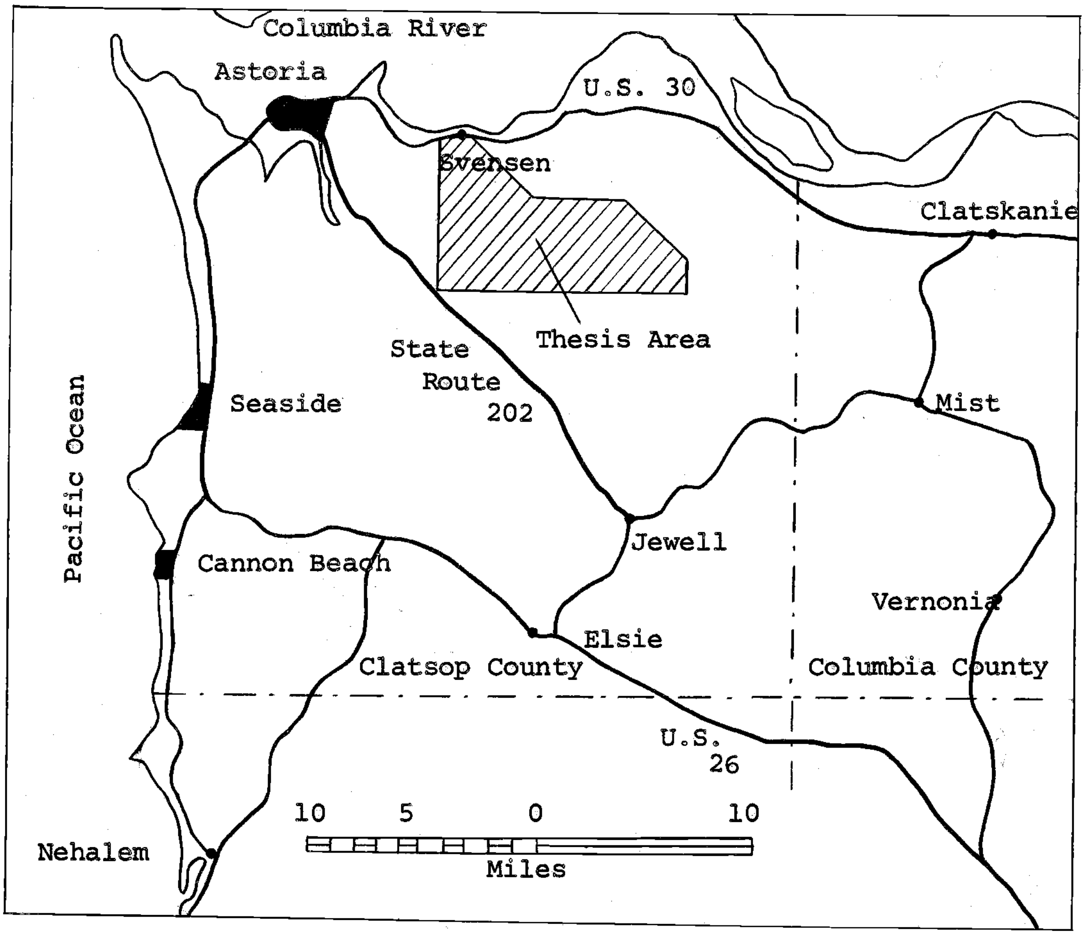
The objectives of this study are: 1) to construct a geologic map of the thesis area; 2) to describe the sedimentary and volcanic rock units; 3) to unravel the stratigraphy and analyze the sedimentary units as to paleoenvironments, provenance, and ages; 4) to determine the derivation of the basalts that form Wickiup Mountain; 5) to interpret the depositional and tectonic history of the area; and 6) to evaluate the economic potential of the area, with an emphasis on petroleum.

Location and Accessibility

The thesis area is approximately 47 square miles in size and is in northeastern Clatsop County, Oregon, six miles east of the City of Astoria (Figure 1). The town of Svensen on the Columbia River is partially included in the northwestern corner of the area, and a segment of Big Creek is near the eastern boundary (Plate I). The Astoria Reservoir and Bear Creek are also within the study area. Elevations range from near sea level at the Columbia River to 2700 feet on Wickiup Mountain.

Accessibility is generally good. The Columbia River Highway (U.S. 30) is directly north of the area, and the Nehalem Highway (State Route 202) is near the southwestern corner (Figure 1). Most of the interior is accessible by logging roads.

Most rock exposures are in logging-road cuts, deep stream channels, or basalt cliffs and ridges. Much of the northwestern part of the area has been recently logged and contains many new roadcut exposures. Rocks on the western side of Wickiup Ridge are well exposed, and Big Creek in



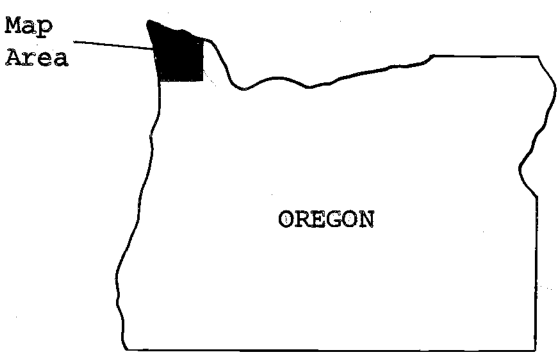


Figure 1. Index map showing the location of the thesis area.

the east contains numerous stream cuts of sandstones and mudstones.

However, because of a dense undergrowth and lack of logging roads, field work is extremely difficult in some sections of the thesis area. These include the southwesternmost and southeasternmost parts of the study area, and the east-central side of Wickiup Ridge (Plate I).

Permission must be obtained from the Astoria city engineer before working in the Astoria Watershed. The Boise-Cascade Corporation should be contacted before entering the Big Creek drainage area, as current logging activity makes the Big Creek Mainline extremely hazardous to travel. The Crown Zellerbach Corporation should be notified before working in the western part of the thesis area.

Previous Work

The first pioneering geological reconnaissance of northwestern Oregon was undertaken by Diller (1896). In an oil and gas investigation of northwestern Oregon that included the study area, Warren and others (1945) mapped undifferentiated Tertiary sedimentary rock and basalt at a scale of 1:143,000.

The Miocene Astoria Formation and the overlying basalts are the most extensive stratigraphic units in the thesis area, according to a geologic map of western Oregon compiled by Wells and Peck (1961). Pliocene nonmarine sandstone and sandy siltstone are shown to occur in the northern part of the area, along with a syncline trending northwest through the central part.

The western part of the area was mapped by Dodds (1963) in a paleontological M.S. thesis completed at the University of Oregon. He included "Oligocene to early Miocene" siltstones and fine-grained carbonaceous sandstones in the Astoria Formation. A late Miocene "post-Astoria" sandstone unit is shown to occur extensively throughout the western part of the thesis area. Dodds (1963) postulated a middle Miocene hiatus between the Astoria Formation and "post-Astoria" sandstone.

Schlicker and others (1972) included the western part of the study area in an environmental geology study of coastal Clatsop and Tillamook Counties. They recognized undifferentiated Oligocene to Miocene sedimentary rocks and a late Miocene sandstone, and reported on the engineering properties of the rock units. Beaulieu (1973) completed a similar engineering geology study of inland Clatsop and Tillamook Counties, which included the eastern part of the thesis area.

Snavely and others (1973) stated that some Columbia River Plateau-derived basalt flows extended as far west as Big Creek, where they entered a marine embayment and formed pillow lavas and breccias. They reported Yakima- and late-Yakima-type chemistries from samples collected on Nicolai

Mountain, adjacent to the eastern boundary of the thesis area.

Cooper (1975, personal communication), in a recent regional stratigraphic investigation of the Astoria Formation, has recognized a thick Astoria-age sandstone (Big Creek sandstone member) along Big Creek, and also in a considerable part of the western half of the thesis area. He has also mapped, on a reconnaissance scale, Oligocene to early Miocene sedimentary rocks, a "post-Astoria" sandstone unit, and the Silver Point mudstone member of the Astoria Formation.

Methods of Investigation

Field Methods

Field work was conducted during the summer of 1976 and the spring of 1977. Mapping utilized aerial photographs and topographic maps at a scale of 1:12,000. U-2 Hi-Flight infrared imagery aided in the mapping of structure and placement of contacts. These data were later transferred to Svensen (1955) and Cathlamet (1953) U.S. Geological Survey 15' quadrangle maps enlarged to a scale of 1:15,840 (Plate I).

Stratigraphic sections were measured with an Abney level mounted on a five-foot staff (Appendices I-III). A Brunton compass was used to measure trough cross-stratification orientations, which were later rotated on a stereonet to correct for tectonic tilt (Potter and Pettijohn, 1963). Lithologic descriptions were aided with the use of a grain-size chart and a Geological Society of America Rock-Color Chart (1970). Sediment-size classification is that of the National Research Council (Lane and others, 1957), and stratification and cross-stratification terminology is after McKee and Weir (1953).

Basalts were mapped as two separate units (Depoe Bay and Cape Foulweather Basalts) on the basis of hand specimen examination for the absence or presence of phenocrysts (Snavely and others, 1973). Identifications were later confirmed by chemical analyses. Volcaniclastic terminology is after Fisher (1961, 1966).

Representative samples of major lithologies were collected for laboratory analysis (see Appendix XIV and Plate I for locations).

Analytical Methods

Laboratory study of rock samples included size analysis of sandstones, petrography, X-ray diffraction, pyrolysis-fluorescence of mudstones, whole-rock chemical analysis of basalts, and preparation of fossils for identification.

Size analyses of 24 sandstones were carried out utilizing Tyler sieves graduated in quarter-phi intervals (Appendix X). The moment measures of Folk and Ward (1957) were computed from cumulative curves and plotted in all possible combinations on binary graphs. The appropriate parameters were plotted on Passega's (1957) "CM" diagram.

Tetrabromoethane (sp. gr. 2.95) was used to separate the 2.5-3.5 phi-size fractions obtained from sieving into light and heavy mineral separates. Seven heavy mineral separates were mounted in Canada balsam and line counted with a petrographic microscope (Appendix VIII).

Thirty thin sections of sandstones, mudstones, and basalts were examined with a petrographic microscope. Modal analyses were performed on 13 sandstones and four basalts (Appendices VII, XI). Sandstone billets were stained with a saturated sodium cobaltinitrite solution and point counted for potassium feldspar. Sandstone and basalt classifications are those of Williams, Turner, and Gilbert (1954).

The less-than-two-micron fractions from five sandstones and mudstones were analyzed by X-ray diffraction. The method of sample pretreatment and analysis is described in Appendix IX.

Seven mudstone samples were tested for "live" hydrocarbons utilizing a Turner Fluorometer and a method used by the Shell Development Company. This method is described in Appendix XIII.

Whole-rock, major-element analyses of 18 basalt samples were obtained utilizing a combination of X-ray fluorescence, atomic absorption spectrophotometry, and visible light spectrophotometry (Appendix XII). The samples were prepared in accordance with Taylor's Cookbook for Standard Chemical Analysis (1974). The data were plotted on silica-variation diagrams to aid in the identification of petrologic types.

Microfossil samples were disaggregated by the following method: 1) baking the sample at 250°C.; 2) soaking in kerosene; 3) soaking in near-boiling water; 4) soaking in kerosene; and 5) soaking in near-boiling water. Microfossils from the wet-sieved, greater-than-three-phi fractions were picked and mounted for identification by Dr. Weldon W. Rau of the Washington State Geology and Earth Resources Division (Appendices IV, VI).

Unfortunately, the majority of the Foraminifera were highly weathered, and consequently unidentifiable. The abundance of nondiagnostic arenaceous forms complicated this problem. Several 12-foot deep holes were drilled with a power auger in the field in an attempt to obtain unweathered microfossils, but with no success.

Molluscan fossils were identified by Dr. Warren O. Addicott of the U.S. Geological Survey. Dr. C. Kent Chamberlain of the University of Nevada at Las Vegas examined the trace fossils. Fossil identifications of localities are listed in Appendices IV-VI and XIV, respectively.

REGIONAL STRATIGRAPHY

Tertiary Stratigraphic Units

Over 25,000 feet of Tertiary volcanic and sedimentary rocks accumulated in an elongate basin that is now the Oregon and Washington Coast Ranges, Olympic Mountains, and the Puget-Willamette lowland (Snavely and Wagner, 1963). The northern Oregon Coast Range is a north-plunging anticlinal upwarp, which exposes an Eocene to Miocene sequence of strata.

The oldest rocks are the early to middle Eocene Tillamook Volcanics (equivalent to the Siletz River Volcanics) (Figure 2), which are dominantly tholeiitic pillow basalts and submarine breccias with minor interbedded tuffaceous siltstones and basaltic sandstones (Snavely and Wagner, 1964). The base of these volcanics is not exposed (Snavely and Wagner, 1963), but they are thought to overlie oceanic crust (Snavely and others, 1968). Geophysical studies indicate thicknesses up to 20,000 feet near volcanic centers (Snavely and Wagner, 1964).

Overlying the Eocene volcanics in the northeastern part of the Oregon Coast Range are the Cowlitz, Keasey, Pittsburg Bluff, and Scappoose Formations, and the Columbia River Group (Figure 2). The Oswald West mudstones, Astoria Formation, and Depoe Bay and Cape Foulweather Basalts

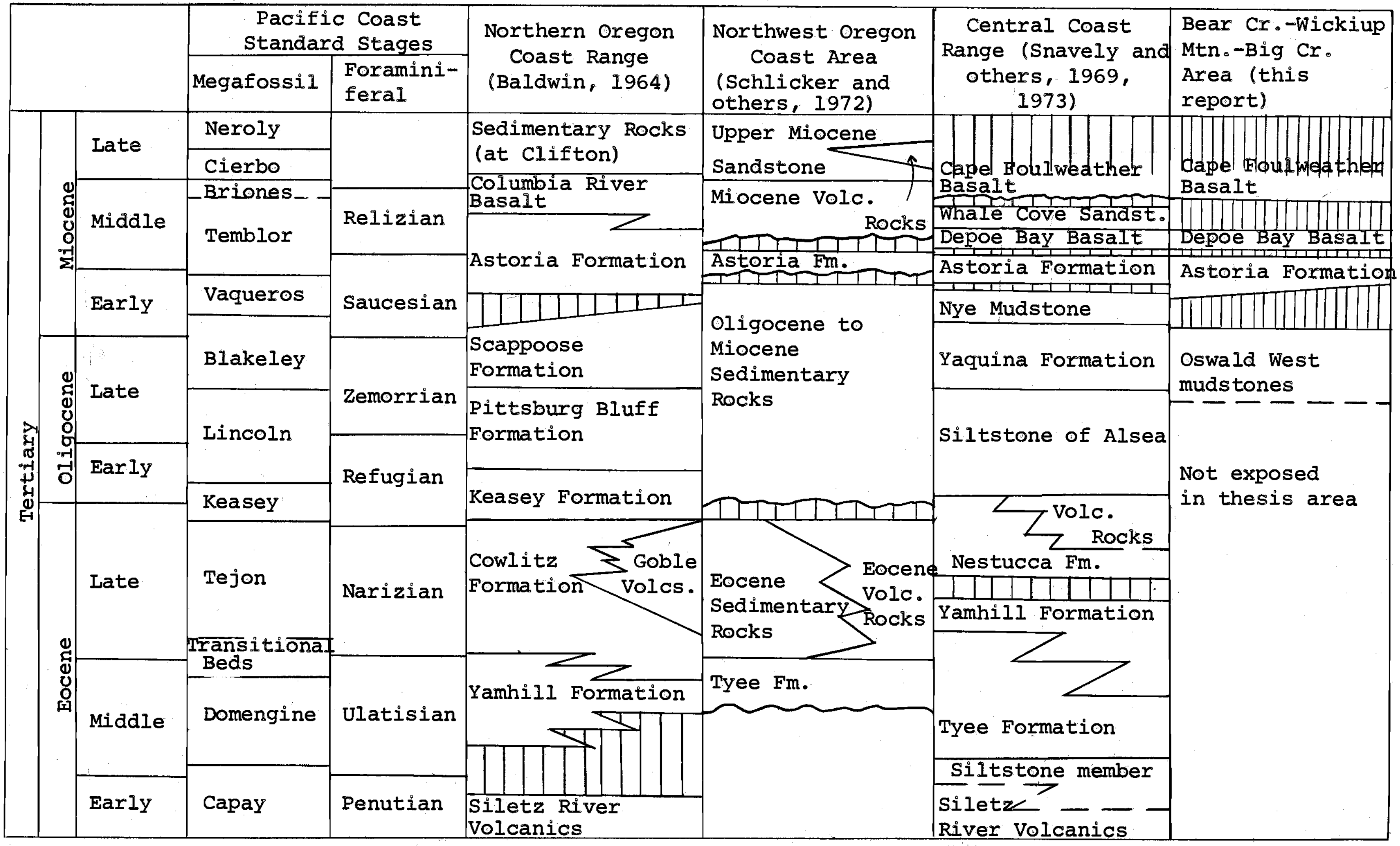


Figure 2. Correlation chart of Tertiary units of the central and northern Oregon Coast Range.

overlie the Tillamook Volcanics on the northwestern limb of the anticlinorium.

The late Eocene Cowlitz Formation unconformably overlies the Eocene volcanics in the northeastern Oregon Coast Range (Warren and Norbisrath, 1946). It consists of 1,000 feet of deep-marine mudstones, arkosic sandstones, and local conglomerates (Niem and Van Atta, 1973). Pillow basalts and breccias of the Goble Volcanics interfinger with the upper part (Wilkinson and others, 1946). In southwestern Washington the Cowlitz Formation is locally more than 8,000 feet thick, of which the Goble Volcanics are considered to be a member (Hendriksen, 1956).

Eighteen hundred feet of tuffaceous siltstones and mudstones, and minor volcanic sandstones, form the latest Eocene to early Oligocene Keasey Formation. The contact with the underlying Cowlitz Formation is not clearly understood, but it appears to be an angular unconformity (Niem and Van Atta, 1973).

The Pittsburg Bluff Formation conformably overlies the Keasey Formation and consists of middle Oligocene massive to laminated beds of arkosic and glauconitic sandstones, siltstones, and mudstones. Local beds of basaltic conglomerates, cross-bedded channels, and coal lenses occur in the upper part (Niem and Van Atta, 1973). Tuffaceous mudstones of Keasey and Pittsburg Bluff age are undifferentiated on the northwestern side of the Oregon Coast Range (Wells and Peck, 1961).

Late Oligocene to earliest Miocene arkosic sandstones and tuffaceous mudstones of the Scappoose Formation conformably(?) overlie the Pittsburg Bluff Formation. The Scappoose Formation is deltaic in origin (Van Atta, 1971), and is equivalent in age to the type deep-marine Oswald West mudstones to the west (Niem and Van Atta, 1973; Cressy, 1974).

The early to middle Miocene Astoria Formation consists of deltaic and shallow-marine arkosic and lithic sandstones, turbidite sandstones, and deep-marine mudstones, and is exposed from Astoria to Newport, Oregon (Cooper, 1978). At Newport, the Astoria Formation is 2,000 feet thick (Snavely and others, 1969). Wolfe and McKee (1972) suggest a thickness of approximately 4,500 feet for the Astoria Formation in southwestern Washington, across the Columbia River from Astoria.

The locally-derived middle Miocene Depoe Bay and Cape Foulweather Basalts unconformably overlie the Astoria Formation in northwest-coastal Oregon. These basalts are petrologically similar and are considered to be coeval with the Columbia River Plateau-derived Yakima- and late-Yakima-type basalts (Columbia River Group)(Snavely and others, 1973).

Plio-Pleistocene valley-fill deposits of the ancestral Columbia River locally overlie the older strata. The most notable of these is the Pliocene Troutdale Formation in the

Portland and Astoria areas (Trimble, 1957; Schlicker and others, 1972).

Pacific Northwest Molluscan Stages

Until recently, California molluscan stages were used for correlation of much of the Tertiary strata in western Oregon and Washington (Figure 2). The exceptions are the "Keasey," "Lincoln," and "Blakeley" Stages. Unfortunately, the warm-water fauna that define the California stages are not commonly found in Pacific Northwest strata. The "Vaqueros" Stage, for example, cannot be recognized in Oregon and Washington (Addicott, 1967).

As a result, new provincial molluscan stages have been proposed by Armentrout (1975) and Addicott (1976a, b) for the Tertiary of Oregon and Washington. The stages commonly referred to in this thesis are "upper Matlockian" (equals "Juanian"), "Pillarian," and "Newportian." The Pacific Northwest stages are correlated to the California stages and to absolute time in Figure 3, and to the lithostratigraphic units used in this thesis in Figure 4.

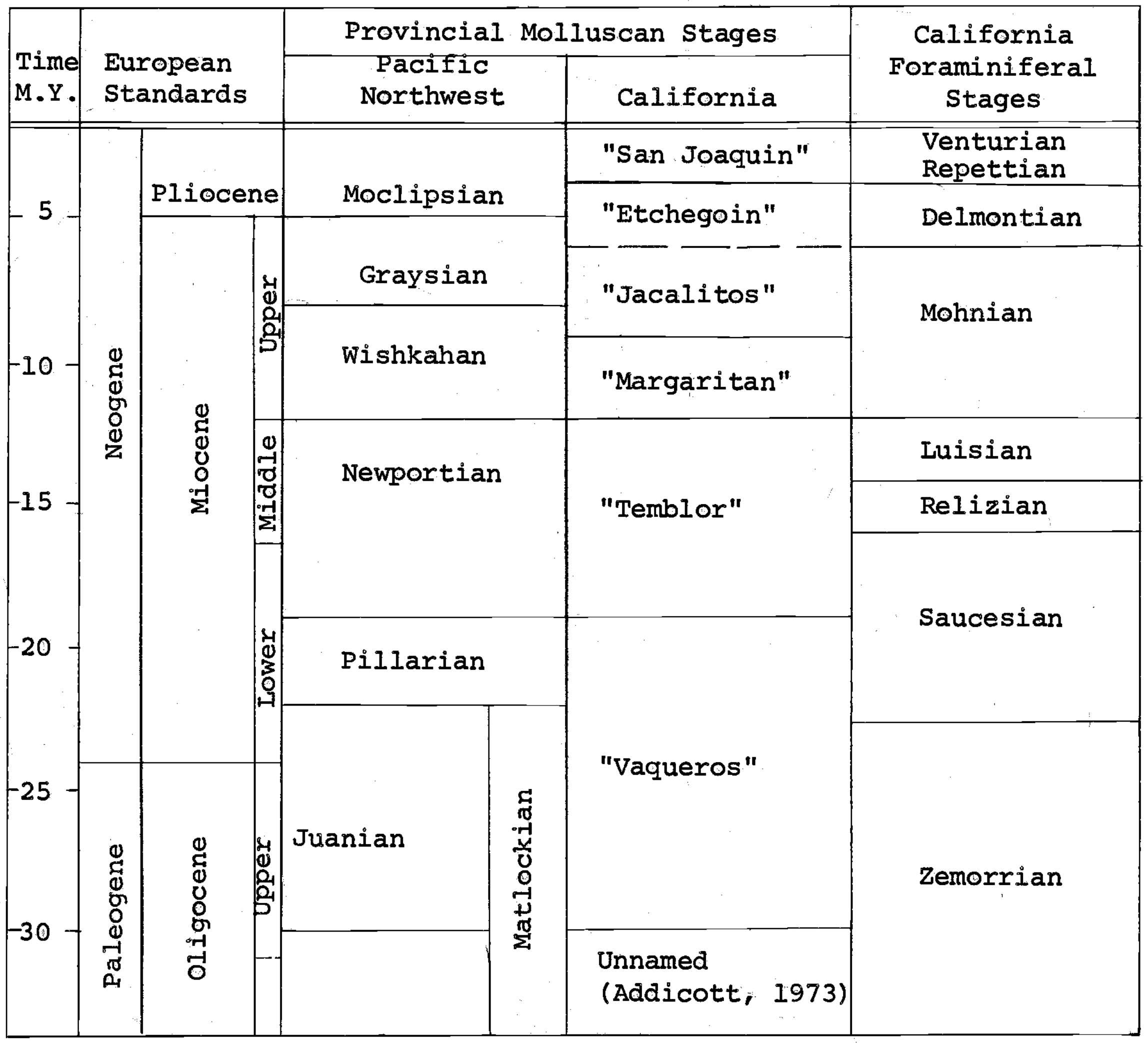


Figure 3. Correlation chart of molluscan and foraminiferal stages (courtesy of Warren O. Addicott, 1977, written communication).

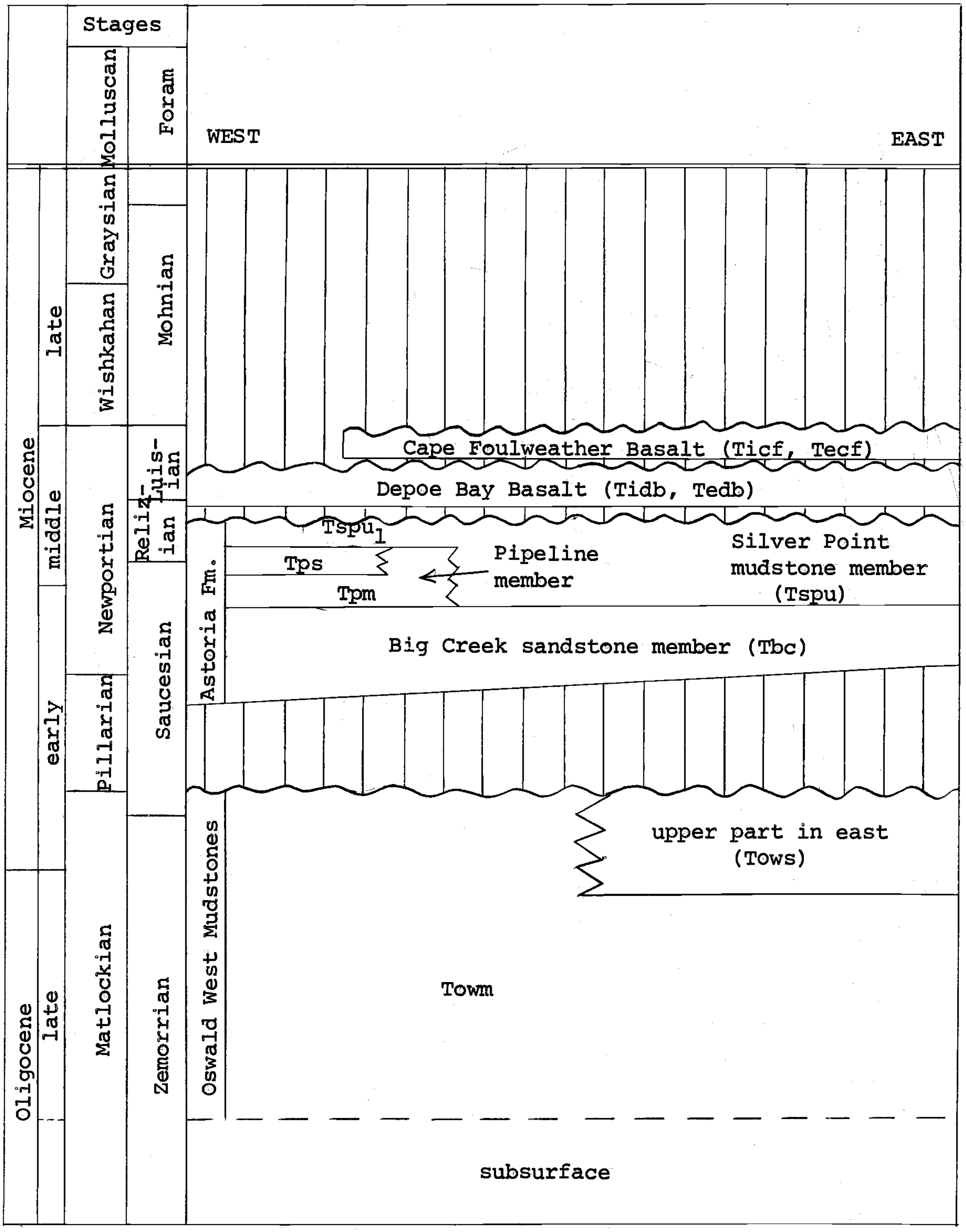


Figure 4. Tertiary stratigraphy of the thesis area.

STRATIGRAPHY AND SEDIMENTATION IN THE THESIS AREA

Six Tertiary rock units are exposed in the Bear Creek-Wickiup Mountain-Big Creek area. They are: the late Oligocene to early Miocene Oswald West mudstones; the Big Creek sandstone member, the Pipeline member, and the Silver Point mudstone member of the early to middle Miocene Astoria Formation; and the middle Miocene Depoe Bay and Cape Foulweather petrologic-type basalts (Figure 4). Quaternary stream alluvium locally overlies these units.

Oswald West Mudstones

Nomenclature

A 1,600-foot sequence of interbedded silty mudstones and tuffaceous siltstones of late Oligocene to early Miocene age is exposed in the sea cliffs along Short Sand Beach in Oswald West State Park, 30 miles south of Astoria (Cressy, 1974). Warren and others (1945) mapped these rocks as "beds of Blakeley age." Niem and Van Atta (1973) and Cressy (1974) informally referred to this stratigraphic unit as the Oswald West mudstones, which is the nomenclature used in this thesis.

Distribution

The Oswald West mudstones are less resistant to erosion than the overlying Big Creek sandstone and tend to form relative topographic lows. The unit is exposed in the southwestern corner of the thesis area, and forms the core of a north-plunging anticline in the southeastern part (Figure 5 and Plate I).

Lithologies and Structures

Two mappable units have been differentiated within the Oswald West mudstones in the thesis area. Claystones and silty mudstones characterize the lower unit (Towm). They are best exposed in roadcuts along Fisher Spur 11-M (SW¼, sec. 9, T. 7 N., R. 8 W.) and Kalina Road (SW¼, sec. 24, T. 7 N., R. 7 W.)(Plate I). A 1,200-foot thickness is estimated for the thesis area, based on regional dip and outcrop pattern. The upper unit (Tows) consists of tuffaceous siltstones and very fine- to fine-grained sandstones with subordinate interbedded silty mudstones. The upper unit occurs only in the eastern part of the thesis area and is thought to interfinger laterally with the lower unit to the west (Figure 4). The best exposures crop out along Big Creek and Tillasqua Creek (secs. 23 and 24, T. 7 N., R. 7 W.)(Plate I). A 240-foot partial section of the upper unit was measured and described along Big Creek (Appendix I). A

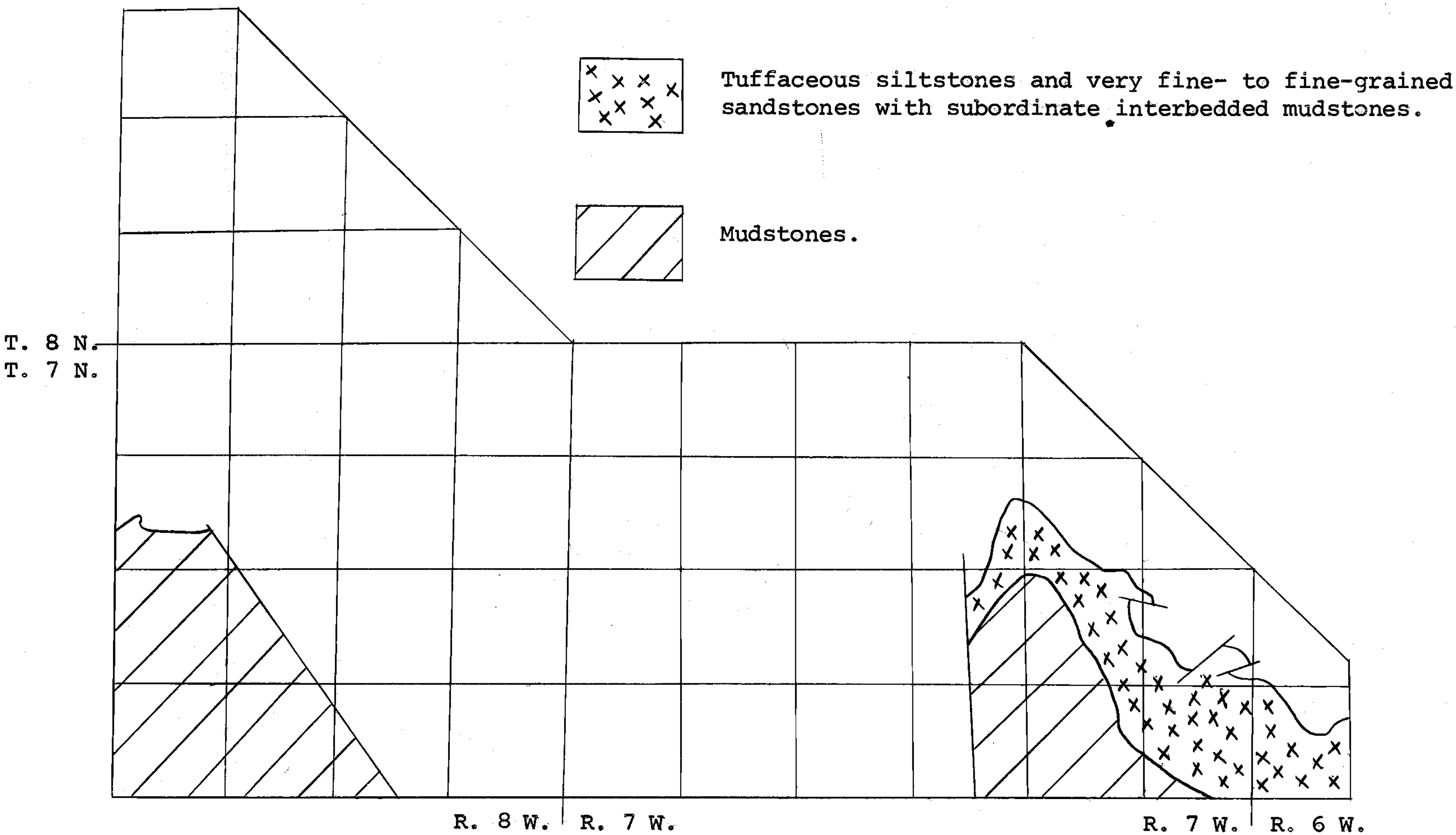


Figure 5. Outcrop distribution of the Oswald West mudstones.

maximum thickness of 1,000 feet is estimated for the upper unit, although structural repetition is possible.

Outcrops of the mudstones that form the lower unit (Towm) are typically deeply weathered to an iron-stained grayish orange (10YR7/4) to moderate brown (5YR4/4). Exposures locally display spheroidal weathering, and commonly have a chippy mudstone talus (Figure 6). Liesegang rings are associated with weathering surfaces. Bedding is obscured, and can be delineated only by rare tuff beds. A mottled appearance and scattered burrow(?) structures are suggestive of bioturbation. A small, three-foot thick, isolated lens of glauconitic sandstone was found near the contact with the upper unit.

The contact between the two units is not exposed, but is presumed to be gradational upward from mudstones below to siltstones and very fine- to fine-grained sandstones above.

Siltstones of the upper unit (Tows) are typically olive gray (5Y4/1) in fresh exposures, but are more commonly weathered to a moderate-yellowish brown (10YR5/4). They are moderately indurated, thin to very-thick bedded, and crop out in steep stream banks along Big Creek. Contacts with interbedded mudstones are sharp, or gradational over a few inches. Rare tuff beds occur in the unit.

Terebellina and _Planolites_ are common trace fossils in the siltstones and mudstones of the upper unit, with rarer

Figure 6. Exposure of lower Oswald West mudstone displaying structureless, weathered character and chippy talus. Note faint, two-inch thick tuff bed above head of hammer. Cut on Kalina Road.

Helminthoida-Scalarituba(?) (Chamberlain, 1977, written communication) (Figure 7; Appendix IV). Profuse bioturbation is typical. Local concentrations of mollusks are present also.

Interbedded with the siltstones are subordinate very fine- to fine-grained feldspathic sandstones. Siltstone-sandstone contacts are sharp. Exposures of the sandstones are up to approximately 25 feet thick, but are estimated to make up no more than 20 percent of the total volume of the upper unit. The sandstones are friable and structureless, and are composed of dominantly subangular to subrounded quartz and feldspar with minor micas and lithic fragments, including rare, dark, subrounded volcanic rock grains up to two millimeters in diameter. Fresh exposures are very light gray (N8), but are more commonly weathered to moderate brown (5YR4/4). Liesegang rings locally may impart a false impression of bedding (Figure 8).

Contact Relations

A lower contact of the Oswald West mudstones does not crop out in the thesis area. The upper contact is described in the Contact Relations section of the Big Creek sandstone member of the Astoria Formation.

Figure 7. Possible meandering, tube-like Scalarituba or Helminthoida burrows in upper Oswald West siltstone. Quarter for scale. Fossil Locality 147.

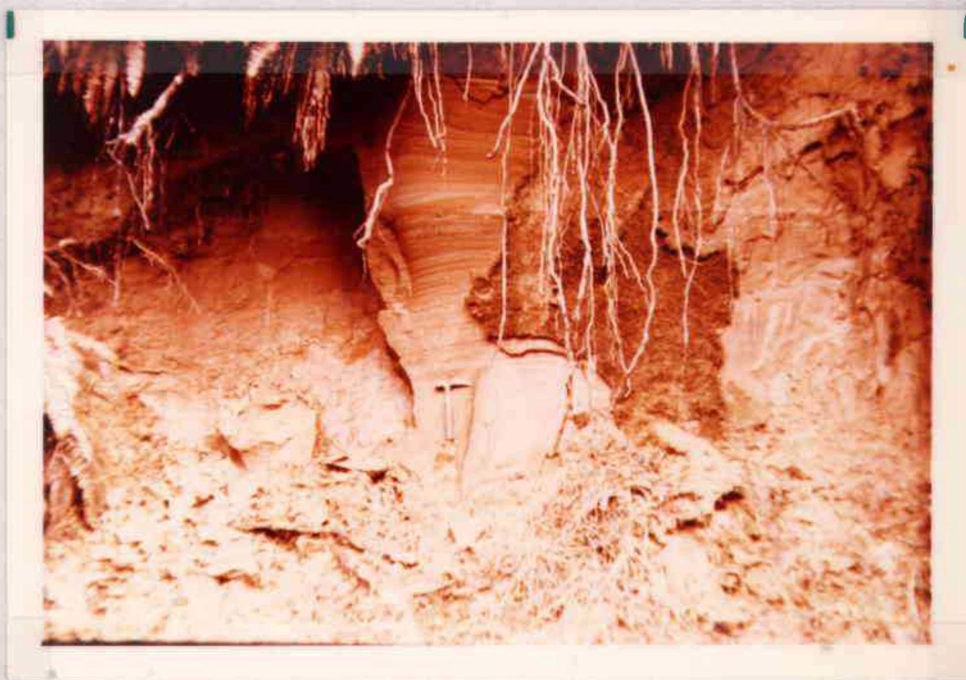


Figure 8. Exposure of fine-grained sandstone in the upper part of the Oswald West. What appear to be laminations are liesegang rings. Cut on Kalina Road, hammer for scale.

Age and Correlation

The lower unit (Towm) of the Oswald West mudstones is considered to be of late Oligocene to earliest Miocene age, based on contiguous Oswald West mudstones to the west of the thesis area which contain Zemorrian Foraminifera (Nelson, 1977, personal communication). Molluscan assemblages in the upper unit (Tows) are of late Oligocene to earliest Miocene age and are referable to the upper part of the Matlockian Stage (Addicott, 1975, written communication to Cooper, fossil localities 208.9 and 209.9; Appendix IV). Thracia schencki, Macrocallista sp., and Periploma bainbridgensis were collected from the upper siltstones and silty mudstones by Cooper and are indicative of a pre-middle Miocene provincial age. Additionally, the collections contain Molopophorus(?) sp. and Acila sp. which are unlike any known species from the Astoria Formation.

The Oswald West mudstones in the thesis area are correlated with the type section at Oswald West State Park (Cressy, 1974), based on similarities in age and lithologies. Both units are late Oligocene to early Miocene and consist of predominantly tuffaceous, bioturbated, marine siltstones and mudstones. Similar rocks have been mapped nearly continuously from the type section to the western boundary of the thesis area by Smith (1975), Neel (1976), Tolson (1976), Penoyer (1977), and Nelson (1977, personal communcation).

The Oswald West mudstones in the study area are considered to be coeval with the Scappoose Formation in the northeastern part of the Oregon Coast Range (Van Atta, 1971; Warren and Norbisrath, 1946; Wells and Peck, 1961), the Yaquina Formation in the Newport area (Snavely and others, 1969, 1976), the upper part of the Lincoln Creek Formation in southwestern Washington (Armentrout, 1975; Wolfe and McKee, 1972), and the upper part of the upper member of the Twin River Formation in the northern Olympic Mountains, Washington (Addicott, 1976b).

Depositional Environments

The molluscan fossil assemblages and sequence of lithologies suggest that the Oswald West strata in the thesis area were deposited in a shallowing, open-marine, continental-shelf environment.

No molluscan or diagnostic foraminiferal fossils were found in the thick, lower bioturbated mudstone unit (Towm) in the study area. However, foraminiferal and molluscan assemblages collected by Nelson (1977, personal communication) in contiguous Oswald West mudstones to the west of the thesis area indicate that they were deposited at outer-sublittoral to middle-bathyal depths.

On the modern middle to outer Oregon continental shelf is a hemipelagic bioturbated mud facies similar in lithologic character and presumed water depths to the lower Oswald

West mudstone unit (Towm). This mud facies develops during periods of peak discharge of the Columbia River and moderate wave conditions (Kulm and others, 1975). Hemi-pelagic mud is transported in suspension by low-density turbid currents and flocculated on the middle to outer continental shelf at depths greater than 90 meters. The thin lens of glauconite observed at the top of the lower unit is also suggestive of "outer-shelf" conditions (Kulm and others, 1975). However, using the modern shelf as a model for an ancient one is questionable, as the sediment supply and erosive and depositional processes have probably not yet equilibrated since the Pleistocene glaciation.

In contrast to the lower mudstone unit (Towm), the molluscan assemblages (Appendix IV, samples 208.9 and 210.9) from the siltstones and very fine-grained sandstones of the upper unit (Tows) are characteristic of the middle to inner part of the sublittoral zone at depths greater than 10 to 20 meters (Addicott to Cooper, 1975, written communication). An assemblage near the gradational contact with the lower unit (sample 209.9) was deposited at possibly middle- to outer-sublittoral depths, which suggests a gradual shallowing of the upper unit.

Small, unclustered, grain-lined burrows (two to five millimeters in diameter) called Terebellina (Chamberlain, 1977, written communication) are common throughout the upper unit. Chamberlain intuitively placed these trace fossils at the outer shelf to upper slope, which is somewhat deeper than indicated by the more ecologically-reliable molluscan fossils. However, this suggests the possibility that the molluscan fossils are not in place and were deposited in deeper water than where they originated. Most of the mollusks are broken, which is compatible with the possibility they were transported.

Assuming the environmental interpretation of the lower unit (Towm) and the molluscan data from the upper unit (Tows) are correct, the Oswald West mudstones in the eastern part of the thesis area represent shoaling and increasingly higher-energy environments during the late Oligocene to earliest Miocene. The thickly bedded, fine-grained friable sandstones in the upper unit are supportive of basin shallowing and/or increased input of coarser grained detritus. The two units (Towm and Tows) are similar to the lower two units of Visher's (1965) regressive-marine sequence.

Local uplift and/or delta progradation from the east are thought to be probable factors in the formation of the regressive sequence. The coeval Scappoose Formation may represent the associated delta facies to the east. A eustatic sea-level rise occurred during the late Oligocene to early Miocene (Vail and others, 1976), which supports a local cause of regression.

Astoria Formation

The first detailed stratigraphic investigation of the rocks exposed at Astoria was accomplished by Howe (1926). He described the stratigraphic section as consisting of a 150-foot thick lower sandstone, a 1,000 foot thick middle "shale," and an upper sandstone. Howe referred the entire section to the middle Miocene and considered it to be equivalent in age to the Temblor Formation of California.

Since Howe's publication, molluscan paleontologists have generally regarded the Astoria Formation as middle Miocene (Moore, 1963). The formation has been correlated and mapped from Newport to Astoria, mainly on the basis of middle Miocene fossil assemblages and not on lithologic similarity to the type area. As a result, a variety of grossly different lithologies and facies have been assigned to the Astoria Formation. Additional complications are caused by the fact that the section at Astoria has been urbanized and is no longer available for study. However, the name Astoria Formation has become deeply ingrained in the literature and should be retained. Cressy (1974) suggested that informal member names be applied to mappable lithologic sequences of strata within the Astoria Formation, which is in accordance with the Code of Stratigraphic Nomenclature (1961). Cressy recognized a distinct, 1,600-foot thick unit of Miocene sandstone which he called the Angora Peak sandstone member. Turbidites and massive mudstones overlying the Angora Peak member were named the Silver Point mudstone member by Smith (1975). Cooper (ms in prep.) refers to the Astoria Formation at Newport as the Newport sandstone member, and has named Miocene sandstones in the vicinity of Big Creek (this thesis area) the Big Creek sandstone member.

The Big Creek sandstone member, the Pipeline member (a new unit), and the Silver Point mudstone member comprise the Astoria Formation in the thesis area (Plate I). The probability of undetected structural repetition through faulting makes any determination of total thickness an approximation, but a maximum of 5,000 feet is calculated from regional dip (14° used) and outcrop distribution.

Big Creek Sandstone Member

Nomenclature. A 1,300-foot section of early to middle Miocene sandstone in Big Creek is referred to by Cooper (ms in prep.) as the Big Creek sandstone member of the Astoria Formation. I have modified the lower part of the type section slightly, so that the unit is readily mapped on the basis of lithologies and stratigraphic relationships.

Distribution. The Big Creek sandstone member is areally the most widespread unit in the map area (Figure 9). It crops out on the nose and flanks of a northward-plunging anticline in the east, and is the dominant

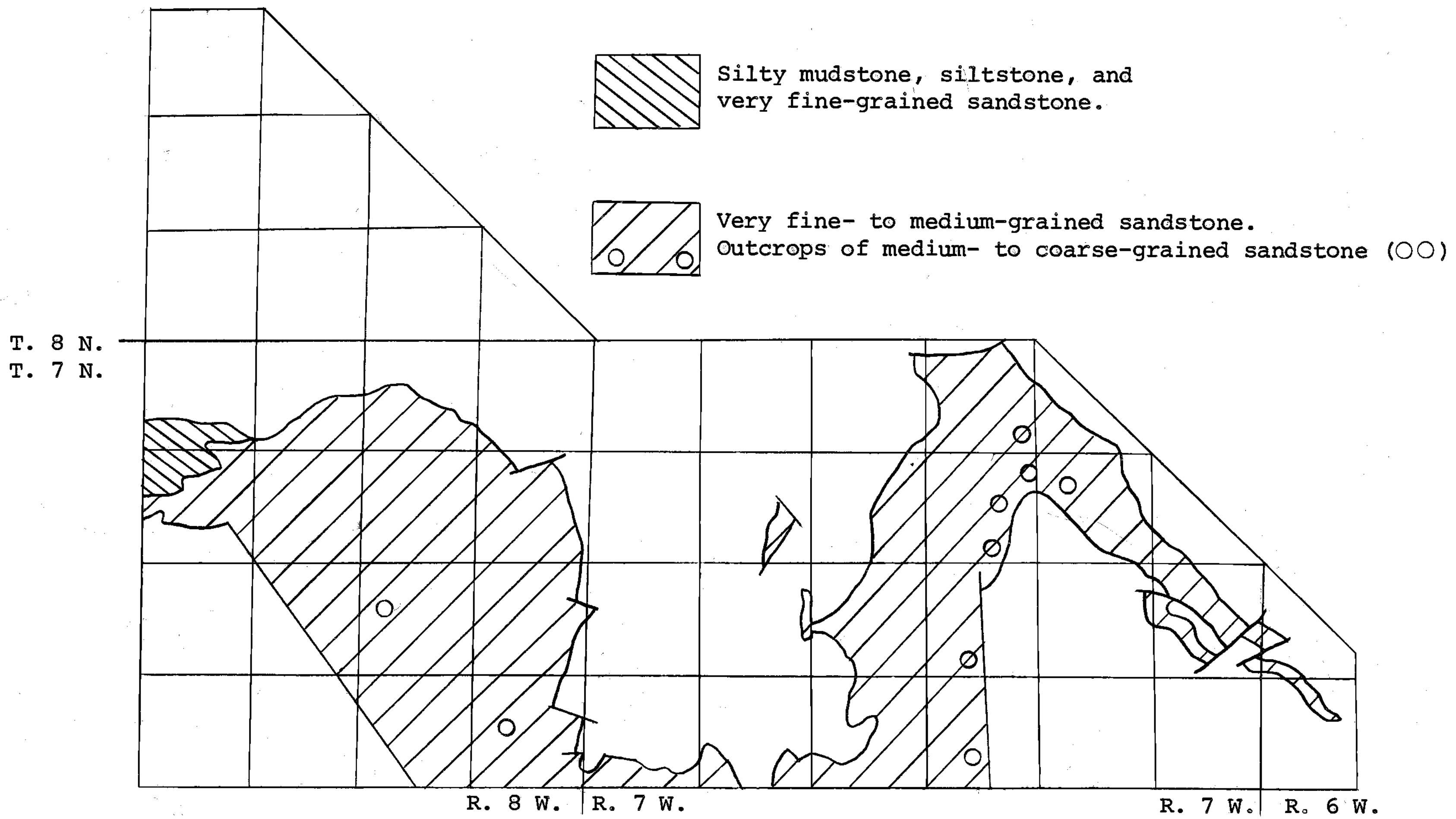


Figure 9. Outcrop distribution of the Big Creek sandstone member.

lithology in the southwestern part of the thesis area (Plate I). Isolated, good roadcut exposures are fairly evenly distributed (e.g., see sample localities). The only continuous outcrop is along Big Creek.

Lithologies and Structures. The Big Creek sandstone in the study area consists almost entirely of micaceous, feldspathic and lithic sandstones. In westernmost exposures, the upper part of the member displays an interfingering relationship with silty mudstones, siltstones, and friable, very fine-grained sandstones (Figure 9). Cooper (ms in prep.) measured 1,000 feet of sandstone at the type section (the lower contact is redefined by me in Contact Relations). A maximum thickness of 1,500 feet is calculated on the basis of map pattern and dip in the westernmost part of the area.

Sandstones are very fine- to coarse-grained, moderately to poorly sorted, and contain subangular to subrounded grains of quartz, feldspar, and volcanic fragments. Fresh exposures are light bluish-gray (5B7/1), and weather to greenish gray (5GY6/1) and light brown (5YR5/6) (Figure 10).

Molluscan fossil hash beds locally occur in the middle and upper parts of the Big Creek sandstone (e.g., localities 130 and 131). *Anadara*, *Solen*, and *Spisula* are common bivalves in these rocks and are easily recognized.

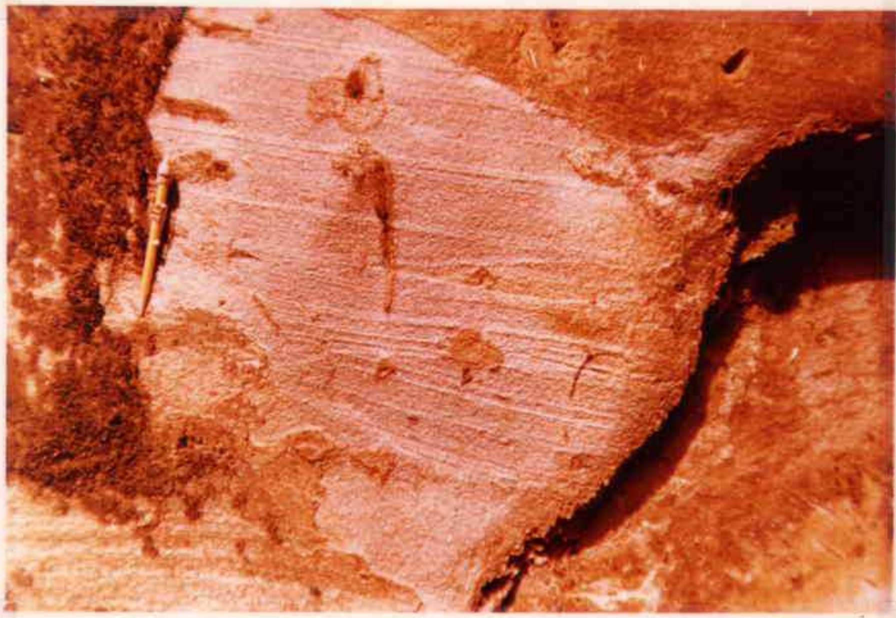


Figure 10. Exposure of fine-grained Big Creek sandstone displaying parallel and cross-laminations. Cut on Fisher spur 11, sample locality 7.

Parallel laminations and rarer cross-laminations are the dominant structures in the Big Creek sandstone. Grain-size and mineralogical differences form most laminae.

The Big Creek sandstone member is an example of a fining-upward sequence. At the type section the lower half of the Big Creek sandstone is generally fine- to medium-grained, moderately sorted, relatively clean, structureless, and thinly to very thickly bedded. Very thin cross-beds and cross-laminations, and one- to three-foot thick channel scours filled with medium- to coarse-grained sandstone occur locally. Rare, carbonized wood fragments are scattered throughout the lower part. At one location (148), about 150 feet above the base of the member, trough cross-beds are emphasized by abundant coaly and carbonaceous stringers. The upper half of the type section consists mainly of faintly parallel-laminated to structureless, very fine- to fine-grained sandstone. Thin beds of structureless, medium-grained sandstone are rare. Near the western boundary of the map area, sandstones immediately above the Oswald West mudstone contact (sample location 7) are fine-grained, and laminated or cross-laminated. These sandstones fine upward and interfinger with coarse siltstones and mudstones in the upper half of the member (cross-hatched on Plate I).

<u>Contact Relations</u>. The lower depositional contact of the Big Creek sandstone is not exposed because of

vegetation and alluvium cover. However, the contact can be very closely located in Big Creek (sec. 10, T. 7 N., R. 7 W.) and along Fisher Spurs 11 and 37 (sec. 9, T. 7 N., R. 8 W.) (Plate I).

Cooper (ms in prep.) included approximately 330 feet of bioturbated siltstones and very fine-grained sandstones in the lowermost part of his Big Creek sandstone type section. Field examination by me revealed that these lithologies are identical to those in the underlying Oswald West mudstones which contain a Matlockian fauna. Macoma arctata has been collected from silty sandstone in the lowermost unit of Cooper's Big Creek section, but this species ranges from late Oligocene to middle Miocene in age (Addicott, 1975, written communication to Cooper, fossil locality 210.9).

Placement of the lower boundary of the Big Creek sandstone at the lowest occurrence of clean, fine- to medium-grained feldspathic sandstone greatly facilitates mapping of the lower contact of the Astoria Formation in the Big Creek drainage area. This contact is covered by recent stream alluvium in Big Creek, but it appears to coincide with unit 11 of Cooper's (ms in prep., Appendix I) Big Creek sandstone type section. The lowest exposure of Big Creek sandstone, as defined by me, crops out south of where Mud Creek enters Big Creek, 1,780 feet south, 460 feet west of the northeast corner of section 10, T. 7 N., R. 7 W.

Olive-gray, coarse Oswald West siltstone is exposed approximately 500 feet upstream. The lowermost exposure of the blue-gray, lithic-feldspathic Big Creek sandstone is very fine to fine grained at the base, but coarsens rapidly upward over 75 feet to fine- to medium-grained sandstone in the majority of the lower 500 feet of the type section. The lower contact is mapped laterally from the type section on the basis of a change from mudstones, siltstones, or silty sandstones to fine- to coarse-grained sandstone. The lower contact in the westernmost part of the field area (spurs 11 and 37) is easily recognized as an abrupt change from mudstones to fine-grained sandstones).

Cressy (1974) postulated that a minor angular unconformity occurs between the Oswald West mudstones and the overlying Angora Peak sandstone member. In the thesis area, differences in attitudes between the Oswald West mudstones and the Big Creek sandstone are small, and are considered inconclusive as to the presence or absence of any angular discordance.

A hiatus is suggested to be between the Oswald West mudstones and Big Creek sandstone member based on the absence of a Pillarian fauna in either of the units. However, this negative evidence is very weak because the lowest assemblage of Newportian fauna collected from the Big Creek sandstone occurs 450 feet above the base of the type section (fossil locality BC-3). Nelson (1977, personal communication) has collected Vertipectin fucanus (Pillarian restricted) 100 feet above the base of the Big Creek sandstone 11 miles to the west. This suggests that the Big Creek sandstone member may be time transgressive. Alternatively, the base of the Big Creek sandstone at the type section is Pillarian, which negates the aforesaid evidence for a hiatus. Support for a disconformity comes from Nelson's (1978) thesis area, where close fossil control and abrupt changes in lithology and depositional environments across the contact of the Oswald West mudstones and a probable Big Creek sandstone equivalent (Tucker Creek member of the Astoria Formation) suggest a marine regression and lacuna.

The Big Creek sandstone has two major fault contacts with the Oswald West mudstones (Plate I). The western fault can be closely located on Bear Creek-Klaskanie Cross-Over Spur 15 (SE¼, sec. 15, T. 7 N., R. 8 W.). The eastern fault juxtaposes the two units on Coon Creek Road (SE¼, sec. 22, T. 7 N., R. 7 W.), and on North Coon Creek Road (S½, sec. 15, T. 7 N., R. 7 W.).

The Big Creek sandstone member is concordantly overlain by the Silver Point mudstone member (Tspu) in the eastern and central parts of the map area, and by the Pipeline member mudstone (Tpm) in the western part (Plate I). The contact with the Silver Point mudstone can be mapped easily on the basis of a sharp change from very fine- or fine-grained sandstone to mudstone. This change is exposed at a quarry along Bear Creek-Klaskanine spur 13 (sample locality 82) and on the A Line (locality 51, Figure 11). A 125-foot section was measured at the A Line roadcut (Appendix II). A two- to ten-foot thick glauconitic sandstone delineates the top of the Big Creek member at all good exposures of the upper contact. The contact with the Pipeline member mudstone is, in part, gradational. That is, interfingering sandstones, siltstones, and mudstones are overlain by mudstone. This contact is mapped on the basis of the glauconitic sandstone mentioned above, and can be observed along Biddle Road (locality 152) and spur 27D-1 (locality 143).

The presence of a zone of glauconite is considered by Krumbein and Sloss (1963, p. 308) to be evidence of a submarine unconformity, indicative of a period of nondeposition. Considering the fact that the overlying mudstones were deposited in significantly deeper water than the Big Creek sandstone (see Depositional Environments sections of the respective units), and that regional dips do not indicate any apparent angular discordance between the units, the contact is considered to be a diastem, or minor submarine disconformity.

The overall mapping pattern (Plate I) suggests that the Depoe Bay Basalt overlies the Big Creek sandstone with angular unconformity. On the southern part of Wickiup

Figure 11. Contact (at five-foot Jacob's staff) of steeply dipping Big Creek sandstone (on right) and Silver Point mudstone (on left). Ten-foot thick glauconitic sandstone lies between camp shovel and Jacob's staff. Part of measured section on A Line.

Ridge and on Nicolai Ridge, the overlying Silver Point mudstone thins to the south and is truncated by extrusive Depoe Bay Basalts.

Age and Correlation. The Big Creek sandstone is of late early Miocene to middle Miocene age and is referable to the Newportian Stage on the basis of fossil collections (Appendix V) and stratigraphic relationships within the thesis area. However, the lower part of the member at the type section may be of middle early Miocene age (Pillarian) based on contiguous mapping and lithologic correlations with Pillarian age Big Creek sandstones to the west of the thesis area, or it may be entirely Newportian and is a time-transgressive unit.

Molluscan fossils from the middle and upper parts of the member in the thesis area that are restricted to the Newportian Stage (Addicott, 1976b) are *Molopophorus matthewi* (fossil localities AOS 74-1, AOS 74-2, BC-3), *Mytilus middendorffi* (AOS 74-2, BC-6), and *Narssarius lincolnensis* (130, 212.9). As is discussed in the Contact Relations section, the lowest Newportian-restricted assemblage (BC-3) occurs approximately 450 feet above the base of the member at the type section. The sandstones below may be Pillarian or entirely Newportian in age. Immediately to the west of the thesis area, Nelson (1977, personal communication) has collected *Vertipecten fucanus* from the lower part of the Big Creek sandstone, and

Patinopecten propatulas from the middle part. These species are restricted to the Pillarian Stage and the Newportian Stage, respectively (Addicott, 1976b). Hence, the middle and upper parts of the type Big Creek sandstone correlate on the basis of age with Nelson's (1978) middle and upper Big Creek sandstones. The lower Big Creek sandstone member is either a time transgressive unit (older in the west, Pillarian, and younger in the east, if entirely Newportian), or the Big Creek member at the type section is Pillarian at the base and Newportian in the upper part and therefore is entirely coeval with the Big Creek member to the west of the thesis area. This problem can only be solved by the discovery of age-definitive fossils near the base of the Big Creek sandstone member at the type section.

I tentatively suggest that the lower part of Howe's (1926) lower sandstone at Astoria (no longer exposed) is correlative to the Big Creek sandstone on the basis of stratigraphic position and gross lithology. Both the lower sandstone and the overlying mudstone at Astoria are referred to the Pillarian Stage by Addicott (1976c). The above, plus the fact that the upper part of the Big Creek member in the thesis area is Newportian, strongly suggest that the sandstone at the base of the Astoria Formation is time transgressive. However, I emphasize that because the strata at Astoria are poorly exposed and the locations of old fossil collections are questionable, this correlation is essentially intuitive at this time.

A transgressive model for the Big Creek sandstone is favored by me for two reasons. The first is that correlative Pillarian sandstones (Tucker Creek member) to the west of the map area were deposited in a very near-shore environment (Nelson, 1978). The thesis area is inferred to be subaerially exposed at that time. The second reason is that the Big Creek sandstone generally decreases in grain size upward. According to Visher (1965), the only marine-sedimentary sequence that fines upward is transgressive.

The upper time boundary of the Big Creek member in the thesis area is bracketed by middle Miocene Depoe Bay Basalt. Dikes and sills of this basalt intrude both the Big Creek sandstones and the overlying mudstones. The Depoe Bay Basalt has been radiometrically dated at 14 to 16 million years (Niem and Cressy, 1973; Snavely and others, 1973; Turner, 1970). These dates fall within the uppermost Saucesian to Relizian foraminiferal stages (Turner, 1970).

Strata considered coeval with the Big Creek sandstone in the thesis area are the upper part of the Angora Peak member to the southwest (Cressy, 1974; Tolson, 1976), the Astoria Formation in the Newport embayment (Newport sandstone member) (Cooper, ms in prep.; Snavely and others, 1969), and the upper part of the Astoria Formation in southwestern Washington (Rau, 1967; Wolfe and McKee, 1972). The lower part of the Big Creek to the west (Nelson, 1978), and also possibly in the map area, is coeval with the lower part of the Angora Peak member, the Nye Mudstone in the Newport area (Snavely and others, 1969), the lower part of the Astoria Formation in southwestern Washington, and the Clallam Formation on the northern flank of the Olympic Mountains, Washington (Addicott, 1976a).

Transport Directions. The Big Creek sandstone is the only unit from which paleocurrents were obtained (Figure 12). Measurements were taken from trough cross-laminations and cross beds. In the eastern part of the thesis area all measurements are from the lower part of the member. In the western part of the area, measurements are from the middle and lower parts of the unit. The paleocurrents in the western part are similar, so they are displayed in one rose to reduce crowding on the diagram. It must be kept in mind that the paucity of transport direction indicators makes the statistical significance of these measurements questionable.

The most striking feature about Figure 12 is the westerly paleocurrents in the eastern part of the area versus the northerly directions in the western part. Nelson (1978) has also determined a northerly transport direction for the Big Creek sandstone to the west of the thesis area. The significance of these data is discussed in the following section.

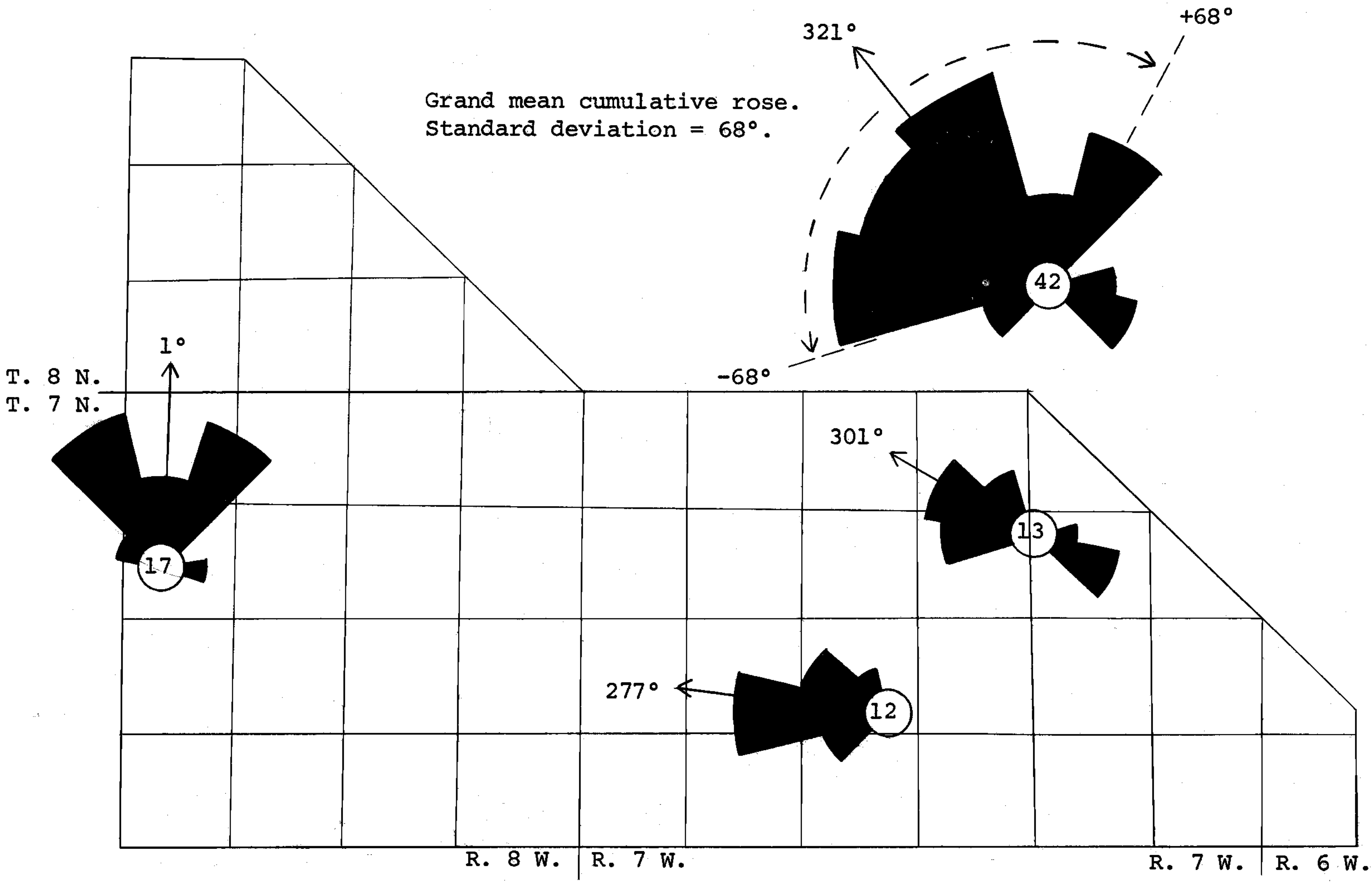


Figure 12. Rose diagrams of paleocurrent measurements from the Big Creek sandstone. Number of measurements and mean azimuth direction with roses.

Depositional Environment. Facies changes, sedimentary structures and lithologies, and molluscan fossils suggest that the Big Creek sandstone member is a transgressive sequence which formed mainly in an inner shelf environment. Littoral and small-scale fluvial deposits are present locally in the lower part.

Littoral and fluvial sandstones are suggested to occur in the lower part on the basis of medium- to coarse-grain sizes, small scour-and-fill channels, and trough cross-bedding. A shelf environment is considered unlikely for the deposition of the cross-bedded and cross-laminated strata. Although Komar and others (1972) have observed ripples on the Oregon continental shelf, there is little cross-lamination in the inner-shelf sands (Kulm and others, 1975). Assuming a north-south Miocene strand line, the westerly trending cross-beds in the eastern part of the thesis area are probably fluvial and/or littoral in origin. The trough cross-beds with carbonized wood fragments (locality 148) are believed to represent rapid deposition and burial in small fluvial channels, since it is unlikely that the carbonaceous debris forming the cross-laminae would be preserved in the surf zone where there is constant wave reworking, agitation, and oxidation. Most of the cross-bedding in the Big Creek sandstone does not contain carbonaceous material, and may, therefore, be littoral. Seaward-dipping trough cross-beds are the common internal structure of the inner surf zone (Clifton and others, 1971). The less common easterly paleocurrents in the lower Big Creek sandstone (Figure 12) may have formed nearshore or in the intertidal zone. On modern high-energy Oregon beaches, lunate megaripples are produced in the wave build-up zone with slip faces inclined landward (Clifton and others, 1971). Trough cross-beds are the common internal structures. Most cross-bedding in the littoral zone also trends landward (Hayes, 1969; Hayes and others, 1969). Alternatively, the bidirectional paleocurrent readings may reflect the ebb and flood tide in an estuarine environment. Bidirectional cross-bedding is preserved in Pleistocene terrace deposits near Willapa Bay, Washington (Niem, 1977, personal communication).

Cross-bedding in the western part of the area indicates a generally northward transport direction (Figure 12). Given a north-south paleostrand line, this suggests longshore currents as the major process, and nearshore deposition for these sandstones.

Scour-and-fill channels in the lower part of the Big Creek member may have been formed by local streams or by nearshore tidal currents. A fossil seal rib collected from a coarse-grained sandstone channel cut into fine-grained sandstone in the western part of the area suggests the latter mechanism, but does not exclude an estuarine environment of deposition.

Upward in the type section cross-bedding and medium- to coarse-grained sandstones are rare. The dominant lithologies are parallel-laminated, very fine- to fine sandstones. On the modern continental shelf of Oregon, sediments in water depths from 32-64 meters commonly consist of horizontally-laminated, fine- and medium-grained sand (Kulm and others, 1975). However, horizontal laminations also can be produced in the surf and swash zones of a high-energy beach (Clifton and others, 1971). In the westernmost part of the area, interfingering with siltstones and mudstones in the upper Big Creek member suggests a relative deepening and/or decrease in energy in the environment.

Most fossil assemblages in the middle and upper part of the member are characteristic of the inner-sublittoral zone or about 10 to 40 meters (Addicott, 1975 and 1977, written communication). Two collections containing *Mytilus middendorffi* (AOS 74-2, BC-6) indicate depths of 5-30 and 0-15 meters in the middle and upper parts, respectively. These assemblages may represent either slight fluctuations in water depth, or transport of these fossils into deeper water. On the other hand, all the depth ranges overlap, and any apparent differences may not be significant. Fossil hash concentrations in the upper part suggest strong tractive currents, but velocities representative of the upper flow regime have been recorded at depths up to 50 meters off the Columbia River (Kulm and others, 1975).

In summary, the Big Creek sandstone member was deposited in a depth range of 0-40 meters. In some of the lower parts of the unit, probable fluvial and/or littoral-nearshore environments can be recognized on the basis of lithologies and sedimentary structures. In the upper part, the finer grained character and molluscan fossil assemblages imply a generally deeper, inner-shelf environment.

The glauconitic sandstone at the top of the Big Creek member contact suggests a period of relatively slow deposition (Pettijohn, 1975) and a significant deepening of the environment. Kulm and others (1975) note that most glauconite on the modern Oregon continental shelf occurs near the outer edge. This outer-shelf to upper-bathyal environment is consistent with foraminiferal data from the overlying mudstones, and is evidence for a continued marine transgression.

Pipeline Member

Nomenclature and Distribution. A distinctive, thick sequence of deep-marine sandstones and mudstones overlies the Big Creek sandstone member in the northwestern part of the thesis area (Figure 13). In his reconnaissance mapping of the Astoria Formation, Cooper (ms in prep.) included the sandstones in this sequence as a deep-water facies of

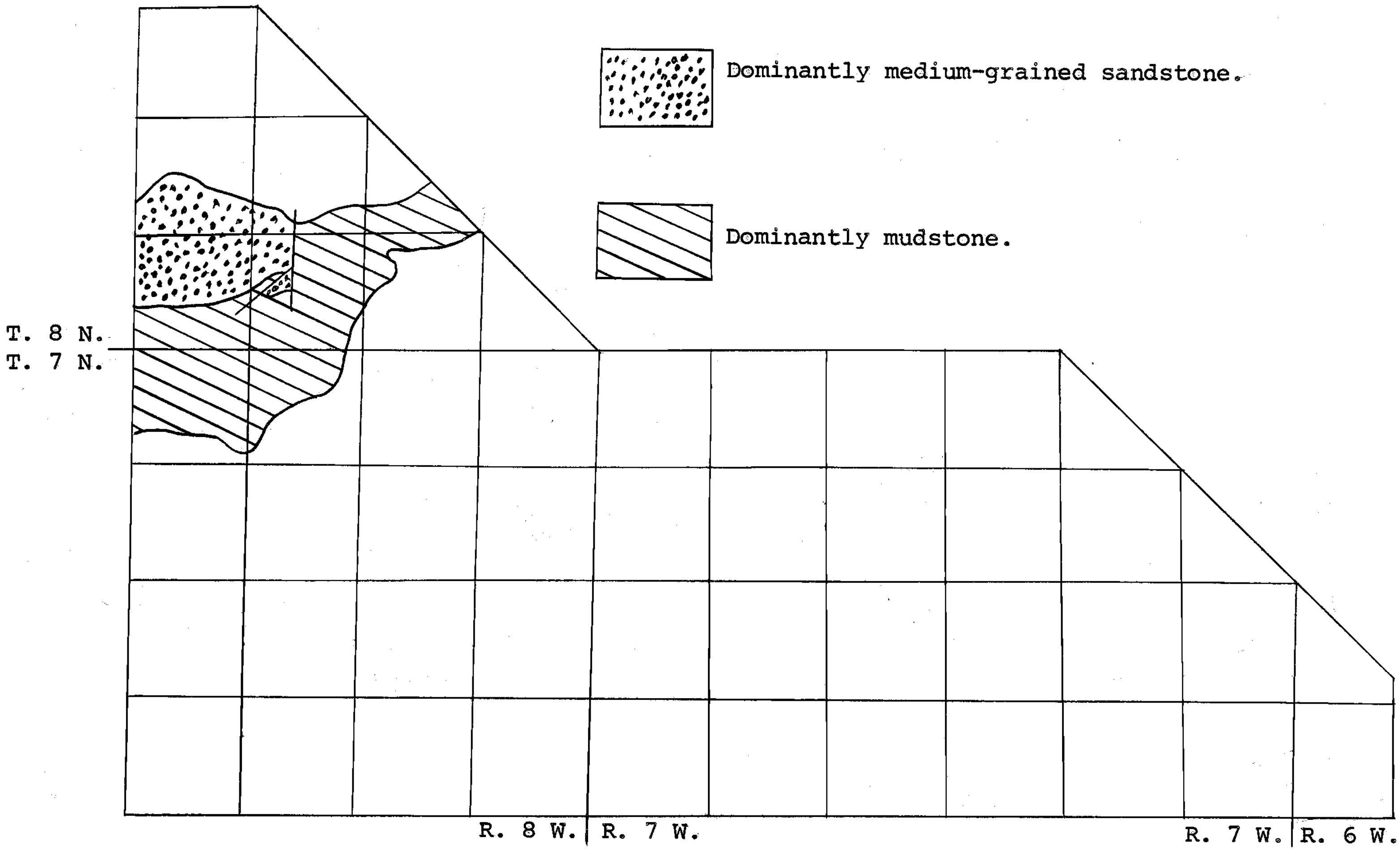


Figure 13. Outcrop distribution of the Pipeline member.

the Big Creek member. My own field work has revealed that this sequence is so significantly different from the Big Creek sandstone in lithologies, geometry, and stratigraphic position as to warrant separation as a distinct member of the Astoria Formation. Nelson (1978) has also been able to differentiate this unit in his thesis area to the west, and has mapped it as far as Astoria. Nelson and I informally propose the name Pipeline member of the Astoria Formation for this unit, after outcrops of sandstone which occur along a large part of the Astoria Pipeline Road.

Unfortunately, a type section could not be measured because of the discontinuous nature of the sandstone bodies and extensive slumping and/or faulting. Small, partial representative sections have been measured by Nelson (1978) and me (Appendix III). Typical exposures of sandstone can be seen on spurs 44-D and 44-H (NW¼, sec. 33, T. 8 N., R. 8 W.). The sandstone is also extensively exposed up to a mile north of these locations (Plate I). The total thickness of the Pipeline member is estimated to be a maximum of 2,600 feet on the basis of regional dips and outcrop pattern.

Lithologies and Structures. The Pipeline member in the map area is subdivided into two parts: a lower mudstone-dominated interval (Tpm, Plate I), and an upper sandstone-dominated interval (Tps)(Figure 4). Because this division is based on the relative amounts of two lithologies, the contact is not distinct and is shown as gradational on the geologic map (Plate I).

In fresh exposures, the mudstones are dark gray, silty, and structureless to laminated. Shaly or papery splitting properties are locally expressed. The mudstones are micaceous, and carbonaceous from finely comminuted plant debris. The much more common weathered exposures consist of nondescript, yellowish gray (5Y7/2) to moderate brown (5YR4/4) mudstone with a chippy talus.

Both the fresh and weathered mudstone lithologies are identical to those of the upper Silver Point member of the Astoria Formation (this thesis). In fact, the mudstone of the Pipeline member (Tpm) essentially is a lateral continuation of the Silver Point mudstone (Figure 4). The two units are at the same stratigraphic position, and were deposited in similar deep-marine environments (see respective <u>Depositional Environment</u> sections). The Pipeline member mudstone (Tpm) is differentiated from the Silver Point mudstone only on the basis of the occurrence of numerous, isolated beds, lenses, and clastic dikes of Pipeline sandstone (estimated to compose 10% of unit) within the Pipeline unit (Figure 14). The total thickness of the Pipeline member mudstone (Tpm) is estimated to be 1,500 feet, but a few erratic attitudes suggest slumping or faulting and possible repetition of parts of the unit.

Very thickly bedded, medium-grained, arkosic sandstones dominate the upper part of the Pipeline member (Tps)

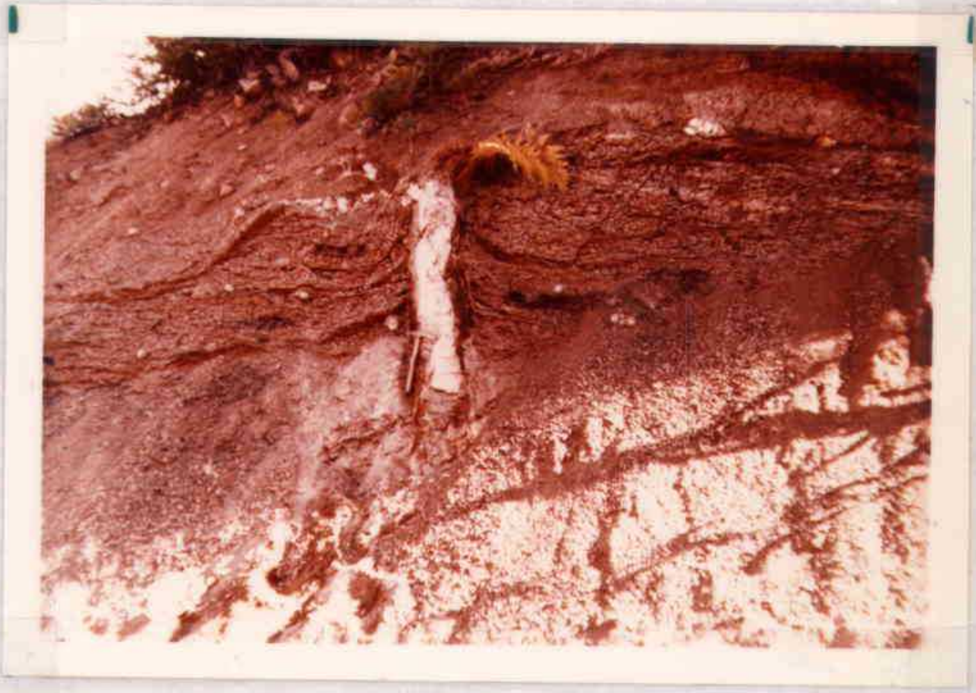


Figure 14. Sandstone dike intruding concretion-bearing carbonaceous Pipeline mudstone. Hammer at dike for scale. Fossil locality 143.

(Figure 15). The sandstones are generally structureless, and white (N9), yellowish gray (5Y5/2), or moderate brown (5YR4/4) in outcrop. Iron staining is common. Rarely, the lowermost or uppermost several inches of sandstone units are parallel laminated. Most of the sandstones are very friable, but clastic dikes are locally well indurated. No fossils have been found in the sandstones (Nelson, 1977, personal communication; Wolfe and McKee, 1972).

The thickest individual sandstone bed that was measured is 39 feet thick (Appendix III). However, this unit is eroded at the top, so the complete thickness is unknown. Nelson (1978) measured a 70-foot thick sandstone bed to the west. The sandstone to mudstone ratio in the upper part (Tps) is estimated to be ten to one.

A trip to the field area in the spring of 1977 revealed that weathering and differential iron staining were beginning to delineate locally what may be a comtinuous succession of thin amalgamated sandstone beds within single thick units. This was observed at the measured section (Appendix III) and at a large outcrop near the mouth of the John Day River in Nelson's (1978) field area.

The total thickness of the Pipeline member sandstone (Tps) is estimated to be 1,100 feet. However, slumping may again be a problem, so this is considered to be a maximum thickness.

Figure 15. Thick, structureless Pipeline sandstone. Note white patch to the right of the two-foot long camp shovel where the iron stain has been scraped off. Spur 44-H off the Astoria Pipeline Road.

The sandstones are complexly interbedded and intertongued with the mudstones. Clastic intrusions are common. Small sandstone bodies in the Pipeline member mudstone (Tps) are typically bounded laterally by mudstone; similar individual thick beds higher in the section cannot be traced for any distance.

Contact Relations. The lower contact of the Pipeline member is discussed in the Contact Relations section of the Big Creek sandstone member. The contact with the laterally equivalent Silver Point mudstone to the east is somewhat arbitrary. On the geologic map (Plate I), a "gradational" contact is drawn between the area where isolated traces of Pipeline sandstone (within Tpm) can be found, and the area to the east where Pipeline sandstone is not detectable. A similar contact relationship exists between the Pipeline member mudstone (Tpm, Plate I) and the overlying Silver Point mudstone ($Tspu_1$).

The upper contact of the Pipeline member sandstone (Tps, Plate I) with the Silver Point mudstone ($Tspu_1$) is easier to discern. It can be recognized as a change (over 300 feet, vertically) from very thick-bedded sandstones with subordinate interbedded mudstones, to mudstone only.

Other than probable slumping in the Pipeline member, no angular discordance is apparent between the Pipeline and Silver Point members. The upper contact is considered to be depositional, and to represent a halt in the major sand input into this particular area.

Two laterally discontinuous, thin beds of Pipeline-like sandstone occur higher in the section. They are not mappable by themselves, but have been delineated on Plate I as isolated patches of Pipeline member mudstone (Tpm). Minor input of sand following the main influx would not be unexpected.

Age and Correlation. The Pipeline member is late early Miocene to middle Miocene age and is referable to the Newportian Stage on the basis of fossil collections (Appendix VI) and stratigraphic relationships. One collection (128) contains *Delectopecten peckhami*, which ranges from the Newportian to Wishkahan Stage, or early to late Miocene (Addicott, 1977, written communication). *Siphogenerina* fragments and *Florilus costiferum*(?) in another sample (108) are probably referable to the Saucesian Stage, and are definitely no older (Rau, 1977, written communication). All fossils are from the Pipeline member mudstone (Tpm).

Stratigraphically, the Pipeline member is bracketed by Newportian Big Creek sandstone below, and by Saucesian upper Silver Point mudstone ($Tspu_1$) above (Nelson, 1978). Middle Miocene Depoe Bay and Cape Foulweather Basalts intrude the Pipeline member mudstone (Tpm). However, it is curious that no workers have actually seen middle Miocene basalt intruding Pipeline-type sandstone strata mapped in Oregon and southwestern Washington (Carter, 1976; Dodds, 1963; Howe, 1926; Nelson, 1977, personal communication; Wolfe and McKee, 1968, 1972; Young, 1966). Basalt intrudes Pipeline-equivalent sandstone in Washington (Wolfe and McKee, 1972, "unit III" of the Astoria Fm.), but is late Miocene Pack Sack petrologic-type. However, Foraminifera from "unit III" are referred to the Baggina washingtonensis zone, which, according to Rau (1967), represents the late Saucesian, Relizian, and possibly early Luisian Stages (early to middle Miocene). In addition, Nelson (1977, personal communication) has collected Foraminifera characteristic of the Siphogenerina kleinpelli zone from the mudstone in the lower part of the Pipeline member to the west. Rau (1967) suggests that this zone falls entirely within the Saucesian Stage. These microfossil data seem to indicate that the Pipeline member is no younger than middle Miocene, and that it is only a coincidence that intrusive middle Miocene basalts have not been observed cutting the sandstone. Still, fossil age control in actual mudstone interbeds within the Pipeline sandstone (Tps) is lacking, and the possibility remains that the sandstones are erosionally unconformable in and younger than the surrounding mudstones.

The Pipeline member is correlative with the upper Silver Point member, the upper sandstone of Howe (1926) at

Astoria, and "Unit III" of the Astoria Formation in Washington (Wolfe and McKee, 1972).

Depositional Environment. The Pipeline member is interpreted to represent an accumulation of "sandflow" and hemipelagic deposits in a submarine, possibly upper-slope, canyon on the basis of fossils, lithologic associations, and geometry. The presence of *Delectopecten peckhami* and *Siphogenerina* (Appendix VI) in the lower mudstone-dominated interval (Tpm) suggests an outer-sublittoral to bathyal environment (Addicott, 1977, written communication; Rau, 1977, written communication). *Siphogenerina* also occurs in thin mudstone interbeds within thick Pipeline sandstone approximately one mile to the west of the thesis area. With the paleobathymetry established, a depositional model can be inferred from the lithologies and geometry observable in the field.

The thickly bedded, structureless, uniformly medium-grained sandstones of the Pipeline member are lithologically similar to the "B2" facies described by Walker and Mutti (1973). Nelson (1978) has described possible dish structures from Pipeline sandstone which suggest similarity with the "B1" facies also. These facies are thought to be common in upper submarine-fan channels (Walker and Mutti, 1973). The "B" facies is commonly associated with pebbly sandstones and conglomerates (facies "A"), but the lack of these lithologies in the Pipeline member may only suggest that there was no coarse-grained source at that time. However, the Pipeline member is thought not to occur in an upper fan, because of the lack of the expected levee deposits (facies "E").

The most important characteristics that serve to distinguish submarine-canyon deposits from other types of channel deposits are a downslope-trending channel geometry and spatial position within a marine sequence (Stanley, 1975). In addition, modern submarine-canyon fills tend to be coarser grained than the surrounding sediments. Sorting in submarine-canyon sands is consistently poor. Grain size may decrease down-axis, but more commonly a change is not apparent. Muds in canyon environments are generally rich in organic matter.

Individual strata in submarine canyons are generally discontinuous (Stanley, 1975). Beds are lenticular and locally occur as isolated slump pods.

A deposit that is remarkably similar to the Pipeline member is the Oligocene Annot Sandstone Formation in the Maritime Alps of France and Italy. Stanley (1975) has interpreted this thick marine sequence in terms of submarine canyon and fan sedimentation models, based in part on studies of modern canyon and slope deposits. It is the canyon-fill facies of the Annot Sandstone that is analagous to the Pipeline member of the Astoria Formation.

The Annot Sandstone canyon-fill facies consists of thick sequences (up to 1,200 feet) of friable, structureless to moderately well stratified, medium- to coarse-grained sandstone strata with a few, thin intercalations of shale or alternating thin sandstone-shale units (Stanley, 1975). Isopach maps reveal an elongate, channel-like geometry. Individual sandstone units are commonly very thick (greater than 30 feet), but probably consist of a series of amalgamated sandstone beds. Sharp bottom and top contacts are typical, and faint to distinct horizontal laminations can be present. Well defined graded beds of siltstone and sandstone are not a predominant lithology.

The preceding descriptions of modern canyon environments and the ancient Annot Sandstone are essentially a description of the Pipeline member. Admittedly, the overall channel geometry is not clearly expressed in the field. However, it can be infered from the fact that small sandstone bodies in the lower mudstone-dominated interval (Tpm) express a channel geometry and major sandstone units higher in the section are laterally discontinuous along strike. Regionally, the Pipeline member is restricted to either side of the Columbia River, suggesting confinement to the ancient Columbia River "downwarp."

Although the canyon-fill facies of the Annot Sandstone is similar to the Pipeline member sandstone (Tps), the associated marginal facies are not. Stanley (1975) notes that turbidites are the dominant lithology in the canyon walls. He does, however, interpret this lithology to have been deposited on the lower continental slope. Faunal data in the Annot sandstone indicate shallowing water depths, and progradation over older submarine-fan turbidites would be expected. The canyon walls of the Pipeline member consist entirely of hemipelagic mudstone. This is reasonable if 1) the Pipeline member is an upper-slope deposit, and 2) it is part of a transgressive sequence.

Turbidity currents are not a probable mechanism for final deposition of the Pipeline sandstone, considering the general lack of grading and typical turbidite structures (Bouma, 1962; Blatt and others, 1972). Middleton and Hampton (1973) have postulated four possible types of single-mechanism sediment gravity-flows. The hypothetical "fluidized-flow" and "grain-flow" deposits are most similar to those of the Pipeline sandstone. Stanley (1975) considers these two gravity-flow mechanisms to be dominant in the deposition of the Annot Sandstone canyon-fill facies. However, he groups both under the more general term "sandflow" because of the difficulty of distinguishing the two types of deposits and the probability that both mechanisms may work together to produce one flow. I use the term sandflow for the Pipeline sandstones because it is more realistic. However, the abundance of associated clastic dikes and sills suggests that the original deposit must have been, at least locally, water-saturated to enable spontaneous liquefaction of the sand (Dott, 1966). The original submarine transport of the water-saturated sand may have been more by the mechanism of upward intergranular flow of water (fluidized flow) than by grain interaction (grain flow), as described by Middleton and Hampton (1973). The occurrence of rare dish structures (Nelson, 1978) is also suggestive of a fluidized-flow mechanism.

In summary, I postulate the existence of an east-west-oriented submarine canyon, possibly the feeder to a submarine fan, late in Astoria time in the approximate position of the mouth of the modern Columbia River. However, this was not necessarily the position of the ancient continental slope. The modern Congo Canyon cuts across the continental shelf and well up into the Congo River (Shepard and Emery, 1973). Bathyal depths are present within the river mouth itself. As for the Pipeline member, some degree of direct connection to river source is suggested by the complete lack of fossils in the sandstones.

Silver Point Mudstone Member

Nomenclature. The name, Silver Point mudstone member of the Astoria Formation, was informally proposed by Smith (1975) for a 650-foot thick sequence of well-bedded silty mudstones and minor interbedded sandstones. The type section is exposed at Silver Point on the Oregon coast, approximately one and one half miles south of Cannon Beach. Neel (1976), Tolson (1976), and Penoyer (1977) have subsequently divided the Silver Point member into upper and lower parts for descriptive purposes. I follow the nomenclature of Penoyer (1977) which differentiates interbedded mudstone and sandstone in the lower part from structureless to laminated mudstones in the upper part. This is consistent with the nomenclature used by Nelson (1978) to the west of the thesis area.

The Silver Point member in the thesis area consists entirely of structureless to laminated mudstone, and is therefore referred to as the upper Silver Point mudstone member on the geologic map (Plate I). A maximum thickness of 1,600 feet is inferred from regional dips and outcrop pattern. The lower Silver Point member, which crops out to the west, apparently pinches out eastward (Nelson, 1977, personal communication) and is not exposed in the map area.

Distribution. The upper Silver Point mudstone is widespread throughout the thesis area (Figure 16). The unit is easily eroded, and commonly crops out in low-lying areas or stream valleys. However, it is also well exposed on steep cliffs of Wickiup and Nicolai Ridge, where it is capped by relatively resistant basalt.

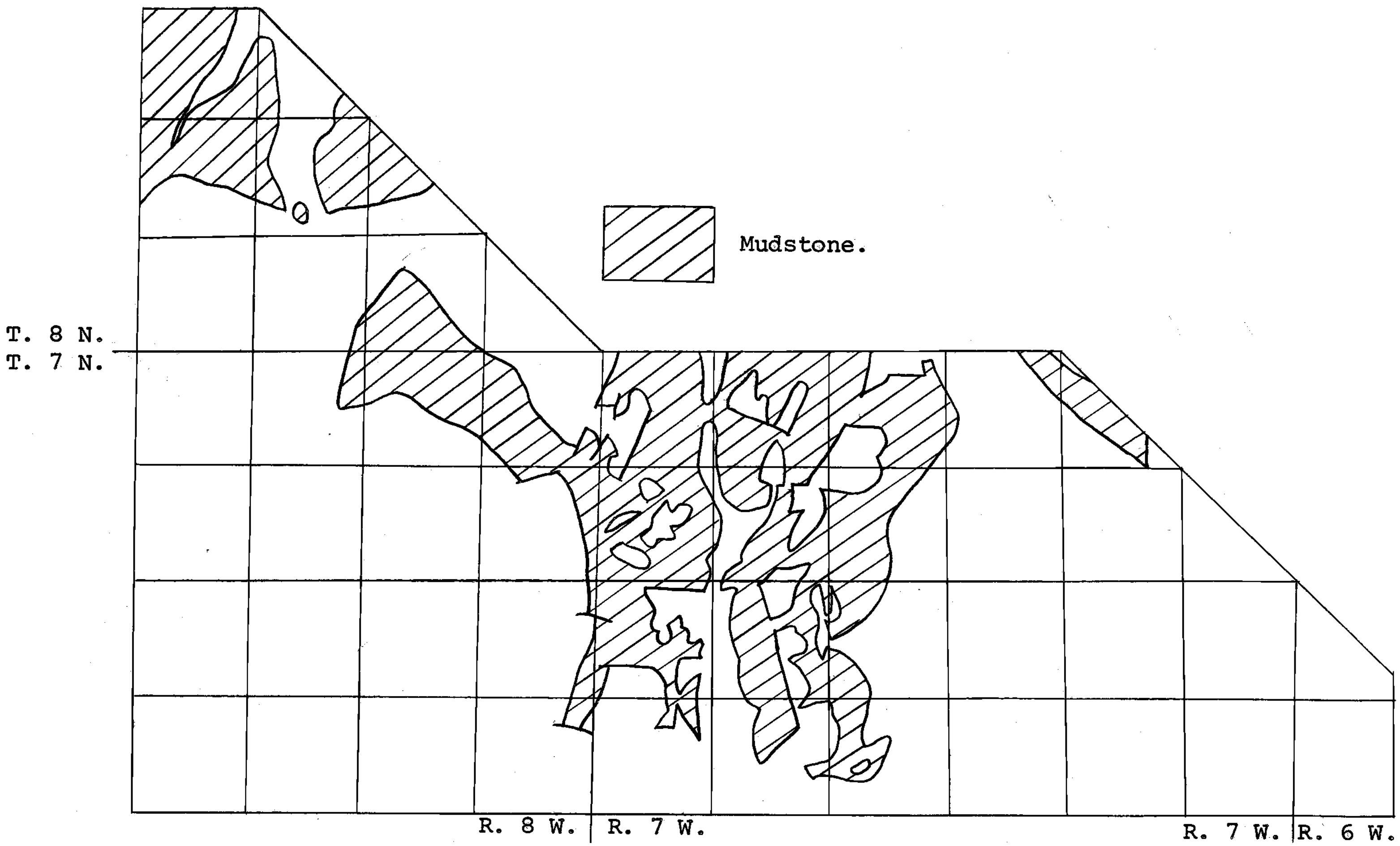


Figure 16. Outcrop distribution of the Silver Point mudstone member.

Lithologies and Structures. As is discussed in the Lithologies and Structures section of the Pipeline member, the Silver Point mudstone is essentially identical to the Pipeline member mudstone, except that the Silver Point mudstone does not contain Pipeline sandstone. Two small, isolated, anomalous outcrops of channelized, very fine-to fine-grained sandstone do occur within the Silver Point mudstone on the west side of Wickiup Ridge (not mappable, designated as SC on Plate I), but are unlike either the Pipeline or Big Creek sandstone lithologies.

Contact Relations. The lower contact of the Silver Point member is discussed in the Contact Relations section of the Big Creek sandstone member. The contacts with the Pipeline member are discussed in the Contact Relations section of that unit.

Extrusive Depoe Bay Basalt overlies both the Big Creek sandstone and Silver Point mudstone with apparent angular unconformity, as suggested by the map pattern (Plate I), and discussed in the Contact Relations section of the Big Creek sandstone member. Contacts with extrusive Cape Foulweather Basalt are also unconformable because the unit is younger than the Depoe Bay Basalt.

Age and Correlation. The Silver Point mudstone member in the thesis area is of late early Miocene age to middle Miocene age and is referable to the Newportian Stage on the basis of stratigraphic relationships. Fossil collections (Appendix III) are not as helpful. Macoma albaria and Nuculana calkinsi from one collection (sample no. 129) occur in both the Pillarian and Newportian Stages (Addicott, 1977, written communication). Foraminifera (sample nos. 53 and 82) restrict the strata only to no older than the Saucesian Stage (Rau, 1977, written communication). Stratigraphic relationships offer the best control in that the Silver Point mudstone overlies the Newportian Big Creek member, and is overlain and intruded by middle Miocene Depoe Bay Basalt.

The upper Silver Point mudstone is correlative with the Pipeline member, the upper Silver Point mudstone of Nelson (1978) and Penoyer (1977), and possibly with the upper Silver Point mudstone of Neel (1976) and Tolson (1976) on the basis of similar stratigraphic position and/or lithologies.

Depositional Environment. A middle- to outer-sublittoral, or possibly bathyal, depositional environment that was significantly deeper than that of the Big Creek sandstone, is inferred for the upper Silver Point mudstone. This conclusion is based on fossil assemblages (Appendix VI) and lithologic similarity to the Pipeline member mudstone.

A molluscan assemblage from Wickiup Ridge (sample no. 129) probably represents middle- to outer sublittoral depths (Addicott, 1977, written communication). A foraminiferal assemblage (sample no. 53) from Wickiup Ridge has a strong inner shelf element (Nonionella miocenica), but has upper bathyal forms also (Rau, 1977, written communication). The fact that N. miocenica is the most common fossil in the assemblage is probably reason enough to eliminate the possibility that N. miocenica was transported to and deposited in a bathyal environment. Rau (1977, oral communication) suggests that since the Foraminifera in this assemblage do not always strictly occur in the environments indicated, the deep- and shallow-water forms may overlap, and a middle- to outer-sublittoral environment of deposition is probable.

Farther to the west, fossils in the laterally equivalent Pipeline member mudstone (see Depositional Environment section of that unit) indicate outer-sublittoral and bathyal depths, suggesting a slightly deeper environment.

Depoe Bay Basalt

Nomenclature

Middle Miocene submarine pillow basalts and breccias, subaerial basalt flows, and intrusives are well exposed at the town of Depoe Bay on the Oregon coast. These basalts were collectively named the Depoe Bay Basalt by Snavely and others (1973). The same name is used in this thesis for middle Miocene basalts with similar lithologies, chemistry, ages, and stratigraphic position to the basalts at the type locality. However, there is no reason to believe that the basalts in the thesis area and those at Depoe Bay were ever contiguous, so the name is used more in a petrologic sense than as a stratigraphic term.

Distribution

Depoe Bay Basalt intrusives crop out extensively throughout the thesis area (Figure 17). Small dikes and sills are not shown on Figure 17, but are very common and are shown on Plate I. Exposures of extrusive Depoe Bay Basalt pillow lavas and breccias are confined to the southern half of Wickiup Ridge and to Nicolai Ridge on the eastern boundary of the map (Plate I, Figure 17). Thick dikes and sills commonly form low elongate ridges and hills above the slope-forming sedimentary strata, and can be seen easily on aerial photographs. The erosionally resistant extrusive basaltic breccias and pillow lavas cap Wickiup Ridge and form cliffs and fault-block topography. Extensive faulting makes estimation of thickness difficult, but the extrusives range to greater than 400 feet thick based on the map pattern.

Intrusives

Depoe Bay Basalt intrusives are most commonly dikes and sills that range from less than a foot to greater than 200

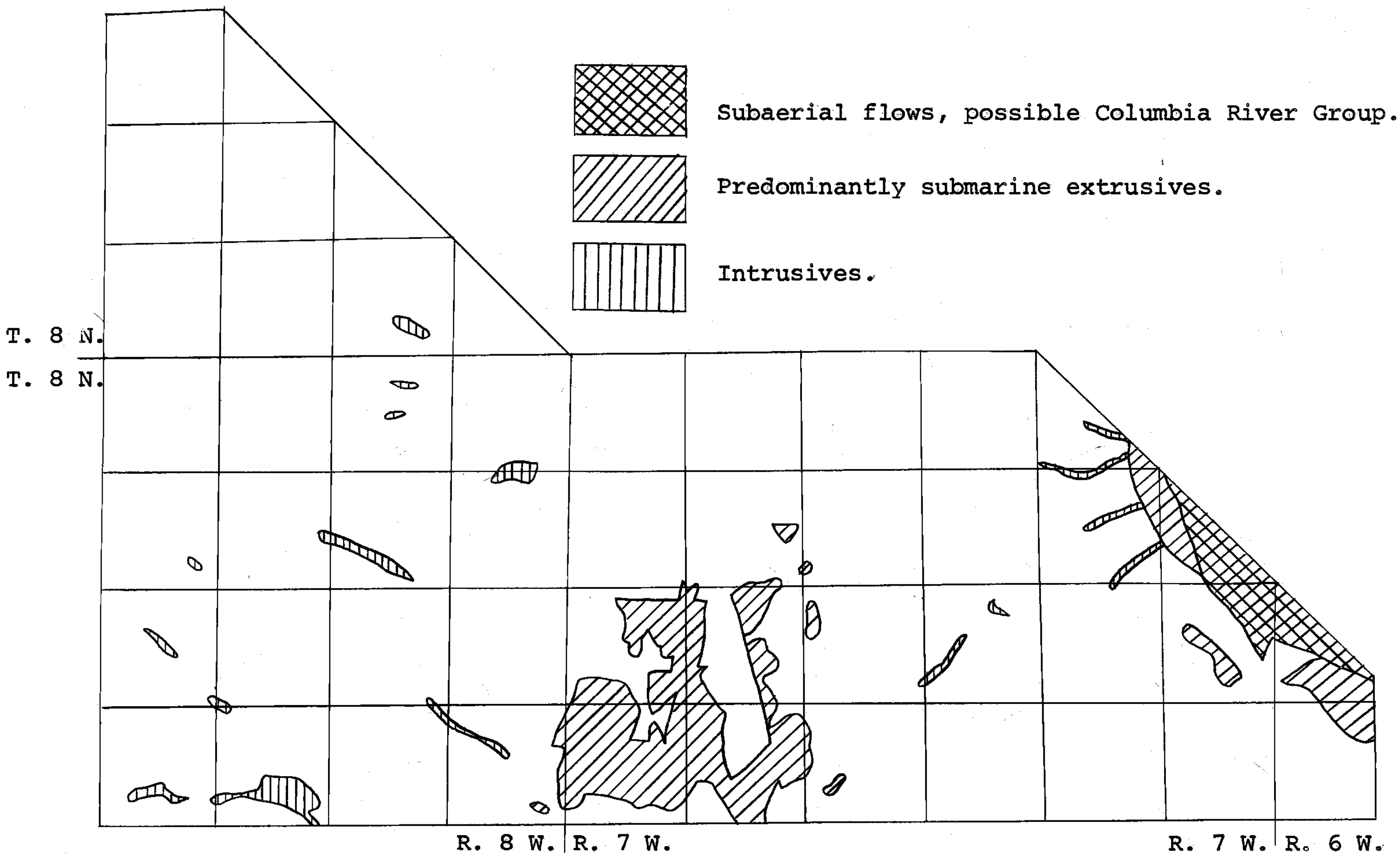


Figure 17. Outcrop distribution of the Depoe Bay petrologic-type basalt.

feet in thickness. Small intrusives (less than ten feet thick) are generally structureless, but the outer parts are common brecciated, or less commonly peperitic. South of Wickiup Lake (Plate I), a ten-foot wide feeder dike is composed entirely of breccia and is gradational at the margins (over a few feet) into highly palagonitized extrusive breccia. Larger intrusives, particularly sills ($Tidb_s$ on Plate I), consist of dense, columnar jointed basalt.

Fresh Depoe Bay intrusive basalt is dark gray (N3) and aphanitic to fine-grained. In the smaller brecciated intrusions, fresh surfaces are rare, and weathered fracture surfaces are extensively iron stained to a dark yellowish orange (10YR6/6). Rare small vesicles also occur in the smaller intrusions and are commonly filled with calcite or chlorophaeite.

Irregular brecciated intrusive basalts which splay, bifurcate, and occur as pods and isolated "pillows" suspended in Silver Point mudstone occur on Wickiup Ridge (Figures 18 and 19). These basalts are interpreted to be shallow intrusions into sea floor muds. Snyder and Fraser (1963a,b) discuss similar examples of intrusive pillow basalt in the geologic record. Foraminifera from the surrounding mudstones (Appendix VI, fossil locality 53) suggest middle- to outer-sublittoral depths (Rau, 1977, written and verbal communication). Penoyer (1977) recognized similar splaying brecciated feeder dikes of Depoe Bay

Figure 18. Irregular, brecciated, near-surface Depoe Bay intrusive in Silver Point mudstone. Near fossil locality 53, on Wickiup Ridge.

Figure 19. Intrusive Depoe Bay pillowed basalt in Silver Point mudstone, directly above outcrop in Figure 18. Pillow is three to four feet in diameter. Fossil locality 53.

Basalt near Saddle Mountain, ten miles to the south.

Extrusives

Pillowed lavas, thick structureless hyaloclastic breccias, and bedded hyaloclastites are the dominant extrusive lithologies of the Depoe Bay Basalt. A small subaerial flow is present at the top of Wickiup Ridge.

Pillow basalts occur in both closely packed accumulations and isolated pillows in a palagonitized hyaloclastite matrix. The pillows are most commonly brecciated, and are altered along fracture surfaces. Fresh surfaces are similar in color and texture to the intrusive basalt. Brecciated pillow basalts appear to be a dominant lithology in the southwestern part of Wickiup Ridge (e.g., quarry 1,300 feet SE of sample locality 82), and in the lower part of the Nicolai Ridge basalts (e.g., sample locality 120).

"Hyaloclastite" has been defined and described by Fisher (1966), MacDonald (1967, 1972), and McBirney (1963). It is a genetic term that indicates fragmentation of lava (of non-explosive origin) by rapid quenching in water. Many of the original angular glassy fragments are altered to palagonite. Hyaloclastites commonly contain isolated pillowed lavas or pillow fragments, or are closely associated with thick accumulations of "packed" pillow basalts. Hyaloclastic deposits are reported to have formed in lakes (Fuller, 1931), under glaciers (Peacock, 1926), and in the deep sea (McBirney, 1963). Carlisle (1963) proposed the term "aquagene tuff" for similar deposits in British Columbia.

Many of the steep cliffs on the west-central side of Wickiup Ridge are formed almost entirely of palagonitized, very thickly bedded hyaloclastic breccias and thinly bedded hyaloclastites (Figures 20 and 21). The well-developed stratification in much of the hyaloclastites is a striking characteristic.

McBirney (1963) states that, even on very low-angle slopes, submarine conditions must be highly favorable to the transport of hot hyaloclastic debris by density currents. Thermal expansion of entrapped sea water may greatly increase the mobility of a hyaloclastic flow. A turbulent hyaloclastite-water vapor mixture would be maintained by continuous contact of seawater with fresh, hot surfaces exposed by progressive shattering of cooling glass during transport.

The stratified hyaloclastites in the thesis area are thought to have been transported and deposited by such a mechanism. Some deposits are graded locally, suggesting a process similar to turbidity currents.

Near the top of Wickiup Ridge a 12-foot thick columnar-jointed flow grades upward into scoriaceous basalt, indicating that Depoe Bay Basalt extrusives built up to, and above, sea level. This is reasonable, considering that

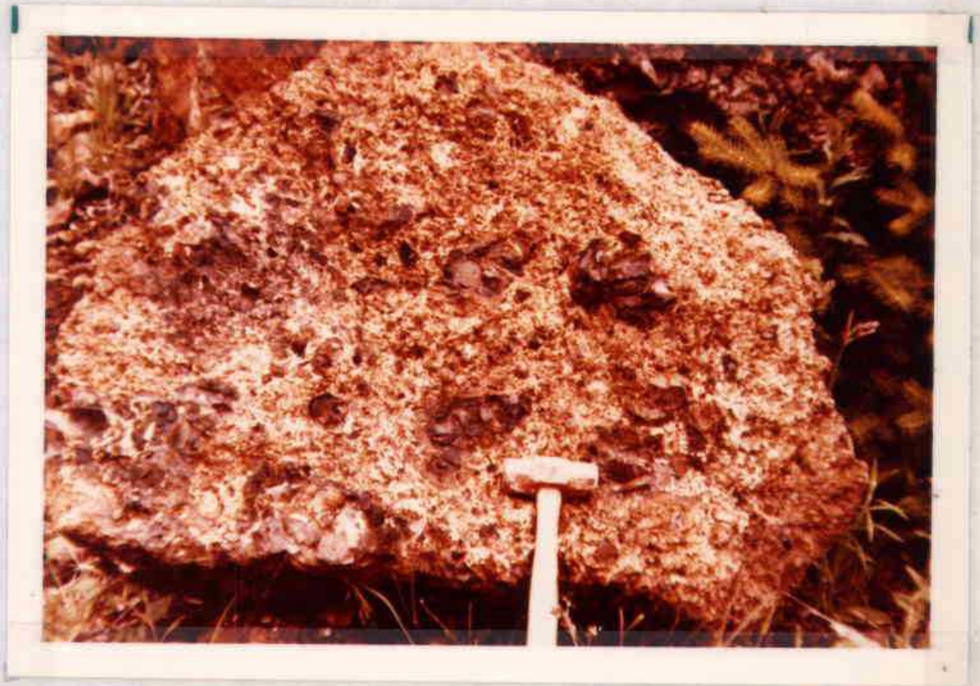


Figure 20. Palagonitized hyaloclastic breccia. Large clasts may be fragments of brecciated pillow basalts. Quarry near Wickiup Lake.

Figure 21. Bedded hyaloclastite on Wickiup Ridge. Note large, isolated basalt clast in center of photo. Bed disrupted by clast is visibly graded at base.

accumulations of greater than 400 feet would certainly be enough to break the ocean surface from middle-shelf depths. Local hyaloclastic conglomerates at the top of Wickiup Ridge suggest minor reworking by currents, and tend to support a near sea-level environment.

Columbia River Group(?)

Vesicular, columnar-jointed subaerial flows cap Nicolai Ridge, and reportedly can be traced eastward to the Columbia River Group at Portland (Niem and Van Atta, 1973; Snavely and others, 1973). The fact that Kienle (1971) has measured westerly flow directions from these basalts at Bradley State Park (five miles northeast of the map area) also infers that a Wickiup Ridge origin of these basalts is doubtful.

A chemical analysis of one of these flows, sampled outside of the map area, revealed a Depoe Bay-type chemistry (Appendix XII, sample 111). As is discussed in the Chemistry section of BASALT PETROLOGY, the lower Yakima Basalt of the Columbia River Group is chemically identical to the Depoe Bay petrologic-type (Snavely and others, 1973). Middle Yakima Basalt (equivalent to Cape Foulweather Basalt) chemistries are reported by Snavely and others (1973, samples MR69-222 and MR69-223) from the same area, but are probably higher in the section. I have also obtained a middle Yakima-type chemistry from a flow stratigraphically above sample 111 (sample 118).

The subaerial flows on the part of Nicolai Ridge that is within the thesis area (Tdbcr) were mapped on air photos solely on the basis of apparent lateral continuity with subaerial flows to the east, and therefore are considered to be Columbia River Plateau-derived lower Yakima Basalt. The underlying pillow basalts are thought to be locally-derived Depoe Bay Basalt on the basis of intrusive dikes beneath the pillows. Of course, there may have been pillow basalts formed by Columbia River Basalt entering a marine embayment, as proposed by Snavely and others (1973). On the other hand, some of the basalt flows may have been locally produced, as they were on Wickiup Ridge. Unfortunately, since the ages, stratigraphic positions, major and trace elements, lead-isotope and strontium-isotope ratios of correlative plateau-derived and coastal-derived basalts are essentially identical (McDougall, 1976; Snavely and others, 1973), any further refinement of the boundary between the two groups is impossible at this time. However, the Big Creek-Nicolai Ridge area does apparently offer a unique opportunity to study this interfingering relationship in detail. Perhaps a concentrated stratigraphic and geochemical study would aid in solving the coastal basalt-Yakima Basalt enigma. A suggested course of study would be to attempt to differentiate the locally-derived and plateau-derived basalts on the basis of the sedimentary interbed lithologies. The locally-derived basalts, which were erupted in a submarine environment, are associated with mudstones only. Sandstones are interbedded with subaerial flows of the Columbia River Group to the northeast of the map area, and may also be interbedded with any pillow basalts formed by the subaerial flows upon entering a marine embayment.

Contact Relations

Depoe Bay Basalt sills and dikes intrude all the sedimentary units in the area except for the Pipeline member sandstone (Tps). Contacts are sharp and planar to highly irregular. Baked zones around some of the thicker sills are a few tens of feet in thickness, but most are only a few inches thick.

The unconformable relationship of the extrusive Depoe Bay Basalt with the underlying members of the Astoria Formation is discussed in the Contact Relations sections of the Big Creek and Silver Point members. The contact is almost invariably covered by basalt colluvium; but where it is exposed in small patches it is sharp and highly irregular. Some ripped-up blocks of the underlying mudstones are incorporated in the basal basaltic breccias. The contact is drawn in many places on Plate I by projection between small isolated exposures of the contact; where exposures were not available, the contact was drawn at the break in slope.

The only place where Cape Foulweather Basalt overlies Depoe Bay Basalt is on the top of Wickiup Ridge (SE¼, sec. 7, and SW¼, sec. 8, T. 7 N., R. 8 W., Plate I). Cape Foulweather appears to unconformably "onlap" Depoe Bay. The exact nature of the contact is obscured in the field by road construction on the top of the ridge and colluvium and vegetation on the flanks, but a change in lithology from nonporphyritic to porphyritic basalt is detectable across the contact over a few tens of feet. The contact can be seen clearly and was mapped on black and white aerial photographs. Chemical analyses of samples from both sides of the contact are compatible with its placement. The contact is thought to be disconformable because the Cape Foulweather overlies both the Depoe Bay Basalt and Silver Point mudstone, but the shallow, northward dips of the two basalt units appear to be concordant.

Age and Correlation

The Depoe Bay Basalt in the study area is considered to be middle Miocene in age. Both Newportian Big Creek sandstone and Silver Point mudstone are intruded and overlain by Depoe Bay Basalt. The Depoe Bay Basalt on the Oregon coast has been radiometrically dated at 14-16 million years (Niem and Cressy, 1973; Snavely and others, 1973; Turner, 1970).

Based on essentially identical lithologic and chemical characteristics, and stratigraphic position, the Depoe Bay Basalt in the thesis area is petrologically equivalent to the middle Miocene Depoe Bay Basalt at Depoe Bay, Oregon. The Depoe Bay Basalt is correlative to the plateau-derived lower Yakima Basalt (Yakima-type of Snavely and others, 1973) of the Columbia River Group for the same reasons, including similarity in age (McDougall, 1976; Snavely and others, 1973). This study, however, tentatively suggests that the lower Yakima basalt on Nicolai Ridge may be slightly younger than the underlying Depoe Bay Basalt.

Cape Foulweather Basalt

Nomenclature

Middle Miocene basalts of local eruptive origin occur at Cape Foulweather on the Oregon Coast, and have been named the Cape Foulweather Basalt by Snavely and others (1973). At Depoe Bay, Oregon, Cape Foulweather Basalt unconformably overlies a sandstone unit that in turn overlies the Depoe Bay Basalt. For the same reasons discussed in the Nomenclature section of the Depoe Bay Basalt, the "Cape Foulweather Basalt" in the thesis area is more correctly designated as "Cape Foulweather petrologic-type basalt."

Distribution

The Cape Foulweather Basalt generally occurs in the north-central part of the thesis area (Figure 22). Most intrusions are too small to be shown on Figure 22. The majority of the exposures are on the northern half of Wickiup Ridge, except for a large fan-like pattern of extrusives that make up the northwesternmost part of the distribution. The outcrop distribution indicates that, locally, the total thickness of extrusives is greater than 450 feet.

Intrusives

Cape Foulweather intrusives are similar in form to those of the Depoe Bay Basalt, but are more commonly peperitic. Multiple, irregular, brecciated dikes near the center of section 7, T. 7 N., R. 7 W. are complexly associated and intermixed with Silver Point mudstone, and grade upward into hyaloclastic breccias. However, structureless to columnar-jointed dikes of dense Cape Foulweather Basalt do occur locally throughout the outcrop area.

The Cape Foulweather Basalt is porphyritic, in contrast to the Depoe Bay Basalt, which is nonporphyritic. The plagioclase phenocrysts, which range from five to twenty millimeters in length, are very sparse, and it is commonly necessary to examine many hand specimens of Cape

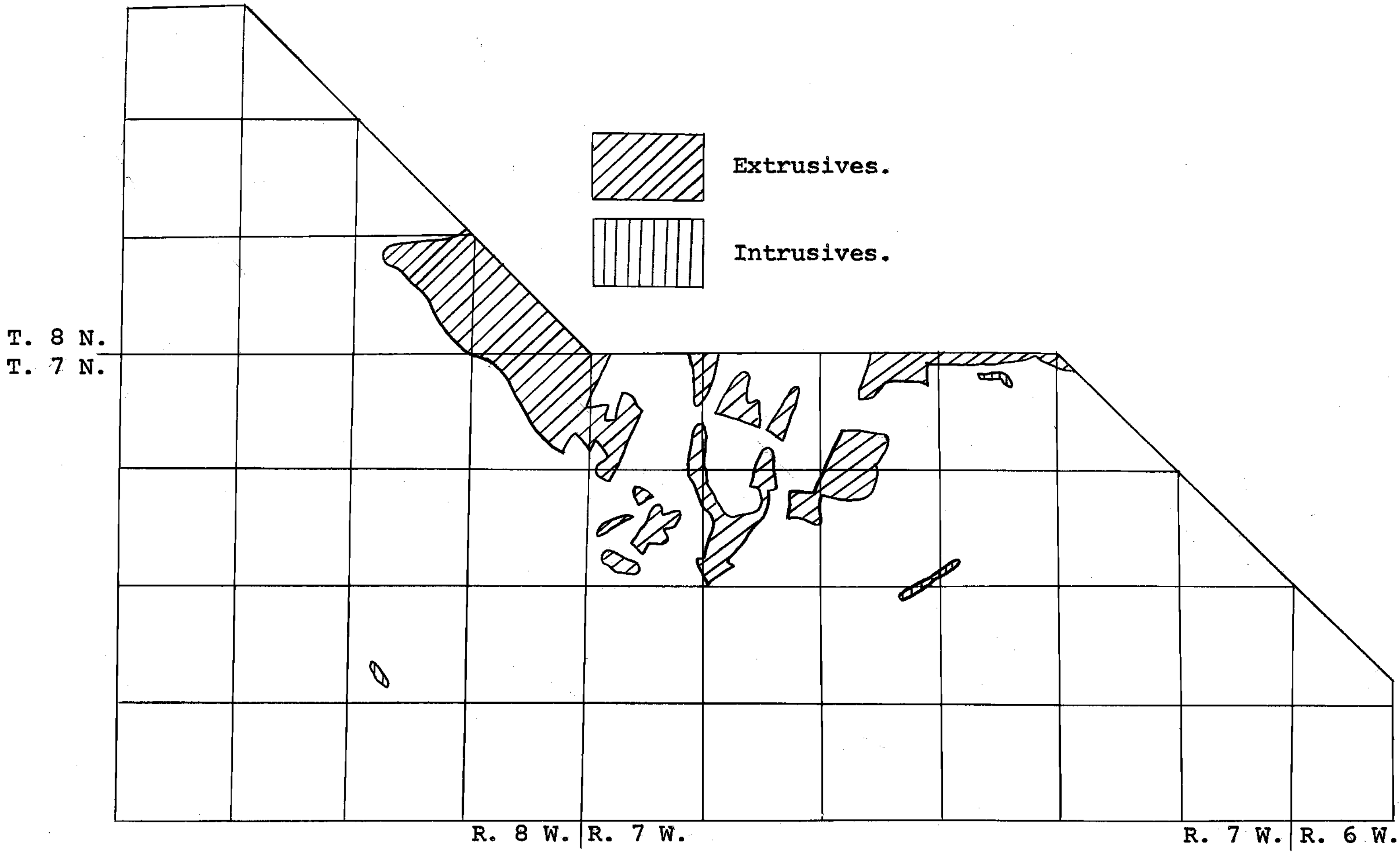


Figure 22. Outcrop distribution of the Cape Foulweather petrologic-type basalt.

Foulweather Basalt in order to find one phenocryst. The groundmass is fine-grained or less commonly aphanitic, dark gray (N3) to grayish black (N2), and weathers to dark yellowish-orange (10YR6/6).

Extrusives

Cape Foulweather Basalt extrusives are similar to those of the Depoe Bay Basalt and are thought to have been formed, transported, and deposited by the same mechanism. That is, thick, structureless to stratified hyaloclastites are the dominant lithologies. Pillow basalts occur (e.g., sample locality 105), but appear to be less common than they are in the Depoe Bay Basalt.

The fan-like outcrop pattern mentioned in the Distribution section (secs. 35 and 36, T. 8 N., R. 8 W., and sec. 1, T. 7 N., R. 8 W., Plate I) offers an opportunity to speculate. Well-bedded, locally-graded, hyaloclastic breccias with minor interbedded mudstones occur in a large quarry at the toe of this "fan." Small specimens of Macoma and Nuculana were collected from a mudstone interbed, suggesting that the depth of deposition was probably in the middle- to outer-sublittoral zone (Addicott, 1977, written and oral communication, fossil locality 171). Only isolated, poor outcrops of basalt breccia occur in the rest of the "fan" area, so the boundaries and the fan shape are inferred from topographic maps and aerial photographs. I postulate that this is the remains of an "archipelagic apron," similar to those that occur around some seamounts and volcanic islands (Menard, 1956). McBirney (1963) believes that such aprons may be formed by hyaloclastic flows.

Contact Relations

Cape Foulweather Basalt intrudes all Tertiary units in the study area except for the Pipeline member sandstone (Tps). The lower contacts of the extrusives are unconformable and are discussed in the Contact Relations sections of the Silver Point mudstone member and the Depoe Bay Basalt. As with the Depoe Bay Basalt, lower extrusive contacts are, for the most part, covered by basalt colluvium, and boundaries between units on Plate I are drawn based on projections from small outcrops of the sharp, irregular contact (e.g., NW cliffs of Wickiup Ridge) and breaks in slope.

Age and Correlation

A lower age limit of middle Miocene can be inferred for the Cape Foulweather Basalt from stratigraphic relationships in the thesis area. However, because no upper limit can be established, the Cape Foulweather Basalt in the study area is considered to be middle Miocene based solely on similarities in petrologic and stratigraphic characteristics to the middle Miocene basalts at Cape Foulweather on the Oregon coast as described by Snavely and others (1973).

The Cape Foulweather Basalt is correlative with the middle Yakima Basalt (late Yakima-type of Snavely and others, 1973) of the Columbia River Group on the basis of similarities in age, stratigraphic position, major and trace elements, and lead-isotope and strontium-isotope ratios (McDougall, 1976; Snavely and others, 1973).

Quaternary Deposits

Stream alluvium and flood-plain deposits are mapped in the lower reaches of Bear Creek and along small segments of Big Creek (Figure 23). These deposits consist predominantly of basaltic cobbles and gravel, and poorly sorted sand, silt, and clay.

Large masses of basalt colluvium almost invariably occur on the slopes of cliffs capped by Depoe Bay or Cape Foulweather Basalt. No attempt is made to show colluvium on the geologic map (Plate I) everywhere it is present because it would obscure other, more important bedrock relationships. Colluvium is shown resting on Silver Point mudstone on the northwestern side of Wickiup Ridge (Qc), because it is conspicuous in the field, and does not crowd other symbols.

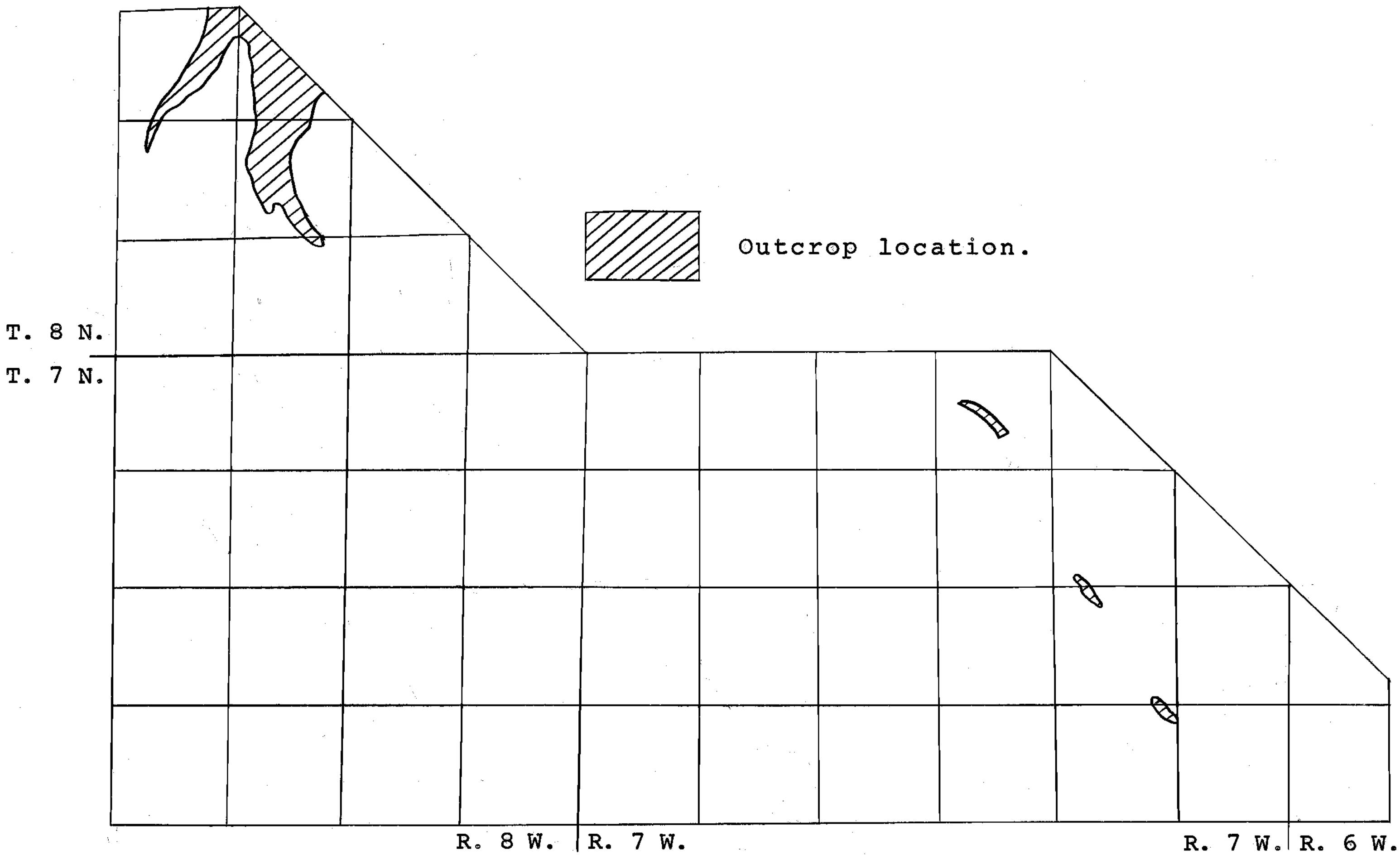


Figure 23. Outcrop distribution of Quaternary alluvium and flood-plain deposits.

SEDIMENTARY PETROLOGY

Sandstones

Classification

Twelve thin sections of Big Creek and Pipeline sandstones were point counted, and the data (Appendix VII) were plotted on the ternary diagram of Williams and others (1954, p. 292) for classification purposes (Figure 24). Almost all samples (except number 116) are wackes (ten percent or more matrix). Most Pipeline sandstones tend to plot as arkosic wackes, whereas the Big Creek sandstones can be classified as feldspathic and lithic (volcanic) wackes. That is, the Pipeline member sandstones generally have a higher relative proportion of feldspar than do those of the Big Creek member.

It is possible that the amount of feldspar is directly related to grain size and therefore is less abundant in the finer grained Big Creek sandstones. However, the difference in grain size between the two members (see Size Analysis section) is certainly not the only controlling factor. The grain-size modes of samples numbers 116 and 148 (Big Creek) are similar to the modes of the Pipeline samples, but the rocks are classified differently. Sample numbers 152 and 84 (Pipeline) are much coarser grained than sample numbers 7 and 93 (Big Creek), yet all four samples have similar quartz contents. Differentiation of the four samples is

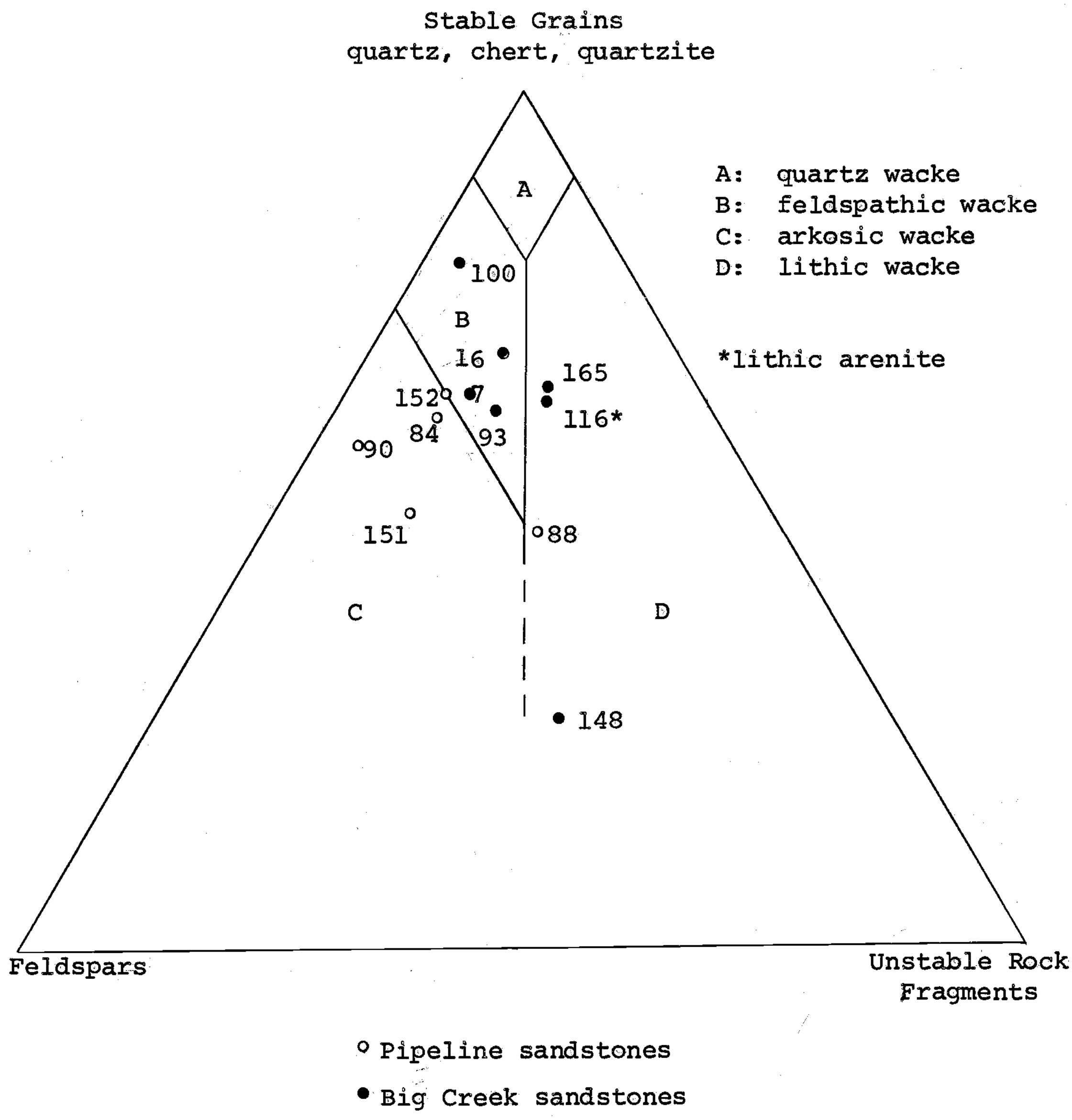


Figure 24. Classification of point-counted sandstone samples (classification after Williams and others, 1954).

based, in this case, on the ratio of feldspar to rock fragments. The only sample interpreted to be fluvial in origin (148, lower Big Creek) has a significantly higher abundance of volcanic rock fragments than the rest of the samples.

Petrography

Framework grains in the sandstones of the Astoria Formation include quartz, feldspar, volcanic rock fragments, mica, and opaque and authigenic minerals (Figures 25 and 26). Minor amounts of plutonic, metamorphic and sedimentary rock fragments, chert, heavy minerals, carbonaceous fragments, and glauconite also occur in the sandstones. Modal and heavy mineral analyses are listed in Appendices VII and VIII. Heavy mineral analysis was also performed on an Oswald West sandstone (Appendix VIII).

Quartz. Table 1 lists the average mineralogic compositions of Big Creek and Pipeline sandstones. Although the average quartz percentages are nearly the same in the two members, the range of values within an individual member is quite large (Appendix VII). Quartz content ranges from 14 to 38 percent in the Big Creek sandstones, and from 24 to 39 percent in the Pipeline sandstones. No trend related to stratigraphy is apparent in either unit.

Strained, monocrystalline quartz is the predominant variety in all samples. Unstrained monocrystalline and strained polycrystalline types occur in nearly equal amounts,

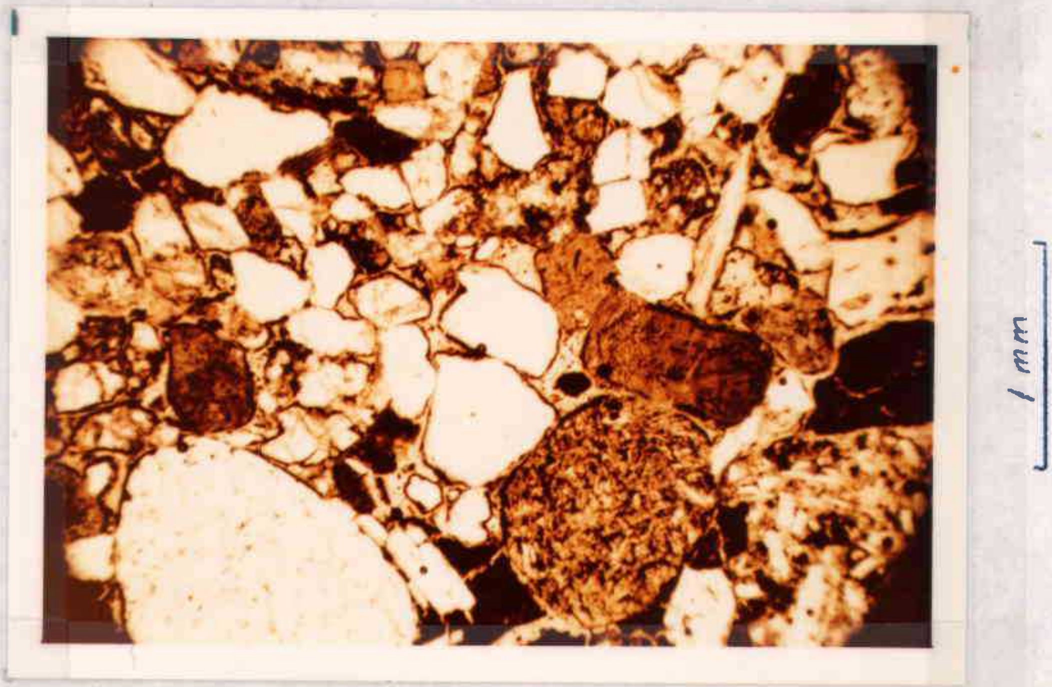


Figure 25. Photomicrograph of lower Big Creek fluvial sandstone, illustrating poorly sorted nature and variety of framework clasts. Note large amount of void space between grains. Large rounded quartzite grain on lower left, volcanic rock fragments on lower right. Parallel nicols. Sample 148.

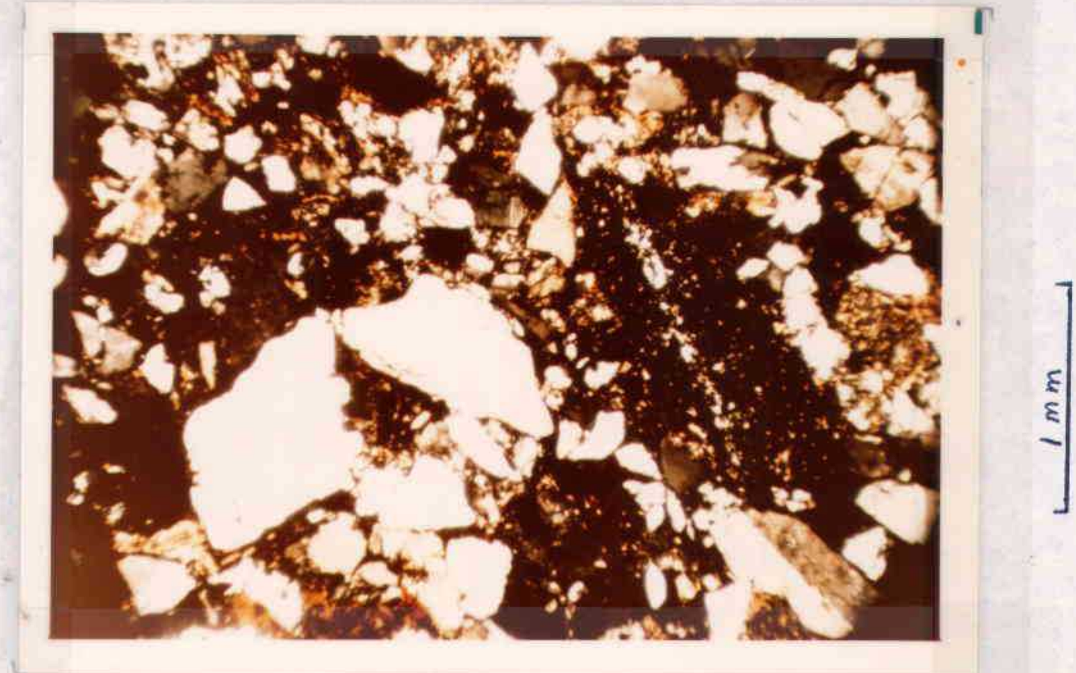


Figure 26. Photomicrograph of Pipeline sandstone, showing poor sorting of angular quartz and feldspar framework grains. Note large, dark, carbonaceous mudstone fragment at center-right. Crossed nicols. Sample 90.

Table 1. Average mineralogic compositions (in percent) of Big Creek and Pipeline sandstones.

Mineral	Big Creek*	Pipeline**
Quartz	30	31
Quartzite	tr	tr
Chert	tr	tr
Plagioclase	3	3
Potassium Feldspar	6	14
Volcanic Rock Fragments	9	7
Plutonic Rock Fragments	tr	-
Metamorphic Rock Fragments	tr	1
Sedimentary Rock Fragments	tr	tr
Mica	5	4
Mafics	1	tr
Opaques	3	tr
Nonopaque Alteration Minerals	3	4
Organic Fragments	tr	tr
Glauconite	tr	-
Matrix	23	23
Carbonate Cement	7	-
Porosity	9	12

* Based on seven samples.

** Based on five samples.

and collectively make up one quarter to one half the total amount of quartz. Most quartz grains are angular to subrounded. Subrounded grains are less common. Rounded grains are rare, although well-rounded chert and quartzite fragments occur locally in small amounts.

<u>Feldspar</u>. Mineralogically, Big Creek and Pipeline sandstones are best differentiated on the basis of feldspar content. Figure 27 is a ternary plot of the relative proportions of quartz, plagioclase, and potassium feldspar in each of the samples. The two member sandstones separate quite well, mainly because of the consistently higher amount of potassium feldspar in the Pipeline sandstones. Plagioclase ranges from trace amounts to seven percent in Big Creek sandstones, and one to six percent in Pipeline sandstones (Appendix VII). However, the average abundance of plagioclase is the same (3%) in both member sandstones (Table 1). On the other hand, the maximum potassium feldspar content in the Big Creek sandstone samples is eight percent (excluding sample 17, a pebbly sandstone), whereas the minimum amount of potassium feldspar in the Pipeline sandstones is eleven percent (Appendix VII). The average Pipeline sandstone contains more than twice as much potassium feldspar as the average Big Creek sandstone (Table 1).

Many of the feldspars in both units are altered to various degrees. Plagioclase grains are commonly totally replaced by sericite and related alteration products.

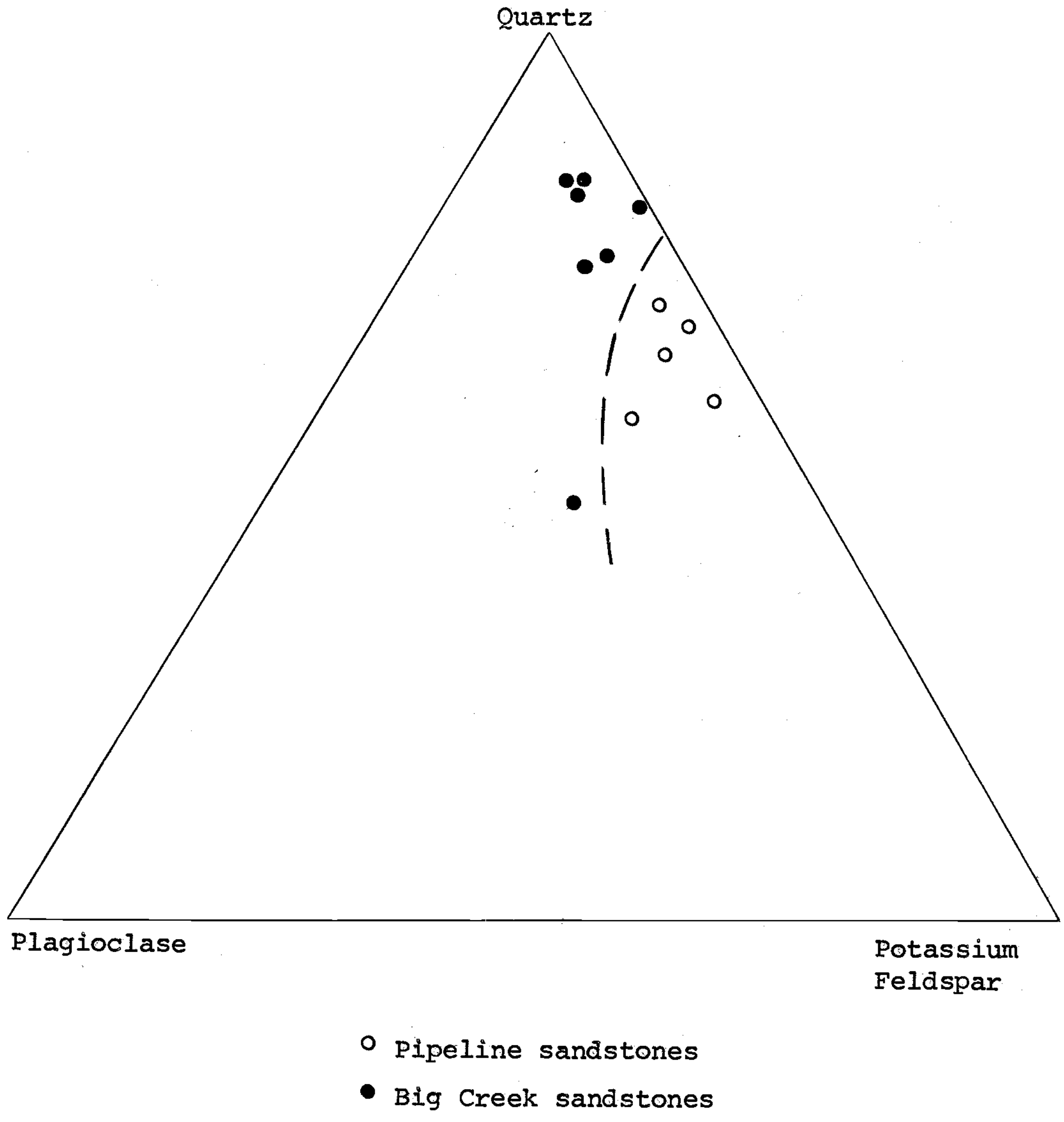


Figure 27. Relative proportions of quartz, plagioclase, and potassium feldspar in the Pipeline and Big Creek sandstones.

Potassium feldspar is generally less altered than plagioclase. Unaltered, properly oriented (a-normal) plagioclase grains, from which an accurate composition can be determined, are lacking. However, zoned plagioclase occurs in both units, suggesting that possibly much of it is volcanically derived. Measurements on phenocrysts in volcanic clasts in a pebbly sandstone from the Big Creek member (sample 17) indicate labradorite compositions (An_{50} to An_{62}). Potassium feldspar is predominantly orthoclase, along with minor sanidine, microcline, and perthite, thus indicating both volcanic and "granitic" derivation.

Rock Fragments. Rock fragments are mainly volcanic, and range from two to twenty percent in both the Big Creek and Pipeline sandstones. A channelized pebbly sandstone in the lower Big Creek member is composed of 53 percent volcanic rock fragments (Appendix VII, sample 17). Minor amounts of metamorphic rock fragments are present in all Pipeline sandstone samples, and also in one sample from the Big Creek member. Traces of plutonic and sedimentary rock fragments occur in a few coarser grained Big Creek sandstones.

Volcanic rock fragments are basaltic and/or andesitic, the majority of which are altered to smectite clays. Intersertal or hyalo-ophitic textures are most common. Less common are felty, or rarely, pilotaxitic textures. As was mentioned in the previous section, measured plagioclase phenocrysts are labradorite. Grains are commonly well-rounded.

Schists and phyllites are the major metamorphic rock fragments. They are typically elongate and angular. Sub-rounded metaquartzites also occur in trace amounts, but are included with "stable grains." Myrmekitic texture suggests a "granitic" derivation for the rare plutonic rock fragments. Sedimentary fragments are small mudstone clasts and trace amounts of rounded quartzite (also included in "stable grains") which are present in trough cross-bedded, lower Big Creek fluvial(?) sandstone. Carbonaceous mudstone fragments occur in the Pipeline sandstone.

Mica. Up to eight percent mica is present in all the sandstone samples examined. Green and red-brown biotite are the dominant varieties. Muscovite fragments are locally contorted or crushed in both the Big Creek and Pipeline sandstones, indicating some degree of compaction. Micas in laminated Big Creek sandstones are commonly oriented parallel to the laminations.

Opaque Minerals. Opaque minerals are generally more common in the Big Creek sandstones than in the Pipeline sandstones, which contain only trace amounts. Detrital opaque grains include magnetite and ilmenite. Leucoxene and pyrite are common diagenetic opaque minerals. Leucoxene occurs as individual grains altered from ilmenite. Pyrite is present as very fine sand-sized particles or as a matrix filling. Pyrite locally fills microfossil tests, and, in one case, had replaced a megascopic part of a gastropod from a Big Creek sandstone.

Nonopaque Authigenic Minerals. "Sericite," or microcrystalline micaceous minerals, are the major alteration products in all the sandstones. They commonly occur as large masses with indistinct boundaries that grade into a diffuse matrix. These sericite masses are undoubtedly altered grains of feldspar or volcanic rock fragments.

Chlorite(?) is a rare alteration product, and occurs as very fine pleochroic blebs with indistinct boundaries.

Heavy Minerals. In this thesis, heavy minerals are those nonmicaceous, nonopaque minerals with a specific gravity greater than 2.95. No obvious stratigraphic trend can be inferred from the analyses listed in Appendix VIII. Most of the listed heavy minerals occur in all the samples and vary widely within a single unit. However, there are a few important differences.

A sandstone sample from the upper Oswald West unit contained a distinctively high amount of heavy minerals in the epidote group. Green epidote is the most common variety (45%) and is significantly more abundant than in the Big Creek and Pipeline sandstones.

The Big Creek sandstone samples show an increase in pyroxene compared to the Oswald West sandstone. Big Creek sample number 7 is highly garnetiferous, and is probably a local concentration of reworked grains.

The Pipeline sandstone samples have several important characteristics. Tremolite-actinolite is present in consistently higher amounts than in the other two units. Glaucophane also was identified in one sample (156). Andalusite occurs in trace amounts, and kyanite and staurolite are relatively high in two samples (84, 152). Therefore, a greater contribution of sediment from a metamorphic source area is suggested for the Pipeline member as opposed to the Big Creek and Oswald West units.

In all the units, hornblende, epidote, garnet, rutile, sphene, staurolite, and tourmaline occur as well-rounded to angular grains. Grains of pyroxene, apatite, andalusite, and kyanite are generally subangular to angular. Monazite is rounded, and euhedral grains of zircon occur locally.

Matrix. Matrix ranges from 8% to 32% in the Big Creek and Pipeline sandstones, and averages 23% in both members. Size analyses (Appendix X) do not reflect this high amount of matrix, probably because of the tendency of the matrix clay to form small, hard grains even after physical disaggregation.

Much of this matrix is undoubtedly diagenetic. Feldspars and volcanic rock fragments commonly are altered.

Grain boundaries can be seen merging locally with the matrix. Many of the sandstones with a lower amount of matrix (perhaps less than 20%) might have been arenites at the time of deposition.

X-ray analysis of the clay-sized fraction from a Big Creek sandstone (Appendix IX, sample 165) indicates the presence of montmorillonite, beidellite or possibly hydroxy-interlayered montmorillonite, chlorite intergrades, and possibly mica. The poorly crystallized chlorites and smectites imply alteration in place. Clinoptilolite, a common volcanic alteration product, is also present.

No peaks were obtained in the low 2-thēta range for the clay-size fraction of the Pipeline sandstone (Appendix IX, sample 156). This suggests a poorly crystallized matrix for this sample.

Cement. Although one sample (16) of Big Creek sandstone consisted of 44 percent calcite cement, this is a local phenomenon. Most sandstones are friable and contain little or no carbonate. Many sandstones in the upper part of the member are indurated, but are bonded by a clay matrix.

Almost all Pipeline sandstones, excepting clastic dikes, are very friable and are devoid of carbonate cement. Clastic dikes are apparently cemented by matrix clays.

Size Analysis

Data generated by grain-size analyses are presented in Appendix X. The data have aided in describing the size distributions and textural maturity of the sandstones. Bivariant plots of the textural parameters of Folk and Ward (1957) have been moderately helpful in differentiating the Big Creek and Pipeline sandstones. Although the usefulness of environmental inferences from these plots is questionable, the statistical limits of Moiola and Weiser (1968), Friedman (1961), Kulm and others (1975), and Passega (1957) are considered.

The upper Oswald West sandstone (Appendix X, sample 175) is fine-grained (Md = 2.80 phi) and poorly sorted (S_1 = 1.37 phi). The grain-size distribution is nearly symmetrical (Sk_1 = 0.07) and is very leptokurtic (K_G = 2.11).

Lower Big Creek sandstones tend to be medium-grained, whereas the upper Big Creek sandstones are very fine- to fine-grained. Sorting values in the member are at the boundary of moderately and poorly sorted. The medium-grained lower Big Creek samples are enriched in fines (positively skewed), possibly by diagenesis. Most of the upper Big Creek sandstones have nearly symmetrical curves. Two samples (15, 165) are negatively skewed, suggesting removal of fines in a beach or shelf environment. Most samples are leptokurtic or very leptokurtic.

Pipeline sandstones are consistently medium-grained, except for rare fine-grained laminated sandstones (sample 162). They are poorly sorted, tending to moderately sorted. The distribution curves are positively to very positively skewed (enriched in fines), and are leptokurtic to very leptokurtic.

Samples 153 through 158 (Pipeline member) were taken at two-foot intervals from the same outcrop, bottom to top. Samples 153 to 155 and 156 to 158 may represent two amalgamated beds. By examining the coarest one percent (Appendix X), it can be noted that the coarser fraction of the lower bed is normally graded, and that the grain size increases again in the bottom of the upper bed, which is again normally graded. The pattern of fluctuation of the median grain sizes of these four samples is less clear, but a relative constancy suggests "coarse-tail" grading for these two sandstone "beds."

All the sandstones classify as texturally immature to submature, according to Folk (1951). That is, most samples have considerable amounts of "clay-sized" material (petrographically, less than 30 microns), are poorly to moderately sorted, and are dominantly composed of subangular grains. Although much of the clay-sized material may be due to diagenetic disintegration of larger grains, deposition and burial before significant reworking may have been major factors involved in producing the grain-size characteristics of these sandstones. The unusually thick accumulation of shelf sands, represented by the Big Creek member, suggests subsidence of the depositional basin. Reworking of sand bodies is less likely in this setting than on a stable shelf. The submarine channel sandstones of the Pipeline member represent a process of rapid sedimentation in a deep-water, relatively low-energy environment.

Bivariant plots of the textural parameters of Folk and Ward (1957) are shown in Figures 28 through 33. This was an attempt to devise another quantitative method to distinguish Big Creek sandstones from Pipeline sandstones. Any apparent separation may be due to the effect of different grain sizes, because the three coarser grained lower Big Creek samples (109, 116, and 149) tend to plot with the Pipeline sandstones on Figures 29, 30, 31, and 32. However, the two members do separate rather well on the plot of deviation versus mean diameter (Figure 28). Therefore, these two parameters are suggested to be the most effective for differentiation of the Big Creek and Pipeline member sandstones. Nelson (1977, personal communication) found mean diameter versus skewness useful for separating these two members of the Astoria Formation to the west of the thesis area.

The plots of textural parameters are not as useful for environmental interpretations. A few Big Creek samples plot in the "mixed" field of Friedman (1961) on Figure 28, but all the rest of the samples are off his graph. On Figure 29,

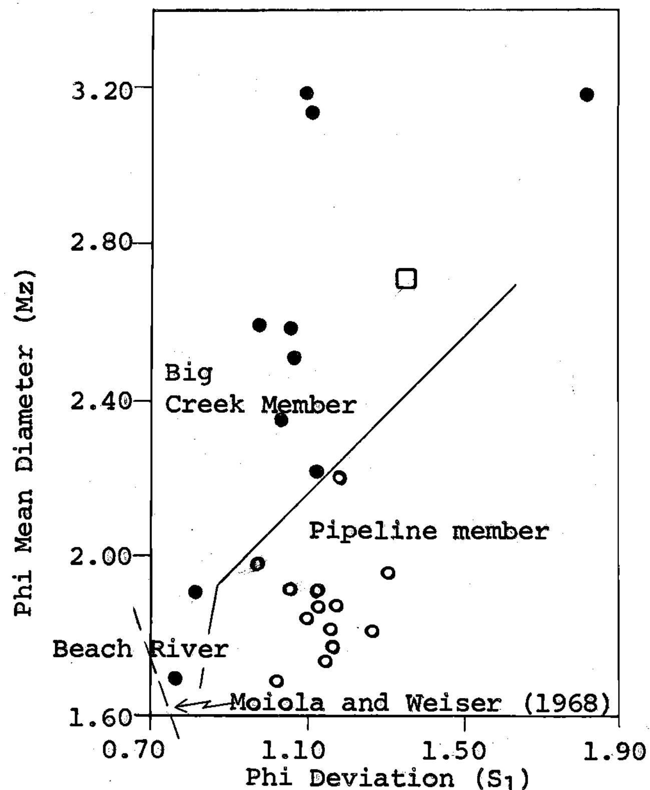


Figure 28. Bivariant plot of phi deviation versus phi mean diameter, showing good separation of the Big Creek and Pipeline members, Environmental fields of Moiola and Weiser (1968) are indicated.

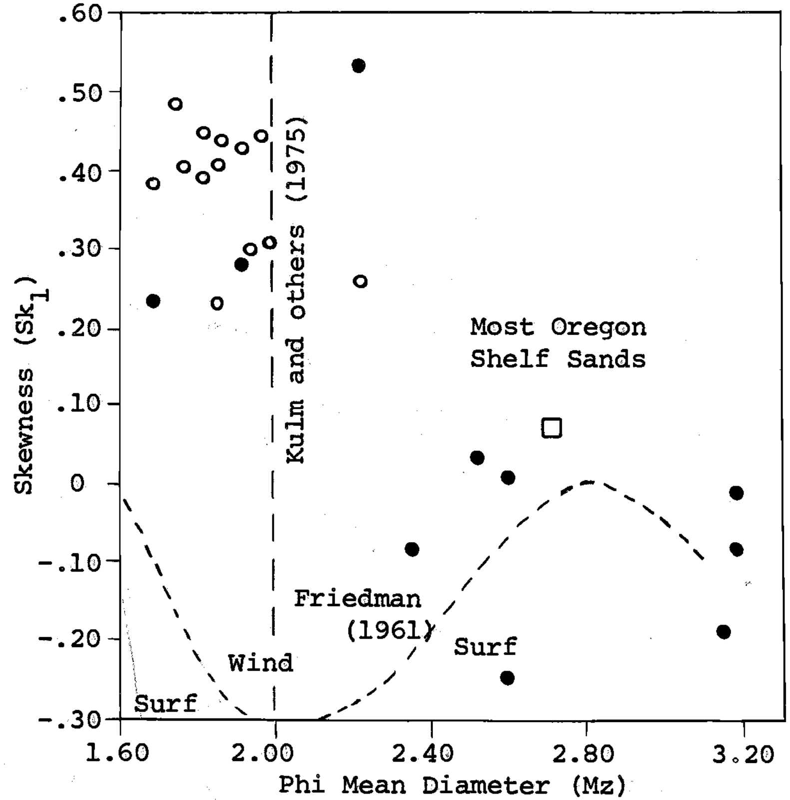


Figure 29. Bivariant plot of phi mean diameter versus skewness, showing poor separation of units. Environmental fields of Friedman (1961) and Kulm and others (1975) are indicated.

□ = Oswald West sandstone ● = Big Creek sandstone ○ = Pipeline sandstone

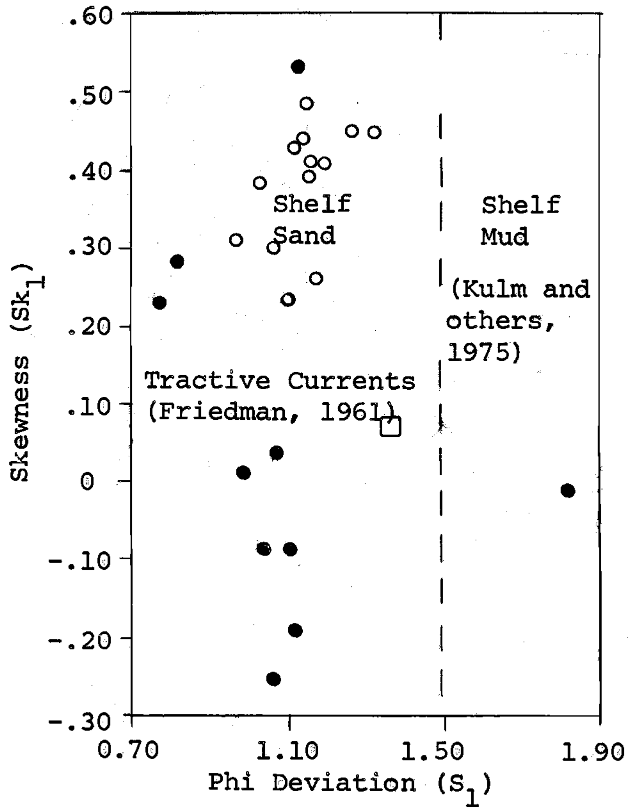


Figure 30. Bivariant plot of phi deviation versus skewness, showing poor separation of units. Environmental fields of Friedman (1961) and Kulm and others (1975) are indicated.

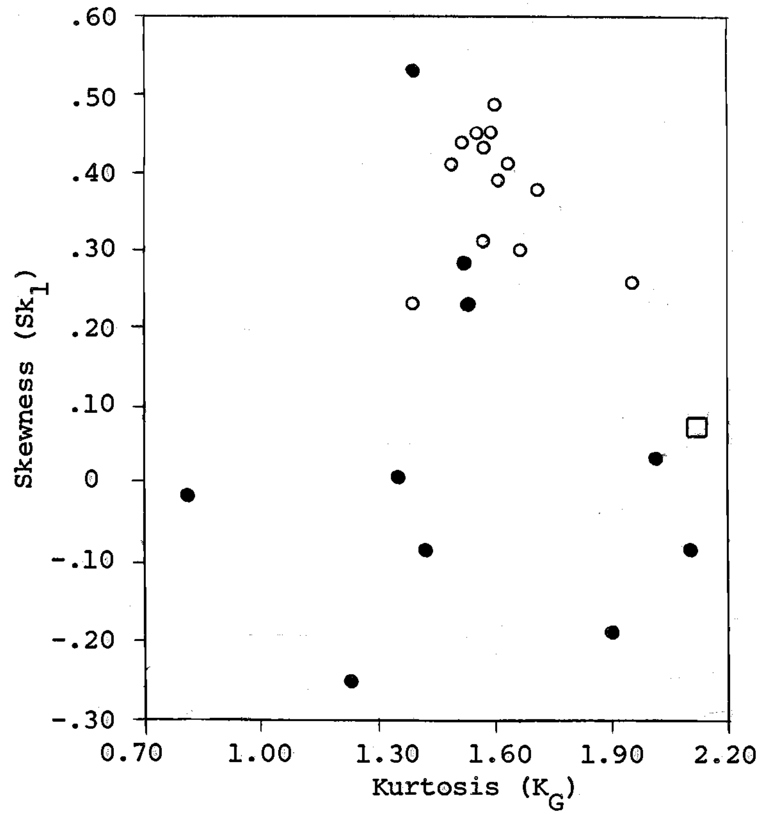


Figure 31. Bivariant plot of kurtosis versus skewness, showing poor separation of units.

□ = Oswald West sandstone ● = Big Creek sandstone ○ = Pipeline sandstone

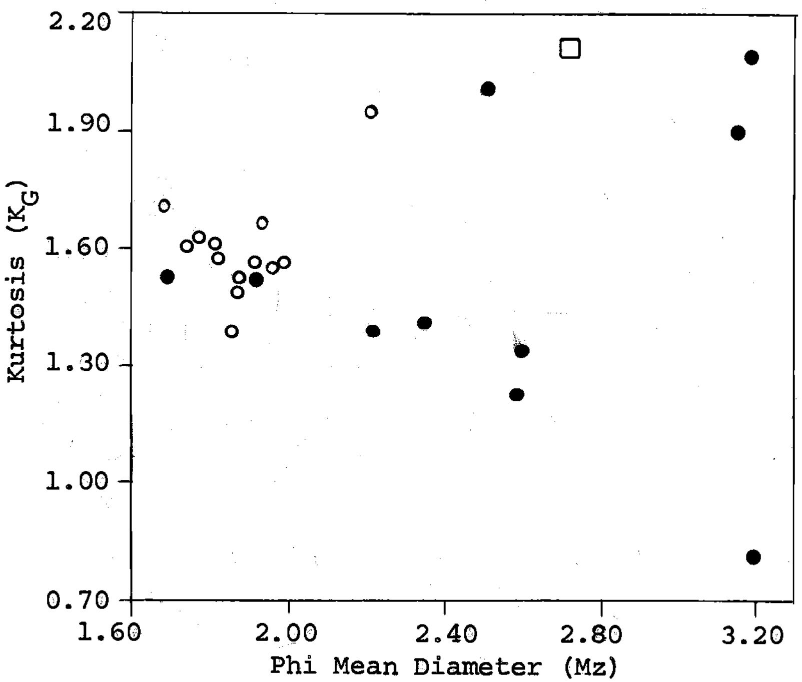


Figure 32. Bivariant plot of phi mean diameter versus kurtosis, showing poor separation of units.

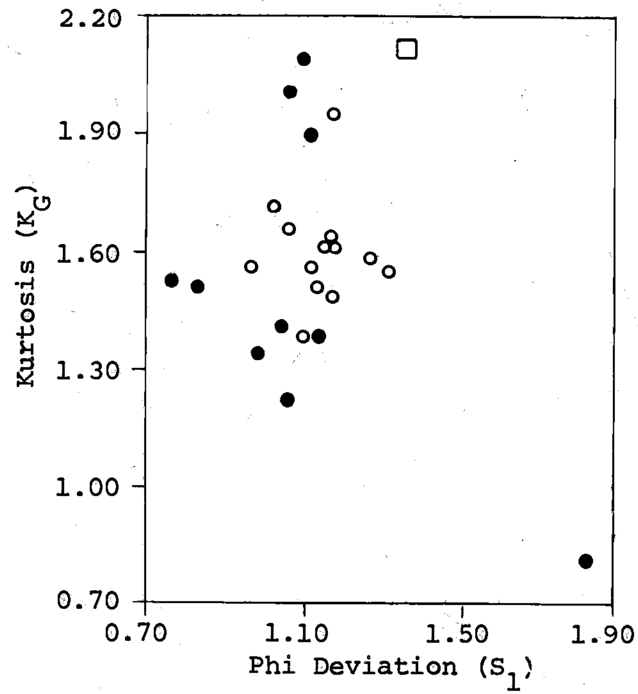


Figure 33. Bivariant plot of phi deviation versus kurtosis, showing very poor separation of units.

□ = Oswald West sandstone ● = Big Creek sandstone o = Pipeline sandstone most sandstones plot in Friedman's "wind" field. All the samples are within the "tractive currents" field of Friedman in Figure 30, and comparison with all the above plots implies that perhaps tractive currents were a dominant depositional process.

Kulm and others (1975) have utilized mean diameter and skewness parameters to plot sands from the modern Oregon continental shelf (Figure 29). Most of the Big Creek sandstones plot within the area in which most present-day shelf sands plot; that is, they are between two and four phi-size. Two of the coarsest Big Creek samples plot outside this field, but there are present day scattered sands on the shelf greater than two phi, also. Almost all the Pipeline sandstones are coarser than two phi, and therefore are not similar to the average modern shelf sands.

Kulm and others (1975) have also differentiated shelf sands from other shelf sediments utilizing a bivariant plot of deviation versus skewness (Figure 30). All samples plot within the shelf-sand field, except for one Big Creek sandstone which plots in the "mud" field.

The coarsest one percentile and median of all samples were plotted on the "CM" diagram of Passega (1957) (Figure 34). Most sandstones, except for four of the finer grained Big Creek samples, plot in the "beach" field. It is interesting that most Pipeline samples plot in or near the "river" or "turbidity current" fields. However, three Big

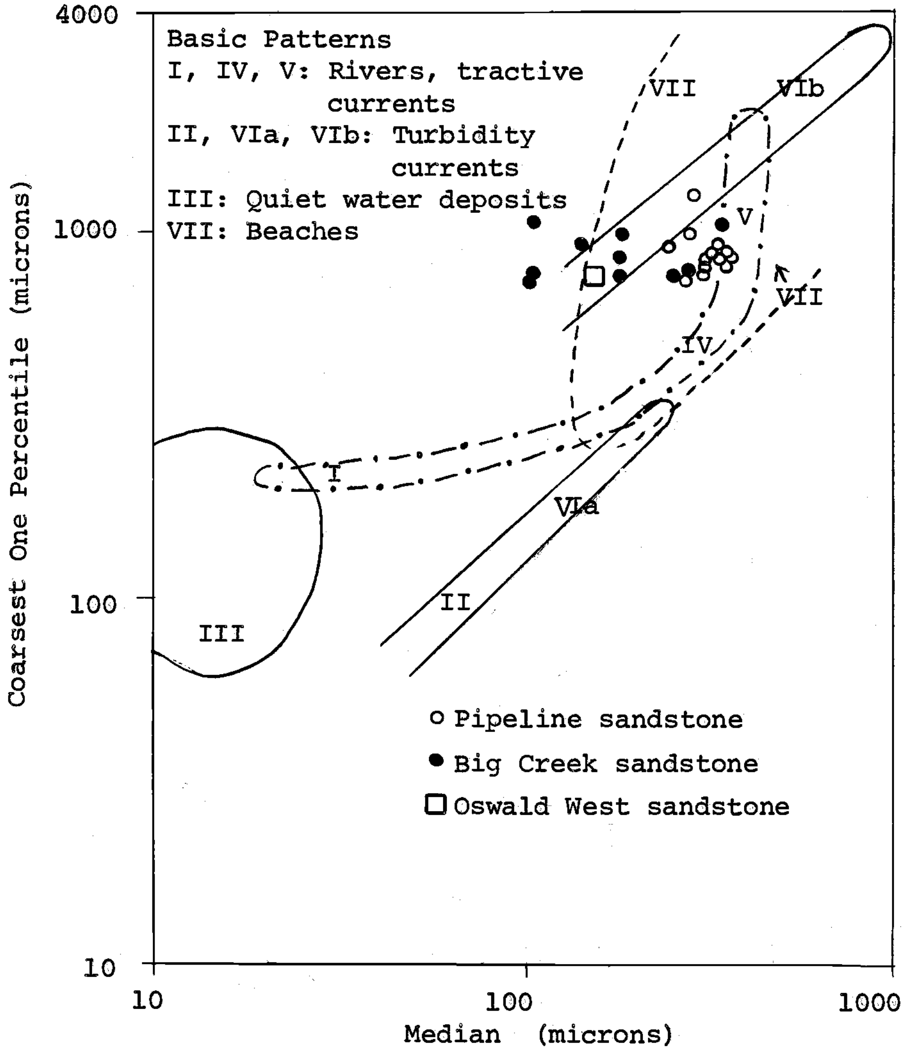


Figure 34. CM diagram (Passega, 1957) of sandstone samples.

Creek samples also plot as "turbidity currents." The "CM" diagram is evidently not suitable for these particular rocks.

Mudstones

Mudstones from the Oswald West mudstones (upper part) and the Silver Point mudstone member have been examined petrographically. X-ray analyses of mudstones from these units and a mudstone from the Pipeline member provided clay mineralogy data (Appendix IX).

Many of the rocks in the upper part of the Oswald West mudstones are considered to be "siltstones" (see Lithologies and Structures section of that unit). This is a useful field term because these strata contain recognizably more coarse silt than do the mudstones in the lower part of the Oswald West and other mudstone units. However, visual estimation with a petrographic microscope reveals that many of the "siltstones" consist of less than 50 percent coarse silt (30-60 microns). Although indistinct grains of fine silt (4-30 microns) may be an important constituent, petrographically these rocks are best described as "silty mudstones" or "muddy siltstones."

Silt-sized and rare sand-sized grains consist of subangular quartz and feldspar, mica, foraminiferal tests, molluscan fragments, and rare glauconite and pyrite. Most of the rocks are tuffaceous, and commonly sickle- and bubble-wall-shaped shards of glass are detectable (Figure 35). One sample contained nearly 50 percent carbonate matrix. Clay minerals include mica, and beidellite or hydroxy-interlayered montmorillonite, which probably are, in part, derived from alteration of the volcanic components.

Oswald West mudstones are structureless on a micro-scale. The grains show random extinction. Burrows commonly can be observed in thin section as well as in hand specimen, indicating the highly bioturbated nature of these rocks.

A thin section of Silver Point mudstone (Figure 36) shows the laminated character typical of much of the unit. Clay-size (less than 30 microns) minerals are dominant and show partial mass extinction. Beidellite or hydroxy-interlayered montmorillonite are the main clay minerals present. Larger grains include subangular to subrounded quartz and feldspar, mica, foraminiferal tests, diatoms, and sponge spicules.

X-ray analysis of a thin mudstone interbed in the Pipeline sandstone indicates the presence of mica and chlorite. With this combination of minerals, the presence or absence of vermiculite or kaolinite cannot be determined.

The mica and chlorite are considered to be detrital. A consistently sharp peak on the diffractogram at 10 Å indicates that the mica is well crystallized, and therefore is probably allochthonous. Chlorite is an abundant detrital component in arctic and temperate regions (Biscaye, 1965).

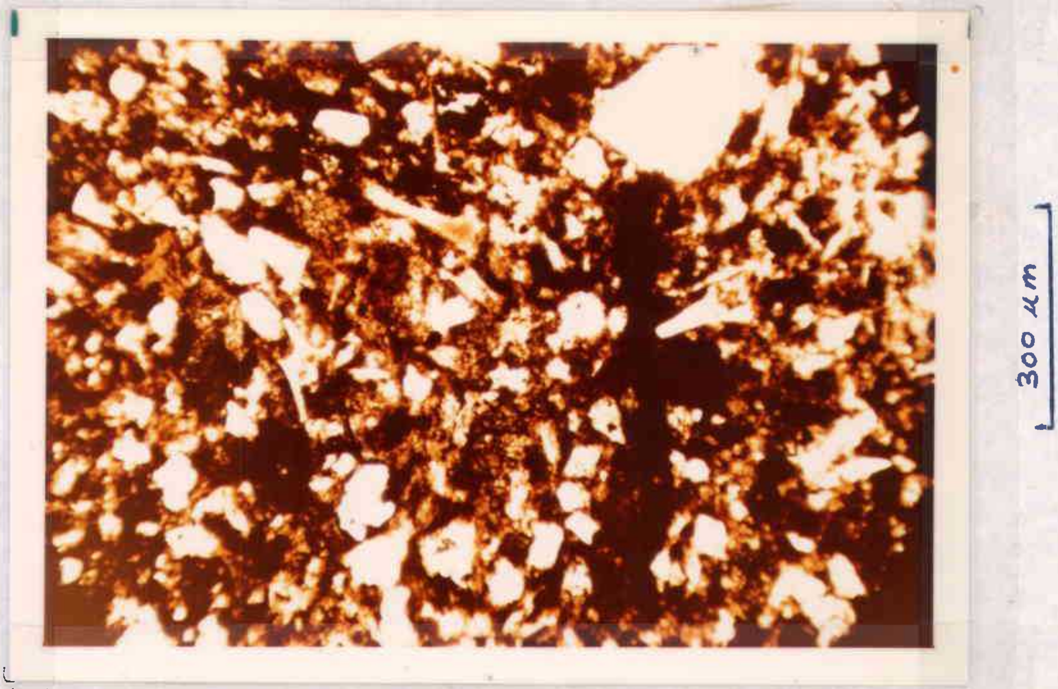


Figure 35. Photomicrograph of siltstone in the upper Oswald West, showing scattered glass shards. Parallel nicols.

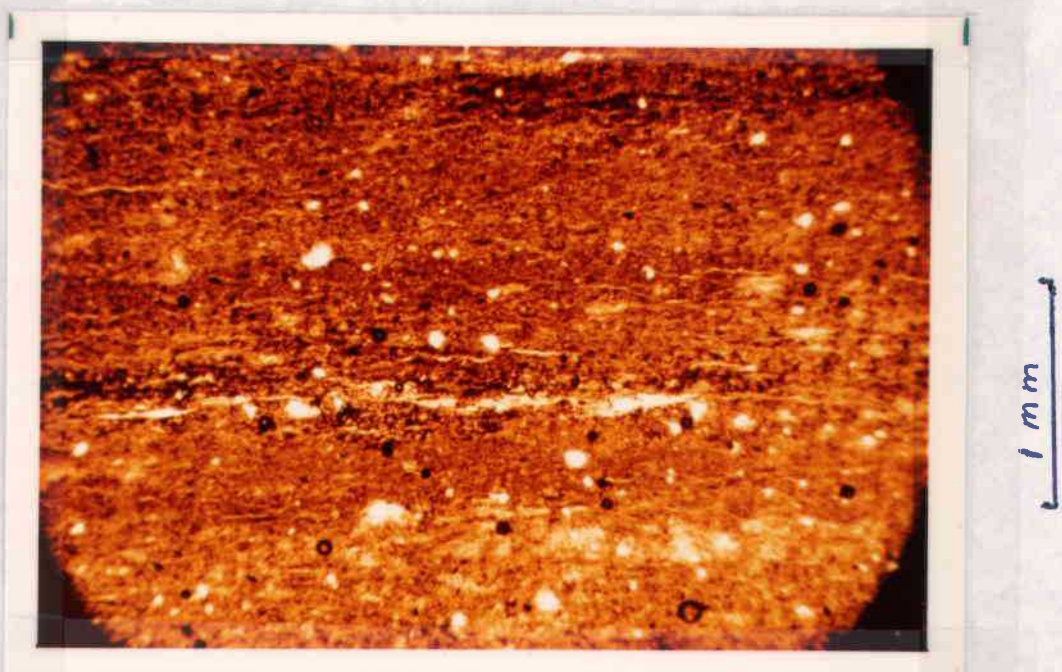


Figure 36. Photomicrograph of Silver Point mudstone, showing typical laminated character. Yellow color is due to iron staining. Parallel nicols.

Provenance

The compositional immaturity of the sandstones in the thesis area and the immature to submature textures indicates relatively rapid erosion, transportation, and deposition with little or no reworking. These characteristics also imply that these rocks are not derived from recycled older Tertiary sandstones in the northern Oregon Coast Range.

The tuffaceous nature of the Oswald West mudstones is indicative of a source with explosive volcanism, probably the ancestral Cascades. Additionally, the heavy mineral assemblage suggests a regionally metamorphosed source area, such as can be found today within the Columbia River system east of the Cascades.

The tuffaceous composition of the Oswald West mudstones has been noted by Cressy (1974), Neel (1976), Penoyer (1977), Smith (1975), and Tolson (1976). In southwestern Washington, the coeval Lincoln Creek Formation is also highly tuffaceous (Rau, 1967; Wolfe and McKee, 1972), reflecting pyroclastic volcanism in the area of the present Cascade Range (Snavely and others, 1963). The Oligocene to early Miocene Little Butte Volcanic Series (Peck and others, 1964) best represents this period of activity in Oregon, and was probably a major source of pyroclastic detritus for the Oswald West. The correlative deltaic deposits of the Scappoose Formation also are tuffaceous (Niem and Van Atta, 1973).

The heavy mineral assemblage of abundant epidote and garnet, including small amounts of kyanite and staurolite, suggests a source area of regionally metamorphosed rocks (Deer and others, 1966). The igneous and metamorphic terranes of British Columbia, north-central Washington, Idaho, and the Blue Mountains of Oregon are the most likely regions. Major formations in these areas include the Permian to Triassic Seven Devils Volcanics (greenstone) and Clover Creek Greenstone, pre-Jurassic gneiss and schist of the Shuswap Complex, Jurassic granitic rocks of the Nelson and Kuskanax Batholiths, and the Cretaceous Colville-Loon Lake, Kaniksu, and Idaho Batholiths. All these rocks lie within the drainage basin of the modern Columbia River. Van Atta (1971) suggested that the coeval Scappoose Formation was supplied by an ancestral Columbia River that drained similar types of source areas.

The Big Creek sandstone member is not ash-rich as are the Oswald West mudstones, but significant amounts of andesitic and/or basaltic rock fragments indicate erosion of local Eocene basalt highlands (Siletz, Tillamook, or Goble Volcanics), or any of the various basaltic or andesitic rocks in the western Cascades. Relatively high amounts of hypersthene in heavy mineral assemblages presume an andesitic source. Small amounts of "plutonic" rock fragments may have been derived from the Cascades or farther to the east. Rare sedimentary quartzite clasts in lower Big Creek are certainly not local, and are possibly derived from Paleozoic formations in Idaho.

The heavy mineral assemblages of the Big Creek member are difficult to interpret because of major inconsistencies. However, considerable amounts of epidote, and traces of staurolite, kyanite, garnet, and tremolite indicate a continuing metamorphic source area, although it may have decreased in importance. The exceptional garnet-rich assemblage (sample 7) is granitic- or metamorphic-derived, but probably is not a first-cycle deposit. This assemblage may have reached its present location via longshore drift. from the Angora Peak member (delta). This suggestion is supported by northerly paleocurrents at the same outcrop.

The Pipeline member sandstone is the unit most clearly derived, in part, from a metamorphic source area. Schist fragments occur in every sample. Volcanic rock fragments, hypersthene, and augite were evidently contributed from the Cascades and Coast Range. However, the higher percentages of potassium feldspar suggest an increase in input from a granitic or gneissic source, possibly one of those described for the Oswald West sandstone. A significant increase in metamorphic heavy minerals (discussed in <u>Heavy Minerals</u> section) supports a provenance east of the Cascades.

This relatively strong input from distant sources appears to reflect the mode of origin of the Pipeline sandstone deposits. Sediment probably was eroded, transported, and channeled directly into a submarine canyon. Tributaries from the Cascades contributed volcanics, but mixing was not a dominant process.

BASALT PETROLOGY

Petrography

The petrographic characteristics of the Depoe Bay and Cape Foulweather Basalts in the thesis area are generally similar to these units at the type localities as described by Snavely and others (1973). Modal analyses of four basalt samples are listed in Appendix XI.

Many Depoe Bay Basalt samples, which appear to be equigranular in hand specimen, are microporphyritic. Phenocrysts are rarely longer than 50 microns. An incipient "microcumulophyric" texture occurs in one extrusive pillow basalt (Figure 37). This particular sample (120) was mapped initially as Cape Foulweather Basalt in the field, based on the occurrence of small plagioclase "phenocrysts," but later was typed chemically as Depoe Bay Basalt (Appendix XII). Closer examination of the hand specimen revealed that the plagioclase "phenocrysts" are actually clusters of smaller grains. One should be careful in the field to be sure that phenocrysts are actually isolated, large, lath-shaped plagioclase before declaring the rock to be Cape Foulweather Basalt. Fine-grained phenocrysts or microphenocrysts may cluster (as in sample 120) to form an apparent megaporphyritic texture.

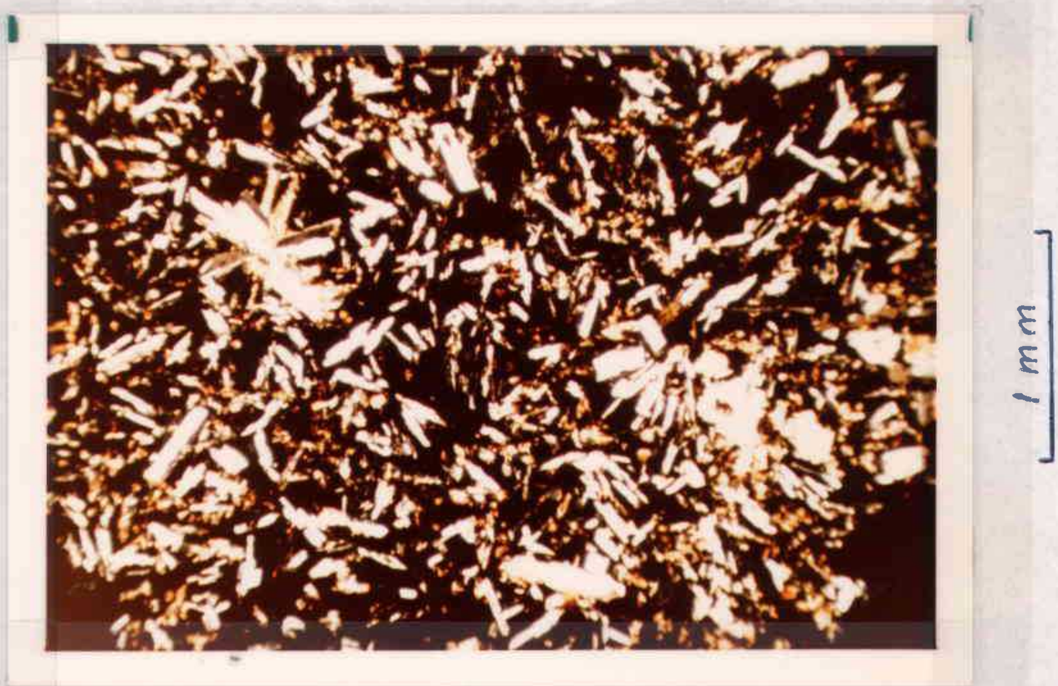


Figure 37. Photomicrograph of extrusive Depoe Bay Basalt, showing incipient "microcumulophyric" texture, and opaque groundmass. Crossed nicols. Sample 120.

The Depoe Bay Basalt has hyalo-ophitic, intersertal, or locally, subophitic texture. Plagioclase is andesine to labradorite (An_{47}-An_{64}) and averages 40 percent of the rock. None of the Depoe Bay samples examined was holocrystalline, which would explain the slightly lower plagioclase percentages than those obtained by Snavely and others (1973; 45-55%) from well-crystallized basalts. Subhedral to anhedral clinopyroxene averages 30 percent, which is in the middle of the range reported by Snavely and others (1973).

A Depoe Bay intrusive (sample 121) consists of 22 percent light- to dark-brown basaltic glass or "tachylyte" (Figure 38). Opaques (seven percent) occur as discrete grains or masses. Extrusive samples from the Depoe Bay and Cape Foulweather Basalts (samples 120 and 55) contain large amounts of opaque groundmass (30% to 48%, respectively) with no apparent crystal form (Figure 37). Peacock (1926) and Peacock and Fuller (1928) suggested that tachylyte is a relatively slow-chilled basaltic glass, which contains segregated iron-oxide minerals or masses. Carlisle (1963) reported tachylyte to be common in the centers of pillow basalts in British Columbia. The opaque groundmass in basalts in the thesis area is considered to be a mixture of basaltic glass and disseminated iron oxides (magnetite?) which are segregated to varying degrees.

Figure 38. Photomicrograph of intrusive Depoe Bay Basalt, showing dark-brown tachylyte grading into opaque areas, suggesting segregation of iron-oxide minerals. Parallel nicols. Sample 121.

A nearly holocrystalline Cape Foulweather intrusive (Figure 39; sample 114) contains a greater amount of plagioclase (51 percent) and clinopyroxene (36 percent) than reported in the type Cape Foulweather Basalts by Snavely and others (1973, p. 408). The proportions of opaques and olivine are similar to the reported values. Rare quartz xenocrysts with well-developed reaction rims of pyroxene are also present.

The texture of Cape Foulweather Basalt is intergranular, subophitic, intersertal, hyalo-ophitic, or vitrophyric, reflecting the wide range of crystallinity. The unit is best characterized by large, scattered plagioclase megaphenocrysts. Plagioclase in the groundmass is labradorite (An_{61}). Clinopyroxene occurs as subhedral to anhedral grains, and olivine commonly has well-developed rims of iddingsite (Figure 39). Calcite commonly occurs in amygdules lined with chlorophaeite.

Chemistry

Snavely and others (1973) reported that the Depoe Bay Basalt is characterized by high SiO_2 content and that the Cape Foulweather Basalt has high contents of total iron, TiO_2, and P_2O_5. I have found TiO_2 content to be the most useful in differentiating the two basalts. Chemical analyses confirmed field identifications.

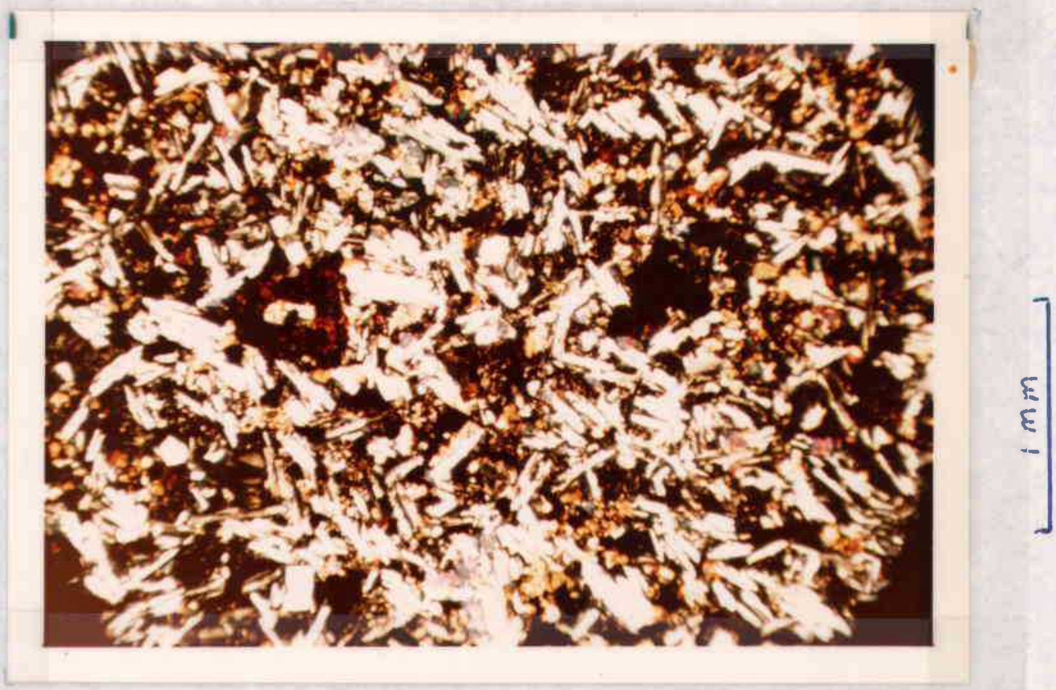


Figure 39. Photomicrograph of intrusive Cape Foulweather Basalt. Note olivine grain with iddingsite rim at left-center. Crossed nicols. Sample 114.

Figure 40 is a silica variation diagram of the data listed in Appendix XII. The two basalt types group well with no overlap. However, some of the samples are not within the compositional fields established by Snavely and others (1973).

A diagram based on silica values will, of course, systematically differentiate samples with high and low SiO_2, no matter how other elements may vary. Sample 25 (Appendix XII) consistently plots to the right of the Depoe Bay field (Figure 40) even though all other elements occur in typical proportions for that petrologic-type basalt. The SiO_2 value of 58 percent is the cause, which is rather high, even for Depoe Bay Basalt. An examination of the total percent (Appendix XII) reveals an excess (101.85%), which is probably mostly SiO_2. A small reduction in some SiO_2 percentages would place almost all the samples in their correct compositional fields. Snavely and others (1973) do mention that different laboratories may determine different silica values for the same rock.

The slight scatter of some of the total-iron plots is the only other problem on Figure 40. The deviations are probably not real. During the course of the analytical procedure, obvious errors in the total iron contents of some of the samples were recognized and eventually traced (by E. M. Taylor) to the method of preparation. The basalts had been melted at an excessively high temperature;

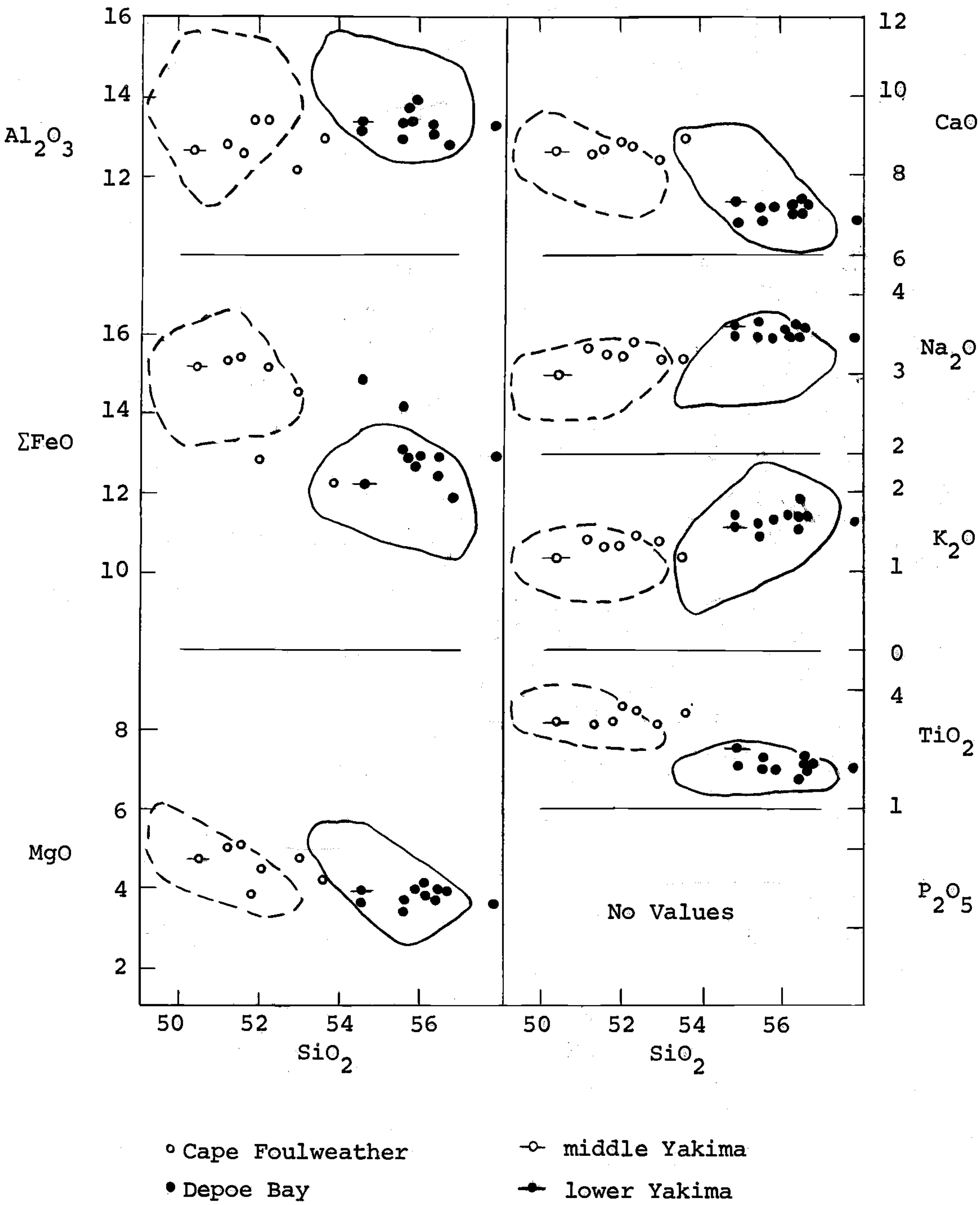


Figure 40. Silica variation diagram of Miocene basalts in the thesis area. Fields enclosed by lines show variations in values reported by Snavely and others (1973). Solid lines enclose Depoe Bay and Yakima-type (lower Yakima) basalt, and dashed lines enclose Cape Foulweather and late-Yakima-type (middle Yakima) basalt.

a reduction to 1000°C. corrected the erroneous iron readings. However, only samples with obviously incorrect values were redone. The samples with anomalous iron plots were not redone, but evidently had smaller, less detectable errors.

CaO and TiO_2 are much more consistent within a single unit than is iron. Note in Appendix XII how these two elements clearly separate the two basalts. CaO ranges from 6.5 to 7.1 percent in the Depoe Bay, and from 8.2 to 8.7 percent in the Cape Foulweather. However, this is apparently a local phenomenon. Nelson (1978) reports a Depoe Bay intrusive with a CaO value of 8.2 percent, and Snavely and others (1973) list a few Depoe Bay Basalts with similar, high CaO contents. Additionally, the correlative lower Yakima Basalts (Yakima-type) tend to have CaO values in the same range. This particular point raises suspicions about the derivation of sample 111, which was collected from a subaerial flow on Nicolai Mountain, and is interpreted by field relations to be Columbia River Group. The CaO value for this sample is low (6.6%), which is more characteristic of the coastal-derived basalts rather than those derived from the Columbia River Plateau (see analyses of Snavely and others, 1973).

TiO_2 content appears to be most effective for differentiation of the Depoe Bay and Cape Foulweather Basalts (including the correlative Yakima Basalts). The highest reported TiO_2 value for the Depoe Bay Basalts is 2.5 percent (Appendix XII; Snavely and others, 1973). The percentages of TiO_2 in Cape Foulweather Basalt are never less than 2.6. These two end values are uncommon.

Table 2 compares the average compositions of the basalts in the thesis area with the averages reported by Snavely and others (1973) for the Depoe Bay and Cape Foulweather Basalts. The similarity of values within each petrologic unit reinforces the findings of these authors. That is, the Depoe Bay and Cape Foulweather Basalts are each distinct petrologic types that can be chemically differentiated throughout the Coast Range.

Table 2. Average chemical compositions (in percent) of Depoe Bay and Cape Foulweather Basalts.

	Depoe Bay		Cape Foulweather	
	1*	2	1**	2
SiO_2	55.9	55.7	52.1	51.9
Al_2O_3	13.3	14.0	12.7	13.9
FeO	12.9	12.3	14.1	14.5
MgO	3.9	3.6	4.6	4.1
CaO	6.9	7.1	8.4	7.9
Na_2O	3.5	3.3	3.1	3.0
K_2O	1.6	1.4	1.2	1.0
TiO_2	2.0	2.0	3.0	3.0

1 This report

2 Snavely and others (1973)

*Based on eleven samples

**Based on seven samples

STRUCTURE

The Oregon Coast Range is a distinct structural province, as determined by geophysical methods. A steep, east-sloping gravity gradient on the eastern margin implies that major faulting separates the Coast Range from the Willamette Valley downwarp or graben (Bromery and Snavely, 1964). Near the coastline of Washington and Oregon, the magnetic-anomaly pattern changes abruptly (Zietz and others, 1971). The Coast Range has no overall pattern and high amplitudes, whereas the shelf has patterned, low-amplitude magnetic anomalies. The linearity of this break suggests major fault control.

The general structure of the northern Oregon Coast Range is a northward-plunging anticlinal upwarp or "anticlinorium." The core consists of Eocene Siletz and Tillamook Volcanics, with younger Tertiary units around the nose and flanks. Normal compressional folds and high-angle faults appear to be the most common structures (Braislin and others, 1971); these trend either northwest (Niem and Van Atta, 1973) or northeast (Bromery and Snavely, 1964). The rocks near the Columbia River, including those in this thesis area, have a regional north dip upon which smaller scale structures have been superimposed.

Figure 41 is a map of the structures that have been recognized in the thesis area. Faults can be mapped readily

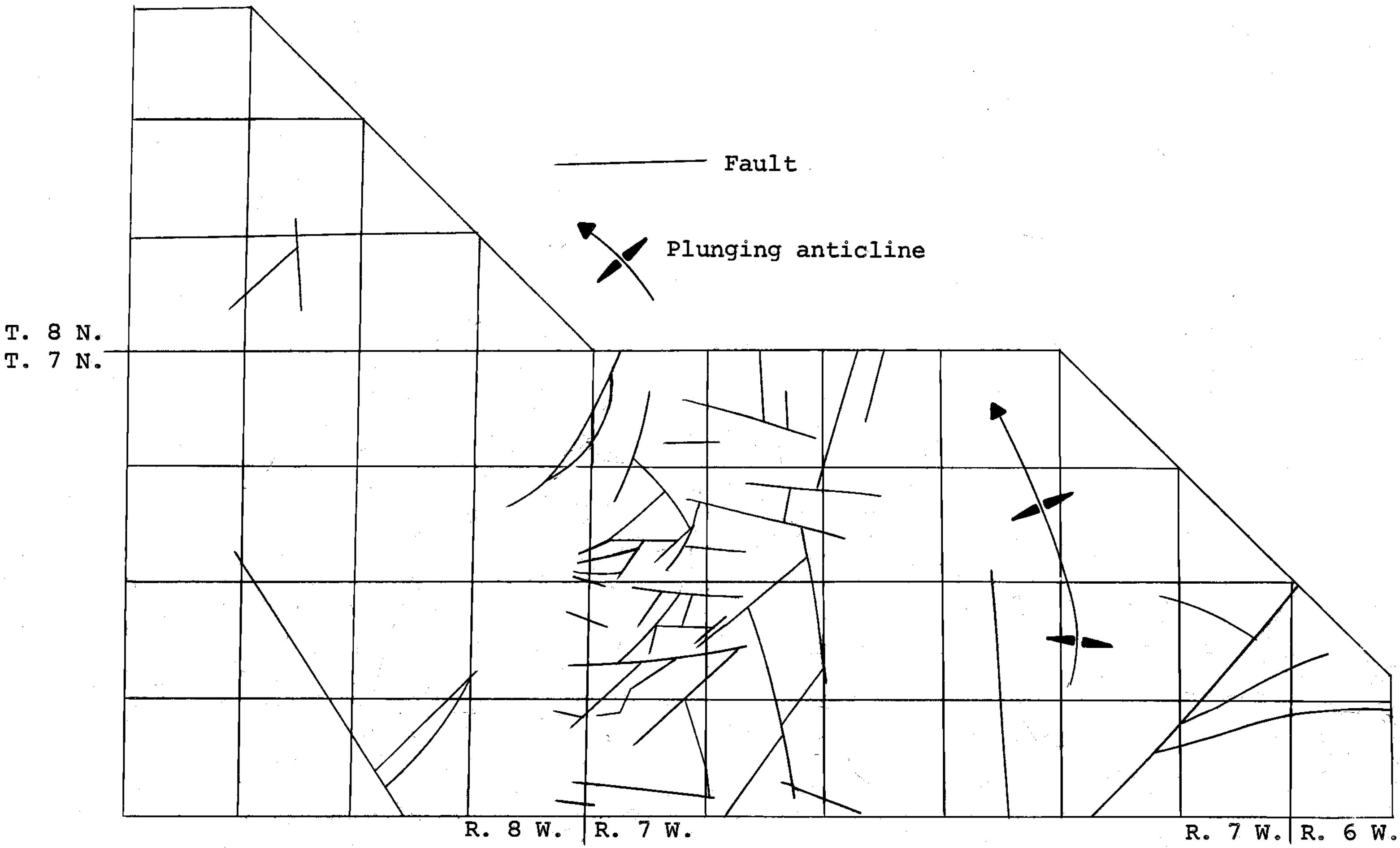


Figure 41. Structure map of the thesis area.

in the basaltic terrane of Wickiup Ridge (center of map), which may be the reason for the apparent concentration of faults relative to the adjacent less-exposed areas. It is difficult to trace structures in the sedimentary units because of the lack of continuous exposure and marker beds. Folds include a northward-plunging anticline in the Big Creek area and a syncline along Wickiup Ridge. The highly faulted nature of this syncline precludes an accurate placement of an axis, so a symbol is not drawn on Plate I or Figure 41.

All faults are high-angle (near vertical), and apparently most are normal as determined from observations on Wickiup Ridge. Displacements commonly range up to 250 feet, and locally as much as 1,000 feet. Most of the indicated faults juxtapose different stratigraphic units. Many were plotted with the aid of aerial photographs.

Faulting followed the deposition of the Astoria Formation, but most occurred after extrusion of the basalts. The major northwest-trending fault in the southwestern part of the area juxtaposes Oswald West mudstone and Big Creek sandstone, but it does not displace the glauconitic sandstone at the upper contact of the Big Creek (Plate I). However, this fault is post-Astoria, based on its truncating a smaller fault which in turn cuts a Depoe Bay intrusive. It is likely a rotational fault with no offset in the north. Similarly, the north-south longitudinal fault that cuts the west limb of the anticline in the eastern part of the thesis area cannot be traced to the top of the Big Creek sandstone. However, the absence of marker beds leaves open the possibility that the fault does cut the Astoria Formation, and simply cannot be detected. A few minor faults in the southern part of Wickiup Ridge cut both the Big Creek and Silver Point members, but evidently do not cut the Depoe Bay Basalt, indicating at least a small amount of pre-basalt faulting. Regional uplift at this time is considered to be the major cause of the angular unconformity between the Astoria Formation and the basalts.

A major northeast-trending fault offsets the subaerial basalt flows on Nicolai Ridge. The fault can be traced through Elk Mountain to the southwest on U-2 high-flight photos, and connects with the northeast-trending lineament shown by Penoyer (1977) to pass through Saddle Mountain.

The limbs of the anticline in the Big Creek area dip gently under Wickiup and Nicolai Ridges. This suggests that the areas of basalt accumulation may have locally downwarped the sedimentary strata. Either the Big Creek area was never covered with basalt or, more likely, the overlying basalt has been eroded from the originally topographically-higher anticline.

Although local groups of faults may be parallel or en echelon, there is no distinct pattern or trend overall.

A northeasterly to easterly strike does appear to be a dominant component, if there is one.

GEOLOGIC HISTORY

Western Oregon and Washington traditionally have been thought to be the site of a eugeosyncline in early Tertiary time (Snavely and Wagner, 1963). That is, an elongate basin existed in which up to 25,000 feet of sedimentary and volcanic rocks accumulated. Vancouver Island and the Klamath Mountains form the northern and southern boundaries, respectively, and the Cascade Range is at the eastern margin. However, the term "eugeosyncline" is used loosely and, as it is defined by Kay (1951), does not really apply to the area. It is better to interpret the rocks in the area in a plate tectonics setting.

The basement rocks of the Coast Range are the Eocene Crescent, Siletz, and Tillamook Volcanics. The lower parts of these units are chemically similar to oceanic tholeiitic basalts (Glassley, 1974; Snavely and others, 1968). The upper parts formed local seamounts and islands. Cady (1975) suggests that the basalts of the Crescent Formation were extruded through older volcanic rocks of the oceanic crust, near or at an active subduction zone. The Coast Range has a crustal thickness (20 km) that is intermediate between that of the oceans and continents (Kulm and Fowler, 1974).

I suggest that the Eocene basalts of the Oregon and Washington Coast Range are compatible with a continental-margin arc model. Coleman (1975) states that, in well-developed, older arc systems, the basement in front of the main arc will consist of older tholeiitic rocks emplaced in the earlier stages of development. "Frontal arcs" are recognized by Karig (1974) to occur between active volcanic chains and trenches in the western Pacific. Karig considers these features to be thicker oceanic crust which undergo primarily vertical tectonics. The chemistry, thickness, and spacial and temporal relationships to the calc-alkaline volcanism to the east suggest the Coast Range basement rocks fit into this type of arc-system framework.

Sedimentation that followed the eruption of the Eocene basalts clearly occurred in an arc-trench gap setting, as described by Dickinson (1974) and Niem (1976). That is, a magmatic arc (ancestral Cascades) was to the east, and a trench was to the west. Fluviatile-deltaic-shoreline complexes, shallow-marine sediments, pro-delta deposits, and turbidites accumulated on a subsiding, or unstable, shelf. The configuration of the basin fluctuated with time.

The thesis area was at middle-shelf depths during the late Oligocene, during which time the Oswald West mudstones were being deposited. In earliest Miocene gradual shoaling occurred. The outer fringes of a prograding delta slope are presumed to have moved into the area from the east and deposited the siltstones and sandstones in the upper part of the Oswald West. The delta is possibly represented to the east by the Scappoose Formation, which Van Atta (1971) believes was supplied by an ancestral Columbia River.

A rapid regression during the early Miocene is indicated by an abrupt shoaling in Nelson's (1978) thesis area, and less directly by the missing Pillarian Stage in the Big Creek area. Nelson suggests that the strand line shifted to near the position of the modern coast line.

This regression may be related to a change in plate boundaries after complete subduction of the Farallon plate (Atwater, 1970). Dott (1969) noted that many circum-Pacific continental and island-arc regions contain evidence of a discontinuity in structural disturbances and sedimentation at about 25 million years B.P. (upper Matlockian) and inferred that a major change in sea-floor spreading occurred at that time.

The next record of major "deltaic" deposits is the Angora Peak sandstone member of the Astoria Formation, described by Cressy (1974) and Smith (1975). At about 19 million years B.P. (Pillarian-Newportian boundary) the main locus of deposition was approximately 26 miles southwest of the thesis area. Both Cressy and Smith present evidence for a major river system (ancestral Columbia River) which supplied this "delta."

To the north, Nelson (1978) conjectures that some coeval Big Creek sandstone was deposited in a near-shore environment by longshore drift. Northerly paleocurrents, in Nelson's study area and the westernmost part of my map area, support this interpretation. The Big Creek sandstone at that time was most likely a lateral shoreline and shelf facies of the Angora Peak sandstone.

Gradual and continuous transgression had been taking place after the initial deposition of the Angora Peak and Big Creek sandstones. By Newportian time, sedimentation to the west of the thesis area was at middle shelf depths or deeper (Nelson, 1977, personal communication). The main locus of sedimentation had shifted toward the Big Creek area. Unusual thicknesses of fine- to medium-grained sandstones support a more direct sediment input, along with considerable subsidence of the depositional basin.

Transgression continued, and by the middle Miocene (upper Silver Point time) the thesis area was at middle shelf depths or deeper. The ancestral Columbia River is thought to have shifted northeast to near the position of the modern Columbia River. River sands were channeled directly into a submarine canyon, a part of which was in the thesis area (Pipeline member). A slight, later shift of the submarine channel is thought to have halted sand deposition in the map area. However, hemipelagic mud sedimentation continued (upper Silver Point member).

The Depoe Bay and Cape Foulweather Basalts do not fit as easily into a plate tectonics framework. McDougall

(1976) believes that the correlative flood basalts on the Columbia Plateau may be the result of a process similar to that which produced marginal basins elsewhere. The back-arc area (eastern Oregon and Washington) may have been undergoing extensional tectonics in middle Miocene time, a process attributed by Karig (1971) to a rising mantle diapir from a descending lithospheric slab. However, the connection between the plateau-derived and coastal-derived basalts is not clear. The relative amount of coastal basalt is actually small; the total volume of Yakima Basalt is estimated to be 240 times greater (Snavely and others, 1973). Still, the enigma of compositional uniformity in magmas that are extruded from vent areas 500 kilometers apart has not been solved, and the presence of calc-alkaline volcanics between the two vent areas must be explained. Nevertheless, a close relationship does exist between the plateau and coastal basalts, and a continental-margin arc model, although well supported by other associations and probably generally correct, is an over-simplification that does not account for many complex and poorly understood processes.

In the thesis area, the middle Miocene basalts unconformably overlie the Astoria Formation. Submarine extrusion formed local accumulations of pillow basalts and breccias with aprons of hyaloclastites that flowed over a previously uplifted and eroded surface of moderate relief. Workers in the past (Cressy, 1974; Neel, 1976; Penoyer, 1977; Smith, 1975; Snavely and others, 1973; Tolson, 1976) have noted this unconformity, some suggesting regression and subaerial erosion. Subaerial exposure of the sedimentary units is certainly possible; regional uplift may have raised the Astoria Formation and older units above sea level, and then subsidence may have submerged the basin again before extrusion of the basalts. However, a similar erosional unconformity exists between the Depoe Bay and Cape Foulweather Basalts, and so the same cycle must have taken place twice. It is odd that both basalts happen to have been erupted at the same middle- to outer-sublittoral depths. The actual uplift and subsidence may have been related to the eruptive cycles of the basalts, but barring that possibility, and coincidence, another alternative should be considered. That is, the unconformities may have been produced in a submarine environment. Marine erosional unconformities are characteristic of depositional basins of relatively high mobility (Krumbein and Sloss, 1963). The major degradational process is slumping, but marine current energies may also be capable of stripping minor thicknesses of sediment and leveling an area to some extent.

Following the eruption of the Depoe Bay Basalts, basalt of the Columbia River Group flowed down the ancient

Columbia River gorge and covered the local volcanics in the easternmost part of the area.

All the Tertiary units in the area were folded gently and block faulted. Uplift and subaerial erosion occurred throughout western Oregon and Washington during the late Miocene (Braislin and others, 1971).

ECONOMIC GEOLOGY

Petroleum

Oil and gas exploration in northwestern Oregon has been summarized by Neel (1976) and Tolson (1976). Livingstone (1958) and Rau and Wagner (1974) have reviewed the history of exploration and drilling for petroleum in Washington. Braislin and others (1971) summarized the exploration history and evaluated the petroleum potential of western Oregon and Washington and the continental shelf.

Braislin and others (1971) explained the lack of petroleum production in Oregon and Washington by the fact that source rocks, reservoir rocks, and petroleum traps have not been found together. These three elements do not occur together in the thesis area. However, onshore geology suggests potential offshore.

Potential source rocks are not exposed in the map area. Pyrolysis-fluorescence of organic-rich mudstones (Appendix XIII) revealed that all contained less than 0.5 percent "live" hydrocarbons. A coally stringer from a lower Big Creek sandstone contained sufficient hydrocarbons (1.2 percent) to qualify it as a "marginal source." Similarly, Penoyer (1977) analyzed 23 samples from south of the field area and found only one (a Silver Point mudstone) that could be considered, at the most, a "marginal source rock."

However, all the samples that have been analyzed have been collected from roadcuts or similar outcrop exposures; and although the samples appeared to be fresh, weathering may have lowered the results of these tests. Additionally, this method does not measure the amount of light hydrocarbons, such as methane gas.

A recently reported oil seep occurs about three miles west of the thesis area and is discussed in detail by Nelson (1978). The proximity of this seep to old railroad and logging operations strongly suggests that it is a dump that has begun to seep to the surface. However, several major oil companies have analyzed this oil and have determined it to be crude and not a refined product. Mobil Oil Corporation reported that the oil from the seep contained a very high level of normal, unweathered paraffins (written communication to A. R. Niem, May 18, 1977). These paraffins would be quickly degraded by bacterial action if they were near the surface, which is perhaps the strongest evidence for a natural seep. Further research is being done at this time. If this seep is indeed natural, it would be highly significant. Besides being the only reported oil seep in Oregon, it would show that source rocks, from which hydrocarbons have been produced, exist onshore.

Both the Big Creek and Pipeline sandstones are sufficiently "clean" and permeable in outcrop to be potential reservoir rocks. Much of the matrix is almost certainly caused by shallow-weathering effects, so the permeabilities are probably greater in the subsurface. However, the Pipeline and Big Creek sandstones are well exposed, and neither are at great depths beneath the thesis area. These units dip under the Columbia River and crop out as south-dipping strata on the Washington side (Wolfe and McKee, 1968). The sandstones in the upper part of the Oswald West also have reservoir potential, but again, are breached by erosion and are laterally restricted.

The anticline in the Big Creek area represents a potential structural trap. Sandstones occur in middle Oswald West mudstones to the west (Nelson, 1978), and are older than any rocks in the thesis area. This implies that sandstones, which are capped by mudstones, may be present in this anticline in the subsurface. Small, shallow traps also may have been formed by normal faulting and juxtaposition of sandstones and mudstones.

Even though the onshore petroleum potential is low, the offshore possibilities are intriguing. The Pipeline member, if my interpretation is correct, indicates two things. First, the Columbia River sediment source has been in essentially the same position since the middle Miocene. Second, during the middle Miocene, the Astoria area and the adjacent shelf was the site of extensive sand deposition in a submarine environment. The Pipeline member may represent the upper-channel deposits of a more extensive submarine-fan complex, which possibly occupied a position now offshore.

Early and middle Miocene petroliferous marine mudstones of the Hoh rock assemblage on the Washington coast also may have been deposited in the area of the present Oregon shelf. Petroleum production has been obtained from the Hoh mudstones in Washington, but only in noncommercial amounts because of lack of permeability. Stratigraphic traps formed in a channelized or fan environment would be numerous, as displayed by the complex intertonguing of the sandstones and mudstones of the Pipeline member. Thus, an ideal setting for the accumulation of petroleum may be present offshore from the mouth of the Columbia River.

Two major problems are immediately apparent. The first is that Braislin and others (1971) report a major post-middle Miocene unconformity on the Oregon continental shelf. This suggests uplift and erosion, which may have removed much of the middle Miocene sediments. The second problem is the structural discontinuity between the shelf and the Coast Range as suggested by Zietz and others (1971). Vertical or strike-slip movements may have greatly displaced reservoir rocks from their original position off the Columbia River. However, Braislin and others (1971, Fig. 2) show an elongate basin with as much as 25,000 feet of "net objective section" occurring off the Columbia River, which offers hope that much of the sedimentary strata has been preserved. Two wells drilled in the 1960's by Shell Oil Company, approximately 24 miles offshore from the coastal town of Seaside, Oregon, penetrated only siltstones, claystones, a very minor sandstones (Cooper, ms in prep.). Cooper believes that these wells were drilled too far offshore to intersect the Angora Peak sandstone member to the southeast. The Pipeline member, to the northeast, may offer a more promising, but smaller, target.

Crushed Rock

Crushed basalt is a well-developed resource in the thesis area. A quarrying operation becomes uneconomical if the rock is transported more than a short distance, so nearly all the uses are local (Beaulieu, 1973). Most of the basalt is used for logging-road fills or surfaces.

The locations of the main existing quarries are shown on Plate I. In general, intrusive rocks provide the best road material. Submarine extrusive rocks are commonly altered and softer, and contain intercalated sedimentary rocks. However, all of the large, accessible, basalt sills with minimum overburden have been located, and both intrusive and extrusive rocks are being utilized.

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APPENDICES

APPENDIX I

Reference Section C-D

Upper Part of the Oswald West Mudstones

Initial Point (C): 330 feet N., 1390 feet W. of the SE corner of sec. 14, T. 7 N, R. 7 W. Section starts at first outcrop on the east side of Big Creek at eastward to northward bend.

All exposures are cuts along Big Creek. Approximately 40 feet stratigraphically below the initial point are fossil localities 147 and 209.9. The initial point is within 100 feet of the contact and the lower part of the Oswald West mudstones.

Terminal Point (D): 1910 feet S., 2240 feet W. of the NW corner of sec. 14, T. 7 N., R. 7 W. Section ends at last outcrop before alluvium on east side of Big Creek.

Unit	Description	Thickness Unit	(feet) Total
9	Siltstone: same colors as unit 5; sandy; thin- to thick-bedded; scattered burrows at bottom to no burrows at top; moderately indurated.	54	242
8	Covered by stream alluvium and vegetation.	22	188
7	Siltstone: same colors as unit 5; sandy; thin- to thick-bedded; well burrowed.	16	166
6	Covered by stream alluvium and vegetation; possible faulting or slumping suggested by slight difference in attitudes in units 5 and 7.	46	150
5	Siltstone: olive gray (5Y4/1), weathers moderate yellowish brown (10YR5/4); thick bedded; well burrowed.	28	104
4	Covered by stream alluvium and vegetation.	44	76
3	Mudstone: dark gray (N3), weathers light olive gray (5Y5/2), stained to dark yellowish orange (10YR6/6) and light brown (5YR5/6); structureless. Contact: gradational over two inches, planar.	6	32

Appendix I (continued)

Unit	Description	Thickness Unit	(feet) Total
2	Sandstone: medium dark gray (N5), weathers light brown (5YR5/6); very fine-grained; structureless; well burrowed; upper two feet grade into siltstone. Contact: sharp, planar.	9	26
1	Siltstone: olive gray (5Y4/1) when wet, light olive gray (5Y6/1) when dry, weathers moderate yellowish brown (10YR5/4) and brownish black (5YR2/1); thin- to thick-bedded; cliff former; highly bioturbated, *Terebellina* and *Planolites* burrows (fossil locality 107); ovoid, 1 mm pellets. Contact: covered by stream alluvium and vegetation.	17	17

APPENDIX II

Reference Section E-F

Contact of Big Creek Sandstone and Silver Point Mudstone Members of the Astoria Formation

Initial Point (E): 1260 feet N., 580 feet W. of SE corner of sec. 13, T. 7 N., R. 8 W. Section begins at west end of roadcut on the south side of the A Line.

Terminal Point (F): east end of same roadcut, at point where outcrop becomes covered with vegetation.

Unit	Description	Thickness Unit	(feet) Total
8	Silver Point mudstone: same as unit 4; one foot thick baked zone at base; top covered with vegetation. Contact: sharp, slightly undulatory.	16	124.8
7	Depoe Bay Basalt: sill, same as unit 5, but intrudes entirely through mudstone; one inch thick chill margins at top and bottom of unit. Contact: sharp, slightly undulatory.	4	108.8
6	Silver Point mudstone: same as unit 4; one foot thick baked zones at top and bottom of unit. Contact: sharp and undulatory.	10	104.8
5	Depoe Bay Basalt: intrusive; aphanitic; highly weathered; iron stained; one inch thick chill margins at top and bottom of unit; does not completely intrude mudstone in this outcrop, baked mudstone can be seen wrapping around the end of this sill-like apophysis at the top of the outcrop; on north side of road is solid basalt from unit 5 to unit 7 (no interbedded mudstone). Contact: sharp and undulatory.	10	94.8
4	Silver Point mudstone: medium-dark gray (N4) dry, brownish black (5YR2/1) wet; silty; structureless; micaceous; carbonaceous; in direct contact (sharp) with glauconitic sandstone on north side of road; upper eight inches is baked by overlying intrusive basalt. Contact: gradational over one inch, planar.	2.8-4.8	84.8

Appendix II (continued)

Unit	Description	Thickness Unit	(feet) Total
3	Silver Point mudstone: yellowish gray (5Y7/2) to light brown (5YR5/6); silty; structureless; not exposed on north side of road, may be weathered unit 4, or it pinches out. Contact: sharp, planar.	2-0	82
2	Glauconitic Big Creek sandstone: yellowish gray (5Y7/2) to grayish olive (10Y4/2); composed of very fine- to fine-grained quartz and weathered feldspar and medium-grained glauconite pellets; unit contains two three-inch thick, moderate olive brown (5Y4/4), concentrated galuconite zones at the lower contact and three feet up; friable; structureless. Contact: sharp, slightly undulatory.	10	80
1	Big Creek sandstone: weathered to yellowish gray (5Y7/2), greenish gray (5Y6/1), and light brown (5YR5/6); very fine- to fine-grained; moderately sorted; structureless; friable; rich in biotite and muscovite; feldspathic. Contact: covered in vegetation.	70	70

APPENDIX III

Reference Section G-H

Pipeline Member of the Astoria Formation

Initial Point (G): 1800 feet S., 100 feet W. of the NE corner of sec. 32, T. 8 N., R. 8 W. Section starts at sharp hairpin curve on Twilight Mainline Spur 44-D.

Continuous exposure of Pipeline sandstone crops out southward (uphill) along the east side of Spur 44-D.

Terminal Point (H): 2450 feet S., 500 feet W. of the NE corner of sec. 32, T. 8 N., R. 8 W. Section ends at top of bulldozer cut at the NE corner of the intersection of Twilight Spur 44-D and the Astoria Pipeline Road.

Unit	Description	Thickness Unit	(feet) Total
5	Sandstone: same as unit 3; structureless, but lowest one foot shows laminations and small mudstone rip-ups. Contact: sharp, planar.	39	106
4	Mudstone: dark gray (N3), weathers to light brown (5YR5/6); silty; crudely laminated, abundant mica; carbonaceous, fine comminuted plant debris is ubiquitous; splits irregularly; soft sediment deformation (convolute laminations, emphasized by carbonaceous material; minor movement after consolidation indicated by small slickensides patches; intruded by four inch thick clastic dike of medium-grained sandstone; common, burrow-like, medium-grained sandstone lenses which are up to one-half inch thick are probably "micro-apophyses" associated with the clastic intrusion. This exposure is near the top of the outcrop above where the road bends to the west. Laterally, toward the intersection with the Pipeline Road, the unit thins to a few very thin carbonaceous mudstone beds. Contact: sharp, planar.	4	67

Appendix III (continued)

Unit	Description	Thickness (feet) Unit	Total
3	Sandstone: yellowish gray (5Y7/2), weathers to grayish orange (10YR7/4); uniformly medium grained; structureless, but local weathering emphasizes possible faint laminations; moderately sorted; very friable; composition similar to unit 1. Contact: sharp, planar.	25	63
2	Mudstone: yellowish gray (5Y8/1), weathers to moderate reddish brown (10R4/6); very little silt; structureless; mostly weathered and broken into chippy talus. Contact: sharp, planar.	9	38
1	Sandstone: yellowish gray (5Y7/2), iron stained to moderate brown (5YR4/4); medium grained over-all, upper four inches is laminated and fine-grained, laminated part appears to be by itself normally graded; the rest of the unit is apparently structureless, although at this time weathering and differential iron staining has begun to delineate what may be a continuous succession of thin amalgamated sandstone beds; moderately sorted; very friable; dominantly composed of quartz and weathered feldspar, some mica and rock fragments. Contact: covered by vegetation and slump debris.	29	29

APPENDIX IV

Checklist of Fossils from the Oswald West Mudstones

Sample number:	1	28	29	107	119	125	146	147	208.9	209.9	210.9
USGS Cenozoic loc:						M6924			M6521	M6520	M6519
Bivalves:											
Acila sp.	-	-	-	-	-	-	-	-	-	X	-
Macoma arctata (Conrad)	-	-	-	-	-	-	-	-	-	-	X
Macoma sp.	-	-	-	-	-	-	-	-	-	X	-
Macrocallista sp.	-	-	-	-	-	-	-	-	X	-	-
Periploma bainbridgensis (Clark)	-	-	-	-	-	-	-	-	-	X	-
Thracia schenki Tegland	-	-	-	-	-	-	-	-	X	-	-
Yoldia cf. _Y. tenuissima_ Clark	-	-	-	-	-	-	-	-	-	X	-
Gastropods:											
Cryptonatica sp.	-	-	-	-	-	-	-	-	X	-	-
Molophorus	-	-	-	-	-	-	-	-	?	-	-
Foraminifera:											
Non-diagnostic arenaceous forms	X	-	-	-	-	-	-	-	-	-	-
Trace Fossils:											
cf. _Condrites_	-	-	X	-	-	-	-	-	-	-	-
pellets, 1 mm dia.	-	-	-	X	-	-	-	-	-	-	-
Planolites montanus Richter	-	X	-	X	X	-	-	-	-	-	-
Planolites serpens Webby	-	X	X	X	-	-	X	-	-	-	-
Scalarituba-Helminthoida	-	-	-	-	-	-	-	?	-	-	-
Terebellina	-	X	X	?	-	-	X	-	-	-	-
tube, 8 mm dia.	-	-	-	X	-	-	-	-	-	-	-
Other:											
fish scales	-	-	-	-	-	X	-	-	-	X	-

APPENDIX V

Checklist of Fossils from the Big Creek Sandstone Member of the Astoria Formation

LEGEND

Locality	Sample Number	USGS Cenozoic Loc.
A	106.8	M6398
B	BC-3	M6402
C	AOS 74-2	M6382
D	174	M7033
E	37	M6920
F	130	M6926
G	131	M6927
H	108.7	M6399
I	212.9	M6518
J	AOS 74-1	M6387
K	AOS 74-3	M6388
L	AOS 74-4	M6389
M	BC-5	M6403
N	BC-6	M6404

Localities A-C are in the middle part of the member, D is in the middle or upper part, and E-N are in the upper part.

Appendix V (continued)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Bivalves:														
Acila conradi (Dall)	-	-	-	-	-	X	-	-	-	-	-	-	-	-
Acila conradi (Meek)	-	-	-	-	-	-	-	X	X	X	-	-	-	-
Acila cf. *A. conradi* (Meek)	-	-	-	-	-	-	X	-	-	-	-	-	-	-
Anadara cf. *A. devincta* (Conrad)	-	-	-	X	-	-	-	X	-	-	-	-	-	-
Anadara sp.	-	X	-	-	-	-	X	-	-	X	-	-	-	-
Felaniella parilis (Conrad)	-	-	-	-	-	-	-	-	-	X	-	-	-	-
Katherinella angustifrons (Conrad)	-	-	-	-	-	-	-	-	-	-	X	-	-	-
Katherinella sp.	-	-	-	?	-	-	-	-	-	-	-	-	-	-
Lucinoma sp.	-	-	-	-	-	X	-	-	-	-	-	-	-	-
Macoma albaria (Conrad)	-	-	-	-	-	-	-	-	X	-	-	X	-	-
Macoma flagleri Etherington	-	-	-	-	-	X	-	-	-	X	-	-	-	-
Macoma cf. *M. flagleri* Etherington	-	-	-	-	-	-	-	-	X	-	-	-	-	-
Myadesma cf. *M. dalli* Clark	-	-	-	-	-	-	-	-	-	X	-	-	-	-
Mytilus middendorffi Grewingk	-	-	X	-	-	-	-	-	-	-	-	-	-	X
Nuculana cf. *N. ochsneri* (Anderson and Martin)	-	X	-	-	-	-	-	-	-	-	-	-	-	-
Nuculana sp.	-	-	-	X	-	-	-	-	X	-	-	X	X	-
Panopea cf. *P. abrupta* (Conrad)	-	-	-	-	-	X	-	-	-	-	-	-	-	-
Panopea sp.	-	-	-	-	-	-	-	-	X	-	X	-	-	-
Pectinid	-	-	-	-	-	-	-	-	-	-	-	-	X	-
Portlandia sp.	-	-	-	-	-	-	-	-	-	-	-	-	X	-
Securella sp.	-	-	-	-	-	-	-	-	-	X	-	-	-	-
Solen conradi Dall	-	-	-	-	-	X	-	-	-	-	-	-	-	-
Solen cf. *S. conradi Dall*	-	-	-	-	-	-	-	X	-	X	-	-	-	-
Spisula albaria (Conrad)	-	X	-	-	X	X	-	X	X	X	-	-	-	-
Spisula albaria goodspeedi Etherington	-	-	X	-	-	-	-	-	-	-	-	-	-	-
Spisula sp.	X	-	-	-	-	-	X	-	-	X	-	-	-	-
Tellina emacerata Conrad	-	-	-	-	-	X	X	-	-	X	-	-	X	-
Thracia trapezoides (Conrad)	-	-	-	-	-	-	X	-	-	-	X	-	-	-
Thracia cf. *T. trapezoides* (Conrad)	-	-	-	X	-	-	-	-	-	-	-	-	-	-
Yoldia cf. *Y. cooperi* Gabb	-	-	-	-	-	-	X	-	-	-	-	-	-	-
Yoldia sp.	-	-	X	-	-	-	-	-	-	-	-	-	-	-
Yoldia tenuissima Clark	-	-	-	-	-	X	-	-	-	X	-	-	-	-

Appendix V (continued)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Gastropods:														
Actaeon boulderanus Etherington	-	-	-	-	-	-	-	-	X	-	-	-	-	-
Bruclarkia oregonensis (Conrad)	-	-	X	-	-	-	-	-	-	X	-	-	X	-
Bruclarkia cf. B. oregonensis (Conrad)	-	-	-	-	-	X	X	X	-	-	-	-	-	-
Cancellaria oregonensis (Conrad)	-	-	-	-	-	-	-	X	-	-	-	?	-	-
Cancellaria sp.	-	-	-	-	-	X	X	-	-	X	-	-	-	-
Cancellaria weaveri Etherington	-	-	-	-	-	-	-	X	-	-	-	-	-	-
Chlorostoma pacificum (Anderson and Martin)	-	-	-	-	-	?	-	-	-	-	-	-	-	-
Crepidula cf. C. praerupta (Conrad)	-	-	-	-	-	X	-	-	-	-	-	-	-	-
Crepidula nostralis (Conrad)	-	-	-	-	-	-	-	-	-	X	-	-	-	-
Cryptonatica oregonensis (Conrad)	-	-	X	-	-	-	X	X	X	X	-	-	-	-
Megasurcula cf. M. condonana (Anderson and Martin)	-	-	-	-	-	-	-	-	-	X	-	-	-	-
Megasurcula cf. M. wynoocheensis (Weaver)	-	-	-	-	-	-	-	X	-	-	-	-	-	-
Molopophorus matthewi Etherington	-	X	X	-	-	-	-	-	-	X	-	-	-	-
Molopophorus n. sp. aff. M. newcombei (Merrian)	-	-	-	-	-	-	-	X	-	?	-	-	-	-
Nassarius cf. N. arnoldi (Anderson)	-	-	-	-	-	-	-	-	-	-	-	X	-	-
Nassarius lincolnensis (Anderson and Martin)	-	-	-	-	-	X	-	-	X	-	-	-	-	-
Natica clarki Etherington	-	-	-	-	-	-	-	-	X	-	-	-	-	-
Naticid	X	X	-	-	-	X	-	-	-	X	-	-	-	X
Nucella sp.	-	-	-	-	-	-	-	X	-	-	-	-	-	-
Olivella sp.	-	-	-	-	-	X	-	-	-	X	-	-	-	-
Opalia cf. O. williamsoni (Anderson and Martin)	-	-	-	-	-	X	-	-	-	-	-	-	-	-
Ophiodermella cf. O. workensis (Etherington)	-	-	-	-	-	-	-	-	-	X	-	-	-	-
Ophiodermella sp.	-	-	-	-	-	-	-	X	-	-	-	-	-	-
Polinices lincolnensis (Weaver)	-	-	-	-	-	-	X	-	-	-	-	-	-	-
Polinices victorianus Clark and Arnold	-	-	-	-	-	-	-	X	-	-	-	-	-	-
Priscofusus cf. P. coli (Dall) Moore	-	-	-	-	-	-	-	X	-	X	-	-	-	-
Priscofusus geniculus (Conrad)	-	-	-	-	-	-	-	X	-	-	-	-	-	-
Priscofusus cf. P. geniculus (Conrad)	-	-	-	-	-	-	X	-	-	-	-	-	-	-
Priscofusus sp.	-	-	-	-	-	X	-	-	-	-	-	-	-	-
Searlesia carlsoni (Anderson and Martin)	-	-	-	-	-	-	-	-	-	X	-	-	-	-
Spirotropis calodius Moore	-	-	-	-	-	X	-	-	-	-	-	-	-	-
Tectonatica janthostoma (Deshayes)	-	-	-	-	-	-	X	-	-	-	-	-	-	-

Appendix V (continued)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Scaphopod:														
Dentalium sp.	-	-	-	-	-	-	-	-	X	-	-	-	-	-
Other:														
shark tooth	-	-	-	-	-	-	-	-	-	X	-	-	-	-

APPENDIX VI

Checklist of Fossils from the Pipeline Member and the Silver Point Mudstone Member of the Astoria Formation

	Pipeline member			Silver Point mudstone member						
Sample number	108	128	143	45	53	74	82	123	129	144
USGS Cenozoic loc.	M6921	M6922						M6923	M6925	
Bivalves:										
<u>Delectopecten</u> <u>peckhami</u> (Gabb)	-	X	-	-	-	-	-	-	-	-
<u>Macoma</u> <u>albaria</u> (Conrad)	?	-	-	-	-	-	-	-	X	-
<u>Nucula</u> cf. <u>N.</u> <u>nuculana</u> (Dall)	-	-	-	-	-	-	-	-	X	-
<u>Nucula</u> sp.	-	-	-	-	-	-	-	?	-	-
<u>Nuculana</u> <u>calkinsi</u> Moore	-	-	-	-	-	-	-	-	X	-
<u>Thyasira</u> aff. <u>T.</u> <u>gouldii</u> (Philippi)	-	-	-	-	-	-	-	-	X	-
<u>Thyasira</u> sp.	?	-	-	-	-	-	-	-	-	-
Foraminifera:										
<u>Bulimina</u> cf. <u>B.</u> <u>ovata</u> d'Orbigny	-	-	-	-	F	-	-	-	-	-
<u>Florilus</u> <u>costiferum</u>	?	-	-	-	-	-	?	-	-	-
<u>Globigerina</u> sp.	-	-	-	-	R	-	?	-	-	-
<u>Nonionella</u> <u>miocenica</u> Cushman	-	-	-	-	C	-	-	-	-	-
<u>Siphogenerina</u> fragments	R	-	-	-	-	-	-	-	-	-
<u>Valvulineria</u> <u>araucana</u> (d'Orbigny)	-	-	-	-	R	-	-	-	-	-
<u>Virgulina</u> cf. <u>V.</u> <u>californiensis</u> Cushman	-	-	-	-	F	-	-	-	-	-
Non-diagnostic arenaceous forms	-	-	R	F	-	-	F	-	-	-
Other:										
Diatoms	-	-	-	-	-	F	-	R	-	R

C = common
F = few
R = rare

APPENDIX VII

Modal Analyses of Sandstones

Sample Number	Big Creek Sandstone								Pipeline Sandstone				
	148	116	17*	16	7	93	100	165	152	90	88	151	84
Cement ($CaCO_3$)	-	-	-	44	-	6	-	tr	-	-	-	-	-
Matrix	31	8	6	12	22	29	32	28	17	33	20	14	30
Porosity	12	25	3	5	10	3	2	6	11	10	4	23	11
Grains	57	67	91	39	68	62	66	66	72	57	76	63	57
Stable Grains:													
Quartz	14	37	15	22	34	30	38	35	39	29	34	24	32
Quartzite	2	tr	tr	-	-	-	-	-	-	-	-	1	-
Chert	1	-	2	-	-	tr	-	-	-	-	-	tr	-
Feldspar:													
Plagioclase	7	3	3	tr	5	3	3	3	2	2	3	6	1
K-spar	8	5	12	5	7	7	5	4	13	17	14	11	13
Rock Fragments:													
Volcanic	20	11	53	4	6	8	2	11	4	2	20	7	5
Plutonic	tr	tr	1	-	-	-	-	-	-	-	-	-	-
Metamorphic	-	1	-	-	-	-	-	-	2	tr	tr	tr	1
Sedimentary	tr	-	-	-	-	-	-	-	-	tr	-	-	-
Mica	2	2	1	2	8	3	8	8	6	2	2	5	4
Mafics	1	tr	-	tr	tr	1	1	1	-	-	-	tr	-
Opaques	1	2	tr	4	5	5	1	3	-	-	-	tr	-
Alteration Minerals (nonopaque)	1	4	4	1	3	4	7	1	6	4	2	8	3
Organic fragments	1	-	-	tr	-	tr	tr	-	-	-	tr	-	-
Glauconite	-	-	-	-	-	tr	-	-	-	-	-	-	-

Samples are in approximate stratigraphic order. tr < 0.5%.
*Pebbly sandstone, not plotted on triangular diagrams.

APPENDIX VIII

Heavy Mineral Analyses of Sandstones

	Oswald West	Big Creek Sandstone			Pipeline Sandstone		
Sample Number	175	149	7	165	152	156	84
Nonmicaceous, nonopaque grains (=100%)							
Hornblende	8	49	10	49	5	46	4
Green	5	42	7	39	4	35	2
Blue-green	2	3	3	8	tr	4	-
Brown	1	2	-	1	1	7	2
Basaltic	-	2	-	1	-	-	tr
Tremolite-Actinolite	1	-	tr	2	5	4	4
Glaucophane	-	-	-	-	-	tr	-
Orthopyroxene	1	14	2	9	7	12	11
Hypersthene	1	12	2	8	4	12	6
Enstatite	-	2	-	1	3	tr	5
Clinopyroxene	-	2	tr	6	1	7	1
Diopside	-	-	-	-	tr	-	1
Augite	-	2	tr	6	1	7	tr
Epidote Group	54	28	19	29	30	24	29
Clear Epidote	2	2	tr	3	2	3	2
Green Epidote	45	26	15	22	26	16	26
Zoisite	tr	-	1	-	-	-	-
Clinozoisite	7	1	3	4	2	5	1
Garnet	15	2	47	1	20	1	10
Clear	6	1	22	1	12	tr	8
Pink	4	1	22	-	7	1	2
Yellow-brown	5	-	1	-	1	-	tr
Red-orange	-	-	2	-	tr	-	-
Apatite	6	tr	3	tr	-	-	-
Andalusite	-	-	-	-	tr	tr	-
Kyanite	1	tr	tr	-	11	2	18
Monazite	2	-	2	-	2	tr	4
Rutile	-	-	tr	-	2	tr	tr
Sphene	9	2	7	4	3	2	2
Staurolite	1	tr	3	-	6	tr	8
Tourmaline	-	-	1	-	-	-	-
Zircon	2	1	5	-	7	1	8
Micaceous, opaque grains (% of total sample)							
Red-brown Biotite	1	tr	8	11	7	2	14
Green Biotite	1	tr	5	12	4	-	4
Opaques	30	44	56	38	67	45	59

tr < 0.5%

APPENDIX IX

X-ray Analyses of Clay-Size Fractions of Sandstones and Mudstones

Procedure (modified from Harward, 1976)

Each sample was disaggregated by boiling in distilled water. The finer fraction was retained after wet sieving with a four phi-size sieve, and dispersed, by stirring, in a beaker of distilled water. The sample was allowed to settle, and after three hours the suspension, to a depth of ten centimeters, was removed. The suspension was centrifuged at 6000 R.P.M. for ten minutes.

Two-thirds of the clay-size residue which was obtained by the above procedure was placed in a centrifuge tube, and the remainder in another tube. The two-thirds proportion of the sample was dispersed and saturated in 1N $MgCl_2$, and centrifuged to recover the sample. This was repeated three times. The sample was washed by dispersing in distilled water and centrifuging. This was also done three times. The same procedures were followed with the one-third proportion, except a 1N KCl solution was used to saturate the sample.

Two slides were made from the Mg-saturated part and one slide from the K-saturated part. Slides were prepared by allowing the clay to settle and dry on each slide.

The two Mg slides were allowed to equilibrate in a 54% R.H. dessicator. One slide was run on a Norelco diffractometer at 54% R.H. (2-16° 2-thēta). One slide was then placed, flat-lying, over ethylene glycol in a dessicator. A vacuum was drawn, the dessicator heated at 65°C. for three hours, and then allowed to cool for 12 hours, in order to solvate the sample by vapor condensation. The other Mg slide was solvated with glycerol by the same method, using a temperature of 105°C. Both slides were run on the diffractometer at 54% R.H.

The K-saturated slide was 1) heated at 105°C. for three hours, and run at 0% R.H.; 2) equilibrated in a 54% R.H. dessicator, and run at 54% R.H.; 3) heated to 300°C. for three hours, and run at 0% R.H.; and 4) heated to 550°C. for three hours, and run at 0% R.H.

A total of seven diffractograms were obtained for each sample. The results were interpreted utilizing the following table.

Appendix IX (continued). Identification of major clay minerals based on variations in basal 001 d-spacings with different pretreatments (after M. Harward, 1976) (d-spacings in Angstroms, Å).

Treatment	Kaolinite	Halloysite	Mica	Montmor-illonite	Beidellite	Vermic-ulite	Chlorite	Chlorite Intergrades
1. Mg-sat, 54% RH	7.15	10 wet 7.3 dry	10-10.5	15	14.5-15	14.5	14-14.5	14-15
2. Mg-sat, ethylene glycol	7.15	"	"	16.5-17	16.5-17	"	"	14-17
3. Mg-sat, glycerol	7.15	"	"	17.5	14.5-15	"	"	"
4. K-sat, 105°C	"	7.3-7.5	"	10-10.5	10	10-10.5	"	11-14
5. K-sat, 54% RH	"	"	"	12	11.5	"	"	14
6. K-sat, 300°C	"	7.3	"	10.1	10.5	10-10.2	"	11-14
7. K-sat, 550°C	no peak	no peak	"	10	10	10	14.14	10-13

Appendix IX (continued)

Data

Sample No./Unit	Kaolinite	Mica	Montmor-illonite	Beidellite*	Vermic-ulite	Chlorite	Chlorite Intergrades	Other
156/Pipeline as								Feldspar
86/Pipeline ms	?	X			?	X		Amphibole
94/Silver Pt. ms	?			X				
165/Big Creek ss		?	X	X			X	Clinoptilolite
124/Oswald West ms		X		X			?	

*Hydroxy-interlayered montmorillonite may also have the same characteristics.

Appendix X

Statistical Parameters from Sieve Analyses of Sandstones

Samples	Cumulative % Phi Values ± 0.02							Folk and Ward (1957)						Silt and Clay	Coarsest 1%	Median
	5	16	25	50	75	84	95	Md phi	Mz phi	S_1 phi	Sk_1	K_G	Sand %	%	microns	microns
Pipeline Sandstones																
158	0.68	1.08	1.26	1.70	2.38	3.96	4.98	1.70	1.91	1.12	0.43	1.57	91.47	8.53	785	308
157	0.62	1.02	1.22	1.64	2.38	2.96	4.90	1.64	1.87	1.13	0.44	1.51	91.35	8.65	859	321
156	0.52	0.96	1.18	1.64	2.34	2.82	5.08	1.64	1.81	1.16	0.39	1.61	92.11	7.89	908	321
155	0.56	0.90	1.08	1.50	2.22	2.82	5.00	1.50	1.74	1.15	0.48	1.60	91.67	8.33	859	354
154	0.54	0.94	1.14	1.54	2.10	2.58	4.54	1.54	1.69	1.02	0.38	1.71	93.65	6.35	883	344
153	0.52	0.90	1.10	1.58	2.24	2.82	5.06	1.58	1.77	1.17	0.41	1.63	91.93	8.07	895	334
159	0.54	1.00	1.20	1.70	2.54	3.18	5.60	1.70	1.96	1.31	0.45	1.55	89.71	10.29	883	308
160	0.56	0.96	1.16	1.66	2.38	2.98	5.00	1.66	1.87	1.18	0.41	1.49	91.46	8.54	847	316
161	0.86	1.26	1.46	1.90	2.46	2.80	4.66	1.90	1.99	0.96	0.31	1.56	92.86	7.14	717	268
162	0.62	1.34	1.66	2.12	2.66	3.16	5.38	2.12	2.21	1.18	0.26	1.95	90.39	9.61	908	230
163	0.50	0.88	1.10	1.58	2.36	2.98	5.40	1.58	1.81	1.27	0.45	1.59	90.87	9.13	895	334
84	0.54	1.12	1.38	1.80	2.40	2.86	4.66	1.80	1.93	1.06	0.30	1.66	92.85	7.15	1000	287
152	0.28	0.94	1.20	1.74	2.40	2.86	4.36	1.74	1.85	1.10	0.23	1.39	93.83	6.17	1320	299
Big Creek Sandstones																
7	0.88	1.70	2.08	2.60	3.16	3.50	4.40	2.60	2.60	0.98	0.01	1.34	93.04	6.96	747	165
79	0.88	2.36	2.76	3.26	3.66	3.96	5.50	3.26	3.19	1.10	-0.08	2.10	84.94	15.06	790	104
77	0.56	1.70	2.04	2.52	2.94	3.30	4.98	2.52	2.51	1.07	0.04	2.01	91.86	8.14	1000	174
165	0.84	2.18	2.80	3.30	3.74	3.96	5.20	3.30	3.15	1.11	-0.19	1.90	84.15	15.85	758	102
13	0.70	1.20	1.60	3.30	4.44	5.06	6.34	3.30	3.19	1.82	-0.01	0.81	67.69	32.31	1087	102
15	0.64	1.46	2.08	2.80	3.30	3.50	4.26	2.80	2.59	1.06	-0.25	1.22	93.95	6.05	920	144
109	1.04	1.38	1.52	1.90	2.76	3.36	5.24	1.90	2.21	1.13	0.53	1.39	90.28	9.72	747	268
115	0.64	1.38	1.74	2.48	2.86	3.20	4.50	2.48	2.35	1.04	-0.08	1.41	94.10	5.90	847	179
116	0.86	1.26	1.48	1.82	2.30	2.66	3.90	1.82	1.91	0.81	0.28	1.52	95.27	4.73	768	283
149	0.52	1.08	1.26	1.60	2.04	2.38	3.44	1.60	1.69	0.77	0.23	1.53	97.22	2.78	1028	330
Oswald West Sandstone																
175	0.74	1.62	2.24	2.80	3.32	3.72	6.30	2.80	2.71	1.37	0.07	2.11	88.88	11.12	758	144

APPENDIX XI

Modal Analyses of Basalts

	Depoe Bay Basalt		Cape Foulweather Basalt	
	Intrusive	Extrusive	Intrusive	Extrusive
Sample No.	121	120	114	55
Plagioclase	43%	36%	51%	27%
Clinopyroxene	28	32	36	14
Opaques	7	30	8	48
Olivine-Iddingsite	-	-	tr	-
Alteration Products				
Chlorophaeite	-	-	-	4
Chlorite-Smectite	-	-	3	tr
Calcite	tr	2	1	6
Glass				
Tachylyte	22	-	1	-
Sideromelane	-	-	-	tr
Quartz (xenocrysts)	-	-	tr	-

tr < 0.5%

APPENDIX XII

Chemical Analyses of Basalts

Sample No.	Depoe Bay Basalts 25	56	58	83	89	95	102	111*	117	120	121
SiO_2	58.0	54.5	56.4	55.9	56.7	55.5	55.5	54.5	56.4	55.7	55.9
Al_2O_3	13.2	13.1	13.2	13.9	13.8	13.3	12.7	13.2	13.1	13.2	13.6
FeO	13.0	14.8	13.0	12.8	11.9	14.1	12.9	12.4	12.2	12.7	12.6
MgO	3.6	3.7	4.0	4.0	4.0	3.8	3.8	3.8	4.0	4.1	4.0
CaO	6.9	6.5	6.8	7.0	7.1	7.0	6.7	6.6	6.9	6.9	7.0
Na_2O	3.4	3.3	3.4	3.4	3.5	3.6	3.5	3.5	3.5	3.5	3.4
K_2O	1.60	1.70	1.65	1.70	1.50	1.40	1.60	1.65	1.60	1.80	1.70
TiO_2	1.95	1.95	2.00	1.95	2.05	2.05	2.00	2.40	2.00	1.95	1.85
Total	101.85	99.95	100.45	100.65	100.55	100.75	98.70	98.05	99.70	99.85	100.05

Sample No.	Cape Foulweather Basalts 55	69	75	104	105	114	118**
SiO_2	53.8	52.0	53.0	52.2	51.3	51.7	50.5
Al_2O_3	12.6	13.4	12.1	13.2	12.6	12.3	12.5
FeO	12.0	12.4	14.2	15.0	15.1	15.2	15.1
MgO	4.5	4.0	4.8	4.7	4.9	4.9	4.6
CaO	8.7	8.7	8.2	8.5	8.2	8.2	8.2
Na_2O	3.1	3.1	3.2	3.3	3.1	3.1	3.0
K_2O	1.15	1.25	1.20	1.45	1.20	1.20	1.15
TiO_2	3.10	3.20	2.80	3.10	3.00	2.95	3.00
Total	98.95	98.05	99.50	101.45	99.40	99.55	98.05

*Lower Yakima Basalt **Middle Yakima Basalt

APPENDIX XIII

Determination of Weight Percent Total Hydrocarbons

Procedure (after Penoyer, 1977)

Pyrolysis-fluorescence is a quantitative means of determining weight percent total live hydrocarbons in possible mudstone and sandstone source rocks. The procedure, described by Shell Development Company for use in its Northwest Division Source Rock Laboratory, was followed with minor changes. Each sample was prepared by crushing the rock sample to small pieces slightly larger than a coarse powder and thoroughly mixing. A 0.1 gram sample was then placed in a 10x75 culture tube and heated over a Bunsen burner flame until it emitted a red glow. The tube was held in a near-horizontal position to allow the moisture and hydrocarbons to condense along the sides of the tube. After cooling, chlorothene (1, 1,2-trichloroethane, practical grade) was added, followed by immediate decanting of the supernatant to a clean test tube. After calibration of the pre-warmed Turner No. 110 Fluorometer with a known fluorescent standard 42 ± 2 fluorescence units) successive unknowns were determined. Weight percent total hydrocarbon in the samples was determined by comparison of fluorescence readings with an empirically-derived curve provided by Shell Oil Company that relates fluorescence units to hydrocarbon abundance.

Appendix XIII (continued)

Data

Sample No.	Unit	Wt. % Total Hydrocarbons	Source Rock Quality
31	Silver Point mudstone	<0.5	nonsource
45	Silver Point mudstone	<0.5	nonsource
51	Silver Point mudstone	<0.5	nonsource
68	Silver Point mudstone	<0.5	nonsource
81	Silver Point mudstone	<0.5	nonsource
99	Pipeline mudstone	<0.5	nonsource
146	Oswald West siltstone	<0.5	nonsource
148	Big Creek sandstone (coally stringer)	1.2	marginal source

APPENDIX XIV

Sample Locations
(also shown on Plate I)

Sample	Lithology*	Outcrop*	Location ¼	¼	sec.	T. N.	R. W.
1	ms	rc	NW	NW	16	7	8
7	ss	rc	NW	SW	9	7	8
13	ss	rc	same as 174				
15	ss	rc	NW	NE	15	7	8
16	ss	rc	same as 15				
17	ss	rc	NW	NW	14	7	8
25	b	rc	SW	SW	20	7	7
28	ms	rc	SE	NE	23	7	7
29	ms	rc	same as 28				
31	ms	rc	SW	SE	21	8	8
37	ss	rc	NW	SE	12	7	8
45	ms	rc	SW	NE	13	7	8
51	ms	rc	SW	SW	13	7	8
53	ms	cl	SW	NW	17	7	7
55	b	rc	SW	SW	8	7	7
56	b	q	NE	NE	18	7	7
58	b	q	NW	NW	17	7	7
68	ms	cl	NE	SE	7	7	7
69	b	q	SW	NE	7	7	7
74	ms	rc	SW	NE	7	7	7
75	b	q	SE	NW	7	7	7
77	ss	rc	same as 37				
79	ss	rc	NW	NE	11	7	8
81	ms	q	NW	NW	21	7	7
82	ms	q	SW	NW	19	7	7
83	b	q	same as 82				
84	ss	rc	NW	SE	28	8	8
86	ms	rc	NW	NE	33	8	8
88	ss	rc	NW	NE	4	7	8

Appendix XIV (continued)

Sample	Lithology*	Outcrop*	Location ¼	¼	sec.	T. N.	R. W.
89	b	rc	same as 143				
90	ss	rc	NW	NW	3	7	8
93	ss	rc	NW	SE	3	7	8
95	b	q	same as 128				
99	ms	rc	SW	NW	33	8	8
100	ss	rc	NW	NE	9	7	8
102	b	q	SW	SE	35	8	8
104	b	q	SW	NE	5	7	7
105	b	q	NW	SW	4	7	7
107	ms	sc	SW	SE	14	7	7
108	ms	rc	NE	SE	33	8	8
109	ss	rc	SW	SE	22	8	8
111	b	rc	SW	SW	17	7	6
114	b	q	SW	SW	14	7	8
115	ss	rc	NW	NW	11	7	7
116	ss	rc	SW	NW	11	7	7
117	b	rc	SW	NE	11	7	7
118	b	rc	SW	SW	3	7	6
119	md	sc	SE	NW	21	7	7
120	b	q	NW	NW	11	7	7
121	b	q	same as 81				
123	ms	rc	NW	SW	21	7	7
124	ms	rc	SW	SW	24	7	7
125	ms	sc	SW	SW	11	7	7
128	ms	q	SE	SW	34	8	8
129	ms	rc	NE	SW	5	7	7
130	ss	rc	SW	SW	3	7	8
131	ss	sc	NW	NW	3	7	7
143	ms	rc	SW	SW	4	7	8
144	ms	rc	same as 129				
146	ms	sc	SE	SE	24	7	7
147	ms	sc	SW	SW	14	7	7

Appendix XIV (continued)

Sample	Lithology*	Outcrop*	Location ¼	¼	sec.	T. N.	R. W.
148	ss	sc	NE	NE	10	7	7
149	ss	sc	same as 148				
151	ss	rc	NE	SW	33	8	8
152	ss	rc	NE	SE	4	7	8
153	ss	rc	same as 151				
154	ss	rc	same as 151				
155	ss	rc	same as 151				
156	ss	rc	same as 151				
157	ss	rc	same as 151				
158	ss	rc	same as 151				
159	ss	rc	SE	NW	33	8	8
160	ss	rc	SE	NE	32	8	8
161	ss	rc	same as 99				
162	ss	rc	same as 99				
163	ss	rc	NW	NW	33	8	8
165	ss	sc	same as 131				
171	ms	q	NE	NW	35	8	8
174	ss	rc	NE	SE	14	7	8
175	ss	rc	same as 146				
Fossil Localities of Addicott (1975, written communication to Cooper)							
AOS 74-1	ss	sc	same as 131				
AOS 74-2	ss	sc	NW	SE	3	7	7
AOS 74-3	ss	sc	SW	NW	12	7	8
AOS 74-4	ss	rc	NW	SE	2	7	8
Fossil Localities of Cooper (ms in preparation)							
106.8	ss	sc	SE	SE	3	7	7
108.7	ss	sc	same as 131				
208.9	ms	sc	same as 146				
209.9	ms	sc	same as 147				
210.9	ms	sc	NE	SE	3	7	7
212.9	ss	sc	same as 131				

Appendix XIV (continued)

Sample	Lithology*	Outcrop*	Location ¼	¼	sec.	T. N.	R. W.
BC-3	ss	sc	SE	SE	3	7	7
BC-5	ss	sc	same as 131				
BC-6	ss	sc	same as 131				

*ms = mudstone

ss = sandstone

b = basalt

rc = roadcut

cl = cliff

q = quarry

sc = streamcut