AN ABSTRACT OF THE THESIS OF

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Title: TERTIARY STRATIGRAPHY AND SEDIMENTATION IN THE LEWIS AND CLARK RIVER - YOUNG'S RIVER AREA, CLATSOP COUNTY, NORTHWESTERN OREGON

Abstract approved: [signature]

Alan R. Niem

Five early to middle Tertiary bedrock geologic units crop out in the study area. These include the late Eocene to early Miocene Oswald West mudstones; the Tucker Creek sandstone, Big Creek sandstone, Silver Point mudstone, and Pipeline members of the early to middle Miocene Astoria Formation; and the middle Miocene Depoe Bay Basalts. These units are locally overlain by Quaternary floodplain, alluvial terrace, and beach-ridge deposits.

Oswald West mudstones consist of greater than 2,500 feet of poorly stratified to thick-bedded, orange-yellow, tuffaceous, burrowed mudstones and siltstones. Interstratified tuff beds and glauconitic strata are common. Deposition occurred primarily in an open, deep-marine environment (outer shelf to slope). The sandstone-rich middle part of the unit was deposited in a shallower marine, middle to outer shelf environment during an early Oligocene basin shoaling.

Early Miocene regression and tectonism resulted in termination of Oswald West mudstone deposition. Ensuing transgression resulted in deposition of the Astoria Formation over the Oswald West mudstones with slight angular (?) unconformity.

Basal deposits of the Astoria Formation include the interfingering Tucker Creek sandstone and Big Creek sandstone members. The former is a 150-foot thick unit consisting of medium- to very fine-grained, bioturbated, structureless sandstones which fine upward to siltstones and glauconitic sandstones. The 500- to 1,000-foot thick Big Creek member is composed of basal fine-grained, structureless to laminated, locally trough cross-bedded sandstones and, in the upper part, intertonguing fine-grained sandstones, siltstones, and glauconitic sandstone. The fining-upward sequence in each unit represents transition from shallow-marine to deeper marine environments as transgression progressed. These basal sandstones may have been deposited, in part, by northward-longshore drift redistribution of Angora Peak delta front sands.

The approximately 800-foot thick lower Silver Point mudstones are composed of well-stratified, rhythmically interbedded, fine-grained, micaceous, carbonaceous sandstones and dark-gray mudstones. The sandstones represent episodic turbidity current deposition in an open-marine, sublittoral (shelf), depositional environment. Turbidity flows may have originated by slumping of delta-front sands of the Angora Peak delta.

With continued transgression, the deep-marine, interfingering, upper Silver Point mudstone member and Pipeline member were deposited in the study area. The thickness of each unit is greater than 2,000 feet. Well-laminated, locally highly carbonaceous and micaceous, dark-gray mudstones are predominant in the upper Silver Point mudstones. These mudstones are hemipelagic, continental slope to outer shelf deposits. Similar deep-marine mudstone lithologies, which are complexly intertongued with thick, medium-grained, friable, arkosic sandstones, occur in the Pipeline member. The geometry, sedimentary structures, and bedding character of these sandstones are suggestive of deposition by sediment gravity flows (grain flow, fluidized flow), possibly in a submarine canyon or channelized upper submarine fan environment.

Several middle Miocene dikes and sills of Depoe Bay Basalt intrude the Astoria Formation and Oswald West mudstones in the study area. In surrounding areas, extrusive Depoe Bay and younger Cape Foulweather Basalts unconformably overlie older Tertiary strata.

Post-middle Miocene deformation formed east-west-trending folds and northwest- and northeast-trending high-angle faults in the study area. This deformation was accompanied by broad uplift of the Coast Range and termination of marine sedimentation in the study area.

The Olney oil seep is suggestive of the possible presence of subsurface petroleum reservoirs in the study area. Further drilling is necessary to determine the authenticity of the seep. The Pipeline sandstones are potential hydrocarbon reservoirs in the nearby continental shelf.

Tertiary Stratigraphy and Sedimentation in the Young's River - Lewis and Clark River Area, Clatsop County, Oregon

by

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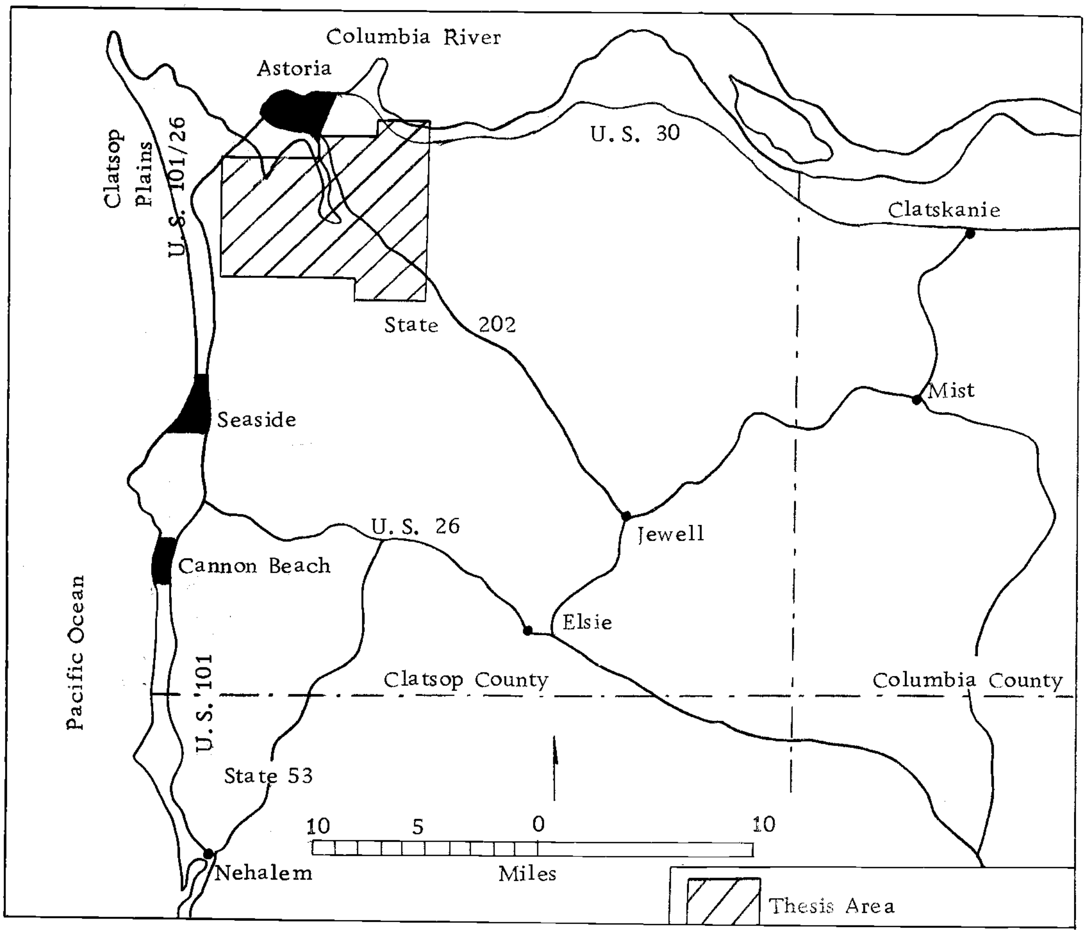
INTRODUCTION

Purposes of Investigation

Since 1972, graduate students at Oregon State University working under the supervision of Dr. Alan R. Niem have been mapping the geology of the coastal and adjacent inland areas of the Coast Range between Nehalem and Astoria, Oregon. As this regional study has progressed, it has become possible to reconstruct the complex history of sedimentation and volcanism in a Tertiary arc-trench-gap setting (Niem, 1976).

This thesis area covers a coastal area of northwestern Oregon previously unmapped in detail (Figure 1). It is a key area because a nearly complete section of late Eocene to middle Miocene rocks occurs within it. In addition, nearly all the rock units previously mapped by Oregon State University graduate students to the south are also present (see Cressy, 1974; Smith, 1975; Neel, 1976; Tolson, 1976; Penoyer, 1977).

As part of an ongoing regional geological investigation, the purposes of this thesis are: 1) to map Tertiary sedimentary and igneous rocks in the Lewis and Clark River - Young's River area;



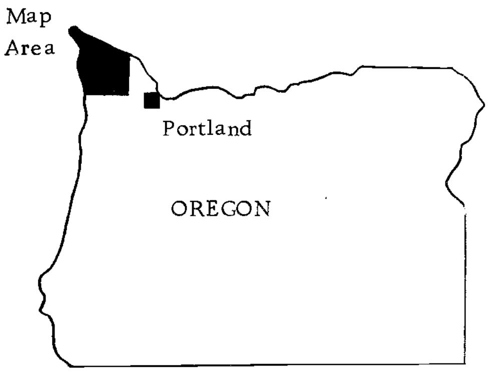


Figure 1. Index map showing location of thesis area.

2) to reconstruct the history of sedimentation, igneous activity, and tectonism in the area; 3) to better define the stratigraphic relations of the early to middle Miocene Astoria Formation; and 4) to assess the economic potential of the area, particularly in regard to petroleum source and reservoir rocks.

Location, Topography, and Accessibility

The study area is approximately ten miles northeast of Seaside, Oregon and 70 miles northwest of Portland, Oregon (Figure 1). The Columbia River and the City of Astoria border the study area on the north; the Clatsop Plains and the Pacific Ocean are adjacent on the west. The highly dissected 68-square mile area is topographically highest in the eastern part with a maximum elevation of 750 feet. The eastern part consists largely of forested hills a few hundred feet in elevation separated by the stream valleys of the Walluski and Klaskanine Rivers and their many tributaries. In the western part, there are two north-south-trending ridges which attain a maximum elevation of 450 feet. They are separated by the alluvial valley of the Lewis and Clark River. The alluvial valley of the Young's River occupies the central part of the study area (Plate I).

The research area is accessible from Portland via U.S. Highway 26, U.S. 101, State Highway 202, and U.S. 30 (Figure 1). The Young's River Loop Road, Lewis and Clark County Road, several city of Astoria roads, and numerous logging roads provide easy access within the study area. Bedrock exposures occur primarily in logging road cuts and to a lesser degree in stream drainages and quarries.

Methods of Investigation

The field work phase of this investigation involved 1) detailed description of outcrop lithologies and sedimentary structures, 2) construction of a geologic map of the study area, 3) collection of rock and fossil samples, 4) measurement of stratigraphic sections, and 5) collection of paleocurrent data.

Field work was undertaken from June through September of 1976 and continued intermittently during the following fall and winter until completion in March, 1977.

Crown Zellerbach Corporation provided four topographic maps (scale 1:12,000) which were used as base maps for geologic field mapping. All data were later transferred to a final base map (Plate I) constructed from the U.S. Geological Survey $7\frac{1}{2}$-minute Astoria, Olney, Gearhart, and Warrenton quadrangle maps and the 15-minute Svensen quadrangle map. U.S. Forest Service 1975 aerial photographs (scale 1:32,000) were used in a limited capacity in field mapping and field location.

Descriptions of stratification, cross-stratification, and grain size follow the formats of McKee and Weir (1953), Bouma and Brouwer (1964), and Wentworth (1922), respectively. Rock colors were described using the Geological Society of America "Rock-Color Chart" (1970).

Azimuths and attitudes were measured in the field with a Brunton compass. A Jacob's staff and Abney level were used to measure two partial stratigraphic sections (Appendices I, II, III).

Laboratory work consisted of 1) thin-section petrography, 2) heavy-mineral study, 3) clay-mineral identification, 4) grain-size analysis, 5) determination of basalt chemistry, 6) paleocurrent analysis, 7) analysis of rock samples for hydrocarbon content, 8) utilization of U-2 high-flight imagery, and 9) preparation of fossils for study.

Modal analyses were performed on 16 of 32 rock samples studied in thin section (Appendix VI). Rock classification follows the schemes of Williams and others (1954). Billets were stained to aid in the identification of potassium feldspar following the method of Bailey and Stevens (1960).

Heavy minerals in the 2.5-3.5 phi-size fractions of ten sandstone samples were segregated using tetrabromoethane (S. G. = 2.95) according to the procedure outlined by Royse (1970). Two hundred non-opaque, non-micaceous minerals were counted for each sample (Appendix V).

The clay mineralogy of four mudstones and the less-than-four phi-size fractions of two sandstones was determined using a Norelco X-ray diffractometer. Pretreatments, following the method of Harvard (1976, personal communication), included cation-saturation, solvation with ethylene glycol and glycerol, heating to 300°C. and 500°C., and control of relative humidity (see Appendix VIII for further discussion). Utilization of the clay-mineral identification criteria developed by Brown (1972) and Carroll (1970) aided in interpretation of clay-mineral diffraction patterns.

Grain-size analysis involved sieving 35 disaggregated sandstone samples through screens nested in $\frac{1}{4}$-phi intervals according to the procedure described by Royse (1970). Cumulative weight percent curves were constructed for each sieved sample on probability paper, and the statistical parameters of Folk and Ward (1957) were calculated. These parameters were then plotted on the binary graphs developed by Passega (1957), Friedman (1962), and Moiola and Weiser (1968) to aid in the interpretation of depositional environment.

Three basalt samples were chemically analyzed by X-ray fluorescence, atomic-absorption spectrophotometry, and visible-light spectrophotometry. Sample preparation followed the procedure outlined in Taylor's "Cookbook for Standard Chemical Analysis" (1974).

Paleocurrent azimuths were corrected for tectonic tilt (see

Potter and Pettijohn, 1963, for procedure), analyzed using the statistical method outlined by Royse (1970), and plotted on a rose diagram (Figure 42).

The hydrocarbon content of selected mudstone samples was determined quantitatively by a pyrolysis-fluorescence technique developed by Shell Research Laboratories which utilizes a Turner No. 110 Fluorometer (see Appendix IX for procedure). This aided in evaluation of the source-rock potential of the study area.

U-2 high-flight infrared imagery (scale 1:62,000), available from the Oregon State University remote sensing laboratory, was utilized in the study of lineaments and geomorphic features in the thesis area.

Mudstone samples containing Foraminifera were disaggregated using a technique suggested by Dr. Richard Thoms (1976, personal communication). Samples were soaked in kerosene for 12 hours and, after decanting the kerosene, boiling water was poured over the samples. The microfossils were separated, mounted, and sent to Dr. Weldon Rau of the Washington Department of Natural Resources for identification and paleoenvironmental interpretation. Dr. C. Kent Chamberlain of the University of Nevada, Las Vegas, and Dr. Warren O. Addicott of the U.S. Geological Survey identified and interpreted trace-fossil and molluscan-fossil assemblages, respectively. Fossil assemblages and locations are listed in Appendix IV and Appendix XI, respectively. Rock sample and fossil localities are also shown on Plate I.

REGIONAL GEOLOGY

Structurally, the northern Oregon Coast Range is a north-plunging anticlinorium comprising over 25,000 feet of Tertiary sedimentary and volcanic rocks (Snavely and Wagner, 1964) (Figure 2). The anticlinorium is cored by Eocene tholeiitic basalts and is flanked by gently dipping late Eocene to middle Miocene tuffaceous mudstones, siltstones, and volcaniclastic and arkosic sandstones. Intercalated with the sedimentary rock sequence are local late Eocene and middle Miocene basalt flows, breccias, pillow basalts, and associated intrusives. The general stratigraphy of the northern and central Oregon Coast Range is illustrated in Figure 3.

Pillow basalts, basaltic breccias, and minor tuffs compose the early to middle (?) Eocene Tillamook Volcanics, the oldest unit exposed in the core of the anticlinorium. Interbedded with the volcanics, particularly in the upper part, are tuffaceous siltstones and graded volcanic and feldspathic wackes. The volcanics are thought to be fissure flood basalts erupted on the ocean floor and that these accumulated in sufficient thickness, in places, to form volcanic islands (Snavely and Wagner, 1963). The base of the Tillamook Volcanics is not exposed, but its thickness probably ranges between 10,000 and 20,000 feet (Snavely and others, 1968). The lower part of the Tillamook Volcanics is considered to be correlative with the early

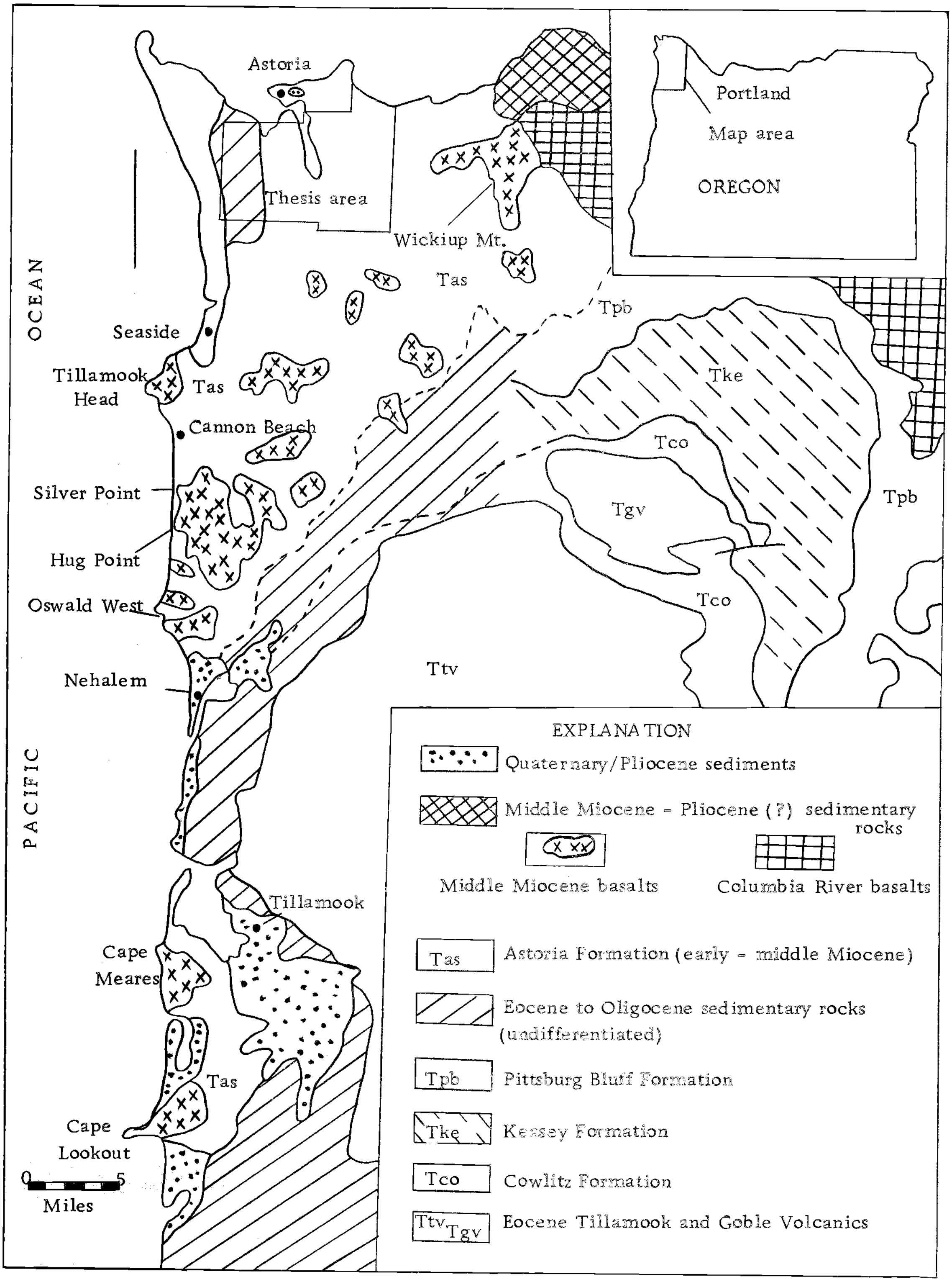


Figure 2. Regional geologic map of the northwestern Oregon Coast Range (modified from Wells and Peck, 1961).

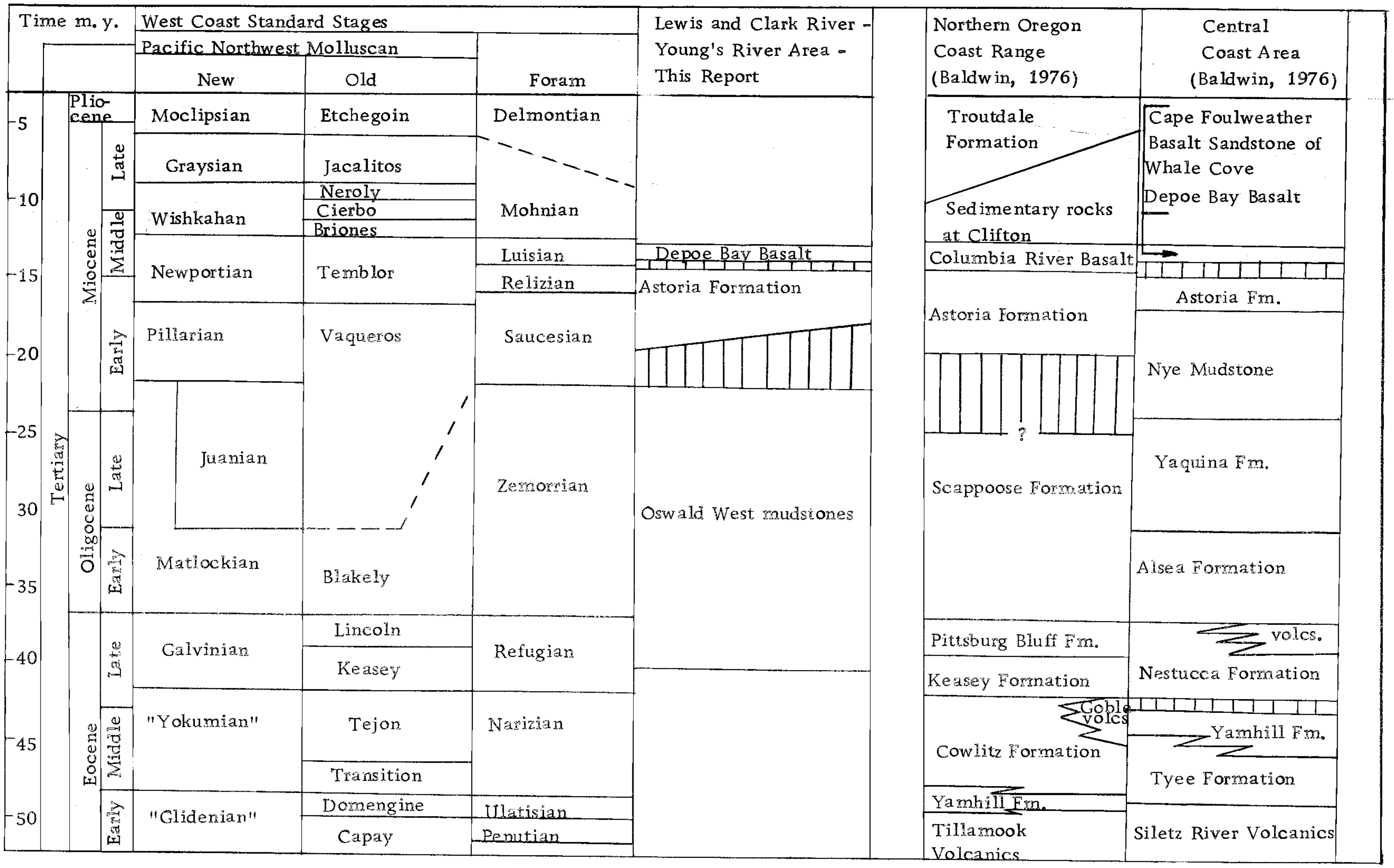


Figure 3. Oregon Coast Range stratigraphy. Correlation of fossil stages to each other and to absolute time scale after Armentrout (1977b) and Addicott (1977). Correlations of Coast Range Formations with fossil stages and time scale tentative.

to middle Eocene Siletz River Volcanics which form the core of the central Oregon Coast Range.

The rock units recognized on the northeast flank of the Coast Range anticlinorium are, from oldest to youngest: the Cowlitz Formation, the Goble Volcanics, the Keasey Formation, the Scappoose Formation, and the Columbia River Basalts. The approximately 1,000-foot thick middle Eocene Cowlitz Formation unconformably (?) overlies the Tillamook Volcanics and consists of marine siltstones, basaltic conglomerates, and arkosic sandstones. Locally basaltic lavas and breccias of the Goble Volcanics interfinger with the upper part of the formation (Niem and Van Atta, 1973).

The overlying deep-marine approximately 2,700-foot thick late Eocene Keasey Formation consists of tuffaceous and pumiceous siltstones and mudstones, and subordinate volcanic sandstones. Rare crinoids occur in the unit (Baldwin, 1976). Contacts with underlying and overlying units appear to be conformable (Niem and Van Atta, 1973).

Several hundred feet of late Eocene to earliest Oligocene mudstones, and subordinate basal arkosic sandstones and siltstones, compose the overlying Pittsburg Bluff Formation. Coaly interbeds apparently interfinger with the basal sandstone member (Baldwin, 1976).

A basal basaltic conglomerate occurs in the 1,500-foot thick

Scappoose Formation at its disconformable contact with the underlying Pittsburg Bluff Formation. The arkosic sandstones and tuffaceous mudstones of the Scappoose Formation are thought to be deposits of a westward-prograding late Oligocene delta (Van Atta, 1971).

Remnants of the subaerial flood basalts of the middle Miocene Columbia River Basalt Group crop out in the lower Columbia River basin (Figure 3). The basalts overlie, with slight angular unconformity, all older formations indicating that deformation and subaerial erosion of most strata occurred before extrusion of the basalts (Niem and Van Atta, 1973).

Because of the greater lithologic homogeneity of rocks on the northwestern flank of the Coast Range anticlinorium, as compared with the northeastern flank, fewer rock units have been formally recognized. On a map of the geology of Oregon west of the 121st meridian compiled by Wells and Peck (1961), three major rock units were differentiated on the northwestern flank: 1) undifferentiated late Eocene to early Miocene sandstones, siltstones, and mudstones, 2) the Miocene Astoria Formation, and 3) middle Miocene basaltic volcanics and intrusives. Additionally, a local middle Miocene (?) to early Pliocene (?) unit has been recognized by most workers (Warren and others, 1945; Wells and Peck, 1961; Niem and Van Atta, 1973; Baldwin, 1976).

The late Eocene to early Miocene sedimentary rocks on the northwestern flank of the Coast Range anticlinorium are probably deeper marine equivalents of the Cowlitz, Keasey, Pittsburg Bluff, and Scappoose Formations on the northeast flank. An informal rock unit within the undifferentiated Eocene to Oligocene sequence was described by Cressy (1974) and named the Oswald West mudstones (see Local Stratigraphic Nomenclature section).

The Miocene Astoria Formation crops out only on the west side of the Oregon Coast Range in a series of embayments extending from Astoria to Newport. Recognized facies of the formation include fluvial-deltaic conglomeratic sandstones, deep-water turbidite sandstones intercalated with mudstones, thinly-laminated hemipelagic mudstones, beach and shelf sandstones, and deep-water channelized sandstones (Niem, 1976; see Local Stratigraphic Nomenclature section). The approximately 2,000-foot thick formation unconformably overlies older strata (Niem and Van Atta, 1973).

The middle Miocene volcanics on the northwestern side of the Oregon Coast Range are locally-derived accumulations of basaltic pillow lavas and breccias which unconformably overlie the Astoria Formation and older rocks. Associated basaltic dikes and sills are numerous.

A middle Miocene (?) to early Pliocene (?) massive to cross-bedded sandstone and laminated mudstone unit crops out along the lower Columbia River in the vicinity of Clifton, Oregon. It is thought to be a deposit of the ancestral Columbia River (Snavely and Wagner, 1963).

A quartz, quartzite, and volcanic pebble conglomerate known as the Troutdale Formation crops out along the lower reaches of the Columbia River from Portland to Astoria. This early Pliocene (?) unit unconformably overlies older units and appears to be fluvial in origin (Schlicker and others, 1972).

Structure in the northwestern Oregon Coast Range consists of northwest-southeast-trending gentle folds and northeast- and northwest-trending high-angle normal and reverse faults. Strike-slip movement along some faults is probable (Snavely and Wagner, 1964). Gravity lows at the northern end of the Oregon Coast Range suggest structural downwarping in the lower Columbia River basin (Bromery and Snavely, 1964).

The Tertiary geologic history of the Oregon Coast Range has been discussed by Snavely and Wagner (1964) and by Snavely and others (1968).

PREVIOUS WORK

Many of the early investigations of the geology in northwestern Oregon focussed on the strata exposed at and around the City of Astoria. J. D. Dana (1849) travelled through the area with the Wilkes exploration expedition and collected molluscan fossils at Astoria. Conrad (1849) initially assigned these fossils to the Miocene but later considered them to be Eocene in age (Conrad, 1865). In subsequent work there was little agreement concerning the age and nomenclature of the strata at Astoria, largely because the geology of the Astoria area had not been mapped in detail (see Moore, 1963, for a compilation of literature on the topic).

However, near-resolution of the controversy came with Howe's (1926) designation and description of the strata at Astoria as the type area for the Astoria Formation. He subdivided the formation into 1) a structureless, fine-grained, lower sandstone member; 2) a 1,000-foot thick middle mudstone member; and 3) a thick, coarse-grained, arkosic, micaceous, upper sandstone member. After studying molluscan assemblages from the type area, he concluded that the Astoria Formation was no older than middle Miocene and could be as young as early late Miocene.

Other early workers in northwestern Oregon investigated the regional geology in order to evaluate economic resources. Diller

(1896) and Washburne (1914) undertook regional mapping studies of the mineral resources and the oil and gas potential of the area, respectively. They noted the presence of "shales," sandstones, and basalt highlands in the Astoria area and to the south but generally found interior exposures discouragingly sparse. The search for oil and gas during World War II involved regional geologic mapping of northwest Oregon by Warren and others (1945). They published a 1:143,000 reconnaissance map which differentiated middle Miocene basalts and the Astoria Formation from older sedimentary strata.

Work in the Astoria area in later years focussed primarily on the age and stratigraphy of the Astoria Formation. Urbanization of the City of Astoria resulted in the loss of type Astoria Formation strata as described by Howe (1926). Many workers then attempted to resolve resulting problems of correlating with the Astoria Formation type area (Seitz, 1948; Lowry and Baldwin, 1952; Stewart, 1956; Dodds, 1963; Moore, 1963).

A small-scale map of the geology of Oregon west of the 121st meridian, compiled by Wells and Peck (1961), differentiated the Astoria Formation and middle Miocene basalts from older undifferentiated rock units in the Astoria area and to the south. Engineering and environmental geology studies of Tillamook and Clatsop counties by Schlicker and others (1972) and Beaulieu (1973) restricted the Astoria Formation to middle Miocene sandstones in order to emphasize engineering properties of various lithologies in the Astoria area.

Recent mapping of the Astoria Formation on the Washington side of the Columbia River north and northwest of Astoria has been accomplished by Young (1966) and Wolfe and McKee (1968, 1972), respectively. Mapping directly north of Astoria is being carried out by Ray Wells of the U.S. Geological Survey (Niem, 1977, personal communication).

The stratigraphy of the northern Oregon Coast Range was reviewed by Niem and Van Atta (1973), and the problem of age and stratigraphy of the Astoria Formation was considered. They concluded that since the Astoria Formation was first investigated, many workers in different parts of western Oregon have mapped and defined the Astoria Formation on the basis of fossils similar to those in the type area, but not on the basis of similar lithologies. As a result, much confusion has arisen concerning the lithostratigraphy of the formation. The stratigraphy of the Astoria Formation has also been reviewed by Baldwin (1976), Beaulieu (1971), Moore (1963), and Dodds (1970).

The petrology and chemistry of the Miocene volcanic and intrusive rocks of the Oregon Coast Range have been studied by Snavely and others (1973) (see <u>Stratigraphic Nomenclature</u> section).

The most recent detailed geologic mapping in the northwest Oregon Coast Range has been carried out by Oregon State University graduate students working under the supervision of Dr. Alan R. Niem (see Stratigraphic Nomenclature section). Areas immediately to the south and east of the study area have been mapped by Tolson (1976) and Coryell (1978), respectively. Mapping farther to the south has been completed by Cressy (1974), Smith (1975), Neel (1976), and Penoyer (1977). Cooper (1978) is completing a regional facies study of the Astoria Formation in the western Oregon Coast Range. An engineering geology study in the immediate vicinity of the City of Astoria, and adjacent to the northern border of this thesis area, has been completed by Carter (1976), an Oregon State University graduate student.

LOCAL STRATIGRAPHIC NOMENCLATURE - RECENT WORK (1974-1977)

Several informal rock units have been named and described by Oregon State University graduate students mapping Oregon coastal areas from Nehalem to Astoria (Cressy, 1974; Smith, 1975; Neel, 1976; Tolson, 1976; Penoyer, 1977; Cooper, 1978). These units include the Oswald West mudstones and three informal members of the Astoria Formation: the Angora Peak sandstones, the Silver Point mudstones, and the Big Creek sandstones. Middle Miocene coastal basalts of Oregon also have been differentiated into several mappable chemical-petrologic types (Snavely and others, 1973).

The Oswald West mudstones are a greater than 1,500-foot thick sequence of deep-marine, bioturbated, well-bedded, silty mudstones. The type section was described by Cressy (1974) at Oswald West State Park, Oregon. Interbedded tuffaceous siltstones and rarer turbidite and glauconitic sandstones are present within the sequence. Fossil assemblages in the unit suggest a late Oligocene to early Miocene age. However, as the Oswald West mudstones have been mapped northward by Smith (1975), Neel (1976), Tolson (1976), and Penoyer (1977), strata as old as late Eocene have been included within the unit because of the lack of any significant stratigraphic break at the base of the Oswald West mudstone type section described by Cressy.

The Astoria Formation

Although Howe (1926) subdivided the Astoria Formation into three informal members at the type section at Astoria, these members have rarely been described in other parts of the outcrop area of the formation. However, several facies variants of the formation, given informal member status by Oregon State University graduate students, have proven to have sufficient lateral continuity to provide a coherent regional stratigraphic picture of the Astoria Formation.

Cressy (1974) proposed the name Angora Peak sandstone member for a thick sequence of sandstones and minor conglomerates which are well-exposed in the coastal area between Nehalem and Cannon Beach, Oregon. The unit consists of approximately 1,800 feet of cross-bedded, shallow-marine and deltaic, arkosic and lithic sandstones, local fluvial-channel conglomerates, minor carbonaceous siltstones, and rare coal seams. He determined that the Angora Peak sandstones overlie the Oswald West mudstones with angular unconformity and constitute the lowermost, oldest part of the Astoria Formation in the Nehalem-Cannon Beach area. Faunal evidence suggests an early to middle Miocene age for the unit (Cooper, 1978).

Overlying and interfingering with the Angora Peak sandstones in the Nehalem-Cannon Beach area and to the north is an informal unit named the Silver Point mudstone member by Smith (1975). The greater than 800-foot thick member contains rhythmically intercalated mudstones and micaceous, carbonaceous, turbidite sandstones in its lower part, and dark gray, deep-marine, well-laminated mudstones in its upper part. The unit is well-exposed at Silver Point, Oregon, the type section (Figure 2). Foraminiferal assemblages and stratigraphic position are suggestive of an early to middle Miocene age for this member of the Astoria Formation.

A third informal member of the Astoria Formation, the Big Creek sandstone member, has been described and mapped by Cooper (1978) and Coryell (1978) in the Wickiup Mountain-Big Creek area east of Astoria (Figure 2). The approximately 1,000-foot thick member consists of fine- to medium-grained shallow-marine sandstones and minor coarse-grained fluvial sandstones. This unit is probably correlative with the Angora Peak sandstone member which crops out to the south (Cooper, 1978; see above). Molluscan fossils suggest an early to middle Miocene age for the unit. The Big Creek sandstones form the base of the Astoria Formation in the area southeast and east of Astoria.

Two additional local tongues of the Astoria Formation, the "J" unit and the Airplane mudstones, were recognized by Tolson (1976) immediately south of the study area. The "J" unit consists of carbonaceous, micaceous mudstones and arkosic, coarse-grained channel sandstones. Well-laminated mudstones compose the Airplane tongue. Both are correlative with and intertongue with the Silver Point mudstone member defined by Smith (1975). Tolson recommended against formalization of these two units because of their lack of lateral continuity.

The Coastal Basalts

Middle Miocene basalts unconformably overlie older strata, including the Astoria Formation, in coastal areas of northwest Oregon. Snavely and others (1973) determined that these basalt flows and breccias, pillow basalts, and associated intrusives, were derived from coastal vents and that three chemical-petrologic types exist. The older Depoe Bay Basalt is typically finely crystalline, non-porphyritic, and has a high SiO_2 content (approximately 55%). The younger Cape Foulweather Basalt is characterized by sparse labradorite phenocrysts and is enriched in oxides of iron (14%), titanium (3%), and phosphorus (0.75%). These two basalt types have been mapped by Oregon State University graduate students (Smith, 1975; Neel, 1976; Tolson, 1976; Penoyer, 1977; Coryell, 1978). The youngest petrologic type, Pack Sack basalt, is found only in southwestern Washington. Each of these basalts has a coeval, chemically equivalent counterpart within the Columbia River Basalt Group (Snavely and others, 1973).

Provincial Molluscan Stages of the Pacific Northwest

Prior to 1975, molluscan stages used in the Pacific Northwest were a combination of locally defined stages (Blakely, Lincoln, and Keasey) and Californian stages (Figure 3, see column heading Pacific Northwest, Old). Overlap between local and Californian stages, and the confusing use of formation names as stage names, has rendered correlation in the Pacific Northwest a difficult problem.

To alleviate confusion, provincial molluscan stages defined specifically for the Pacific Northwest were proposed by Addicott (1976a) and Armentrout (1975) (Figure 3, see column heading Pacific Northwest, New). The Matlockian and Galvinian Stages were proposed by Armentrout and the remaining stages by Addicott. Correlation between the new molluscan stages and the West Coast foraminiferal stages is shown in Figure 3.

DESCRIPTIVE GEOLOGY

Six major bedrock lithologic units have been recognized in the study area, four of which are informal members of the Astoria Formation (Figures 4 and 5). The oldest unit is the late Eocene to early Miocene Oswald West mudstones. This unit is unconformably overlain by the early to middle Miocene Astoria Formation. The latter is composed of, in approximate stratigraphic succession, the Tucker Creek sandstone member, the Big Creek sandstone member, the Silver Point mudstone member, and the Pipeline member.

The youngest bedrock unit in the study area consists of middle Miocene intrusive basalts identified as Depoe Bay chemical-petrologic type. Extrusive equivalents of these basalts are not present in the study area, but where present to the south and east they unconformably overlie the Astoria Formation and the Oswald West mudstones (Penoyer, 1977; Tolson, 1976; Coryell, 1978). Quaternary beach and alluvial deposits overlie older strata with angular unconformity (Plate I).

The Oswald West mudstones, the Silver Point mudstones, the Big Creek sandstones, and the middle Miocene basalts previously have been mapped by Oregon State University Department of Geology graduate students to the south and east of the study area. The Tucker Creek sandstone member is an informal unit recognized only in the

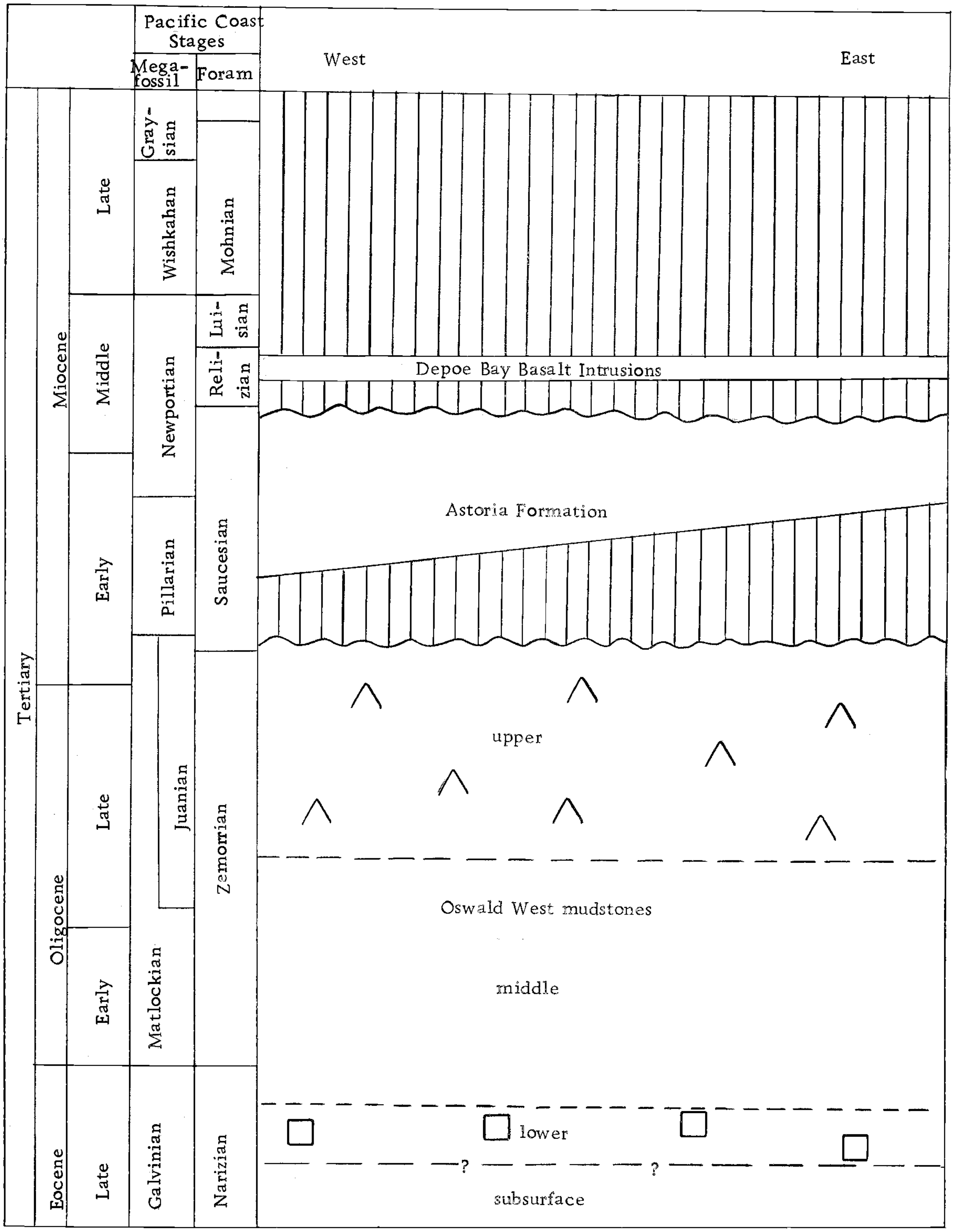


Figure 4. Tertiary stratigraphy of the thesis area.

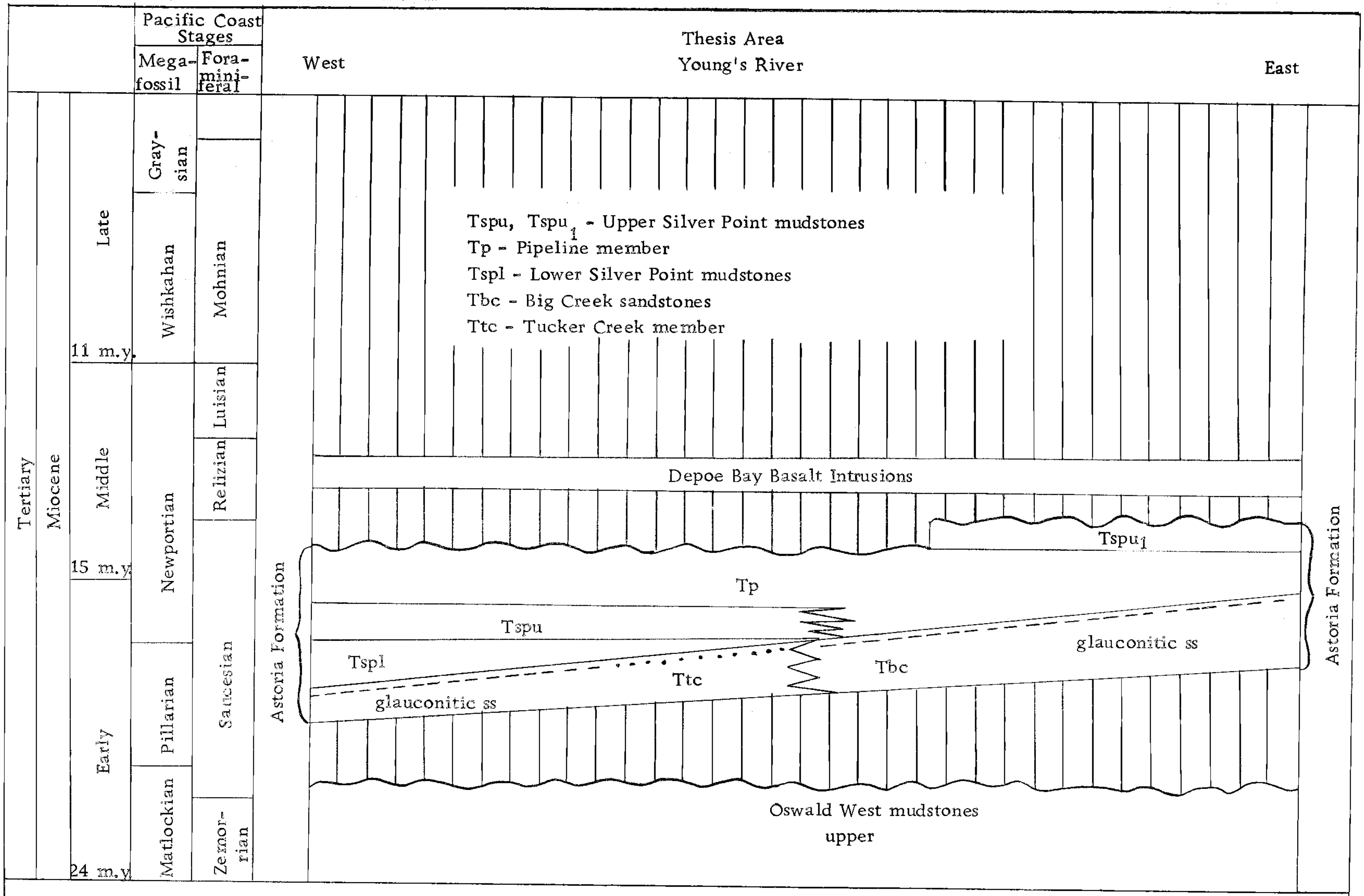


Figure 5. Miocene stratigraphy of the thesis area.

study area. It is a local basal sandstone unit of the Astoria Formation which probably intertongues laterally with the Big Creek sandstone member (Figure 5). The Pipeline member of the Astoria Formation is a previously unrecognized unit which is being defined by George Coryell (1978) and myself.

Oswald West Mudstones

A thick section of late Eocene to early Miocene Oswald West mudstones is represented by extensive outcrops in the western, central, and southeastern part of the study area (Figure 6, Plate I). The moderately well-indurated mudstones and siltstones of the unit are extensively stream-dissected and form low hills (200-300 feet) of moderate relief. The Oswald West mudstones tend to be less slump-prone than the mudstones of the overlying Silver Point member of the Astoria Formation.

Extensive faulting and the lack of correlatable stratigraphic horizons within the unit prohibit accurate determination of its thickness, as exposed at the surface. However, a thickness of 2,000 to 3,000 feet is suggested based on trigonometric calculation utilizing outcrop distribution and regional dips.

The true thickness of the Oswald West mudstones in the study area is not known because the lithostratigraphic base of the unit has not been defined in previous work (Cressy, 1974; Smith, 1975;

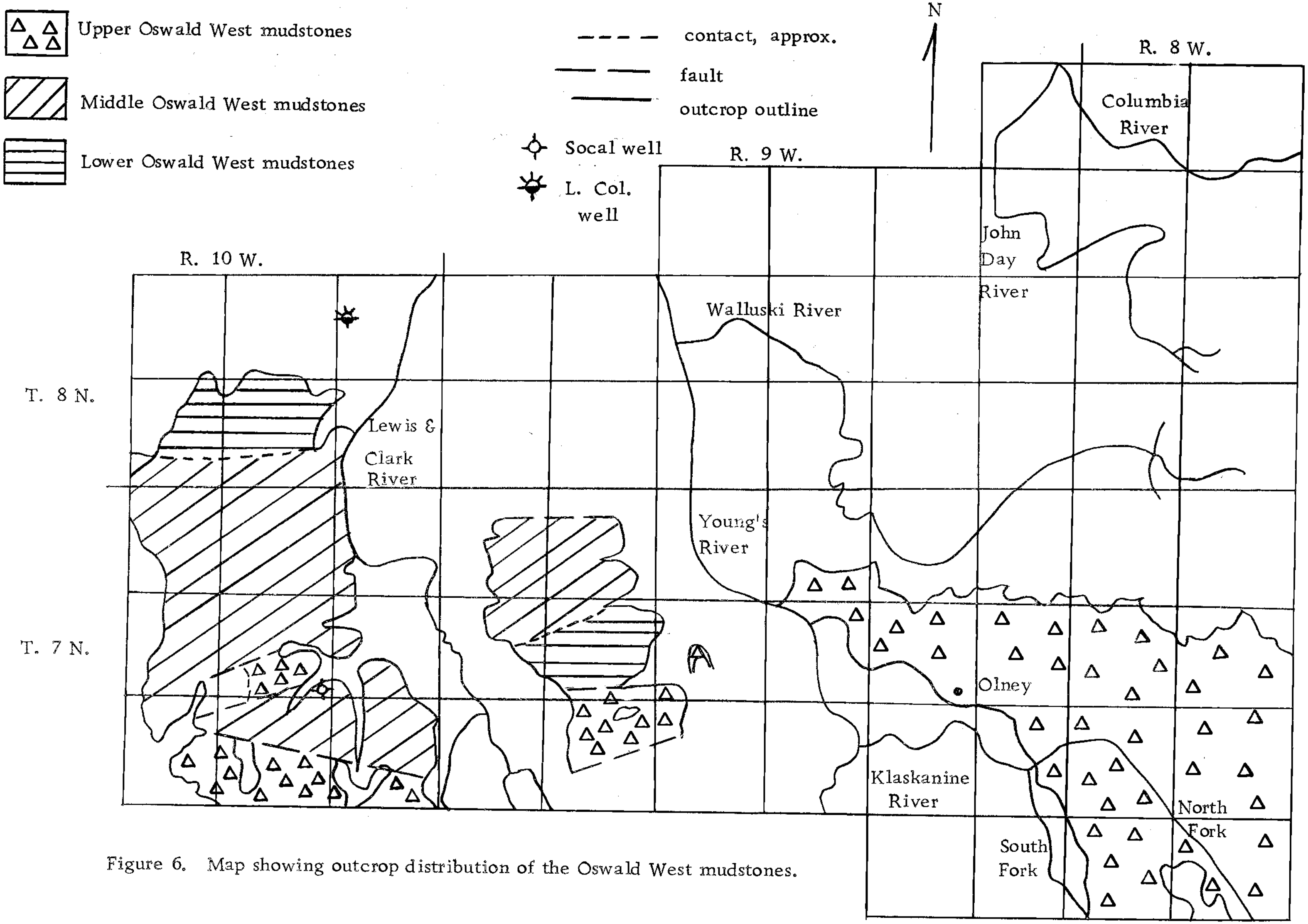


Figure 6. Map showing outcrop distribution of the Oswald West mudstones.

Tolson, 1976; Neel, 1976; Penoyer, 1977). However, based on well logs from the study area, a thickness of up to 5,000 feet for the unit is indicated. Two exploratory wells were drilled by Standard Oil Company of California and Lower Columbia Oil and Gas Company on the north-south-trending ridge between the Lewis and Clark River and the western border of the thesis area (see locations on Plate I, Figure 6). Surface exposures on the ridge consist primarily of southward-dipping Oswald West mudstones. The Socal #1 Hoaglund well penetrated 5,000 feet of reportedly late Eocene (Refugian age) siltstones and mudstones, probably Oswald West mudstones, before encountering 2,000 feet of underlying Tillamook (?) or Goble (?) volcanics (Newton, 1969; Tolson, 1976). Therefore, a maximum thickness of 5,000 feet for the Oswald West mudstones is indicated in this area. A similar thickness of probable Oswald West sedimentary strata (4,800 feet) was encountered in the Lower Col. #1 Brown well drilled 3.5 miles to the north of the Socal #1 Hoaglund well (Newton, 1969; Plate I).

Lithology

The Oswald West mudstones are composed of bioturbated, structureless to poorly stratified, tuffaceous mudstones (Figure 7) and subordinate siltstones and very fine-grained sandstones. On a lithologic basis, the unit is divided into upper, middle, and lower

Figure 7. Contact of sandstone interbed, $Tows_2$, in the middle Oswald West mudstones with underlying silty mudstone. The latter displays characteristic iron-stained Liesegang rings. (sec. 11, T. 7 N., R. 10 W.)

parts (Figure 4). The middle part alone contains significant abundances of sandstone (greater than 10%).

Lower. The lower part of the Oswald West mudstones is composed of 300 to 600 feet of structureless, bioturbated, sparsely micaceous, tuffaceous mudstones with rare very thin-bedded white (N9) tuff beds. Thin-bedded grayish-orange (10 YR 7/4) very fine-grained glauconite-bearing sandstones occur locally. The presence of the latter two lithologies serves to define bedding.

The mudstones are olive gray (5 Y 4/1) in fresh exposures but commonly weather to a yellowish gray (5 Y 7/2). Light blue gray (5 B 7/1), meandering, three- to ten-millimeter long Scalarituba/Helminthoidia fecal-ribbon burrows, identified by Chamberlain (1977, written communication), are common in the mudstones. This bioturbation, along with the typical development of reddish-orange iron-stained Liesegang rings on weathered outcrop surfaces, has resulted in obliteration of most bedding and other primary sedimentary structures in the mudstones (Figure 7). Angular chips (1-10 mm) of talus accumulate at the base of most outcrops.

Rare coiled arenaceous (?) Foraminifera are present in the mudstones but are commonly too weathered to be identifiable.

A gradational contact with the overlying middle part of the Oswald West mudstones is inferred based on the apparent increasing abundance of siltstones and sandstones up-section. The lower contact

Figure 8. Fine-grained sandstone, $Tows_2$, in the middle part of the Oswald West mudstones. Note well-developed platy splitting. (logging road 31, NW 1/4, sec. 11, T. 7 N., R. 10 W.).

is discussed in the Contact Relations section.

The lower part of the Oswald West mudstones is well-exposed along spur H off the Tucker Creek North logging road (NW$\frac{1}{4}$, sec. 8, T. 7 N., R. 9 W.) and along spur 13 off the Clatsop Road (W$\frac{1}{2}$, sec. 35, T 8 N., R. 10 W.)

Middle. Silty tuffaceous structureless mudstones are the dominant lithology in the greater than 1000-foot thick middle part of the Oswald West mudstones. However, interbedded siltstones and fine- to very fine-grained sandstones are common subordinate lithologies. Up to eight-inch thick white (N9) tuff beds also are present.

The mudstones are medium gray (N5) in fresh exposures and are yellowish gray (5 Y 8/1) when weathered. Scalarituba/Helminthoidia burrows identified by Chamberlain (1977) are common. Local concentrations of carbonized wood fragments, comminuted carbonaceous debris, micas, and glauconite occur in the mudstones. Lenses of silicified mudstone also are present.

Iron-oxide concretions one-half to four inches in diameter are common in the mudstones of the middle part. They are composed of a thin one- to five-millimeter thick rind of hard dark brown limonite, and an interior core which is hollow or filled with an orange-yellow powdery clay. Crustacean-bearing calcareous concretions also occur.

Interbedded in the middle part of the Oswald West mudstones are well-indurated to friable, yellowish-gray (5 Y 8/1), siltstones and very fine-grained arkosic and glauconitic sandstones. They range in thickness from less than one inch to greater than ten feet but are commonly thick-bedded. Clay laminae present in the sandstones and siltstones are locally contorted by soft-sediment deformation and superficially resemble Scalarituba burrows (Chamberlain, 1977). Grading, cross-bedding, and other primary sedimentary structures are absent, probably having been destroyed by bioturbation and soft-sediment deformation. Most bedding contacts are irregular and gradational but sharp basal contacts are observed locally. Many siltstone and sandstone beds pinch and swell laterally and in extreme cases occur as oblong pods one- to five-feet in diameter surrounded by mudstone strata. These deformed beds probably formed by foundering of coarse-grained surface sediment (sand and coarse silt) into a "soupy," semi-consolidated, finer grained, clay-rich substrate (Pettijohn, 1975). An excellent exposure of these interbedded lithologies occurs at the junction of spur 11 and logging road 11-21 (sec. 2, T. 7 N., R. 10 W.)

Glauconite is a common and locally abundant constituent of the middle Oswald West mudstones. It constitutes up to 50-percent of some sandstones and occurs in smaller amounts as pods and stringers in the siltstones and mudstones. Locally high concentrations occur in grayish-olive (7 Y 4/2) lenticular channel-like sandstone bodies.

Glauconite grains are concentrated near the bases of these channels and immediately below in small ovoid lenses. The latter appear to be detached pillows of the overlying sandstone. Mudstone ripups are common at the bases of channels. A 50-foot wide glauconitic sandstone channel is exposed in a roadcut at the end of spur Po, W$\frac{1}{2}$, sec. 10, T. & N., R. 10 W. Locations of glauconitic sandstones are illustrated in Plate I.

Two relatively thick arkosic sandstone bodies occur in the middle Oswald West mudstones. An approximately 60-foot thick grayish-yellow (5 Y 8/4) micaceous unfossiliferous sandstone ($Tows_2$), with distinctive platy splitting, crops out along logging road 31 (NW$\frac{1}{4}$, sec. 11, T. 7 N., R. 10 W.) and spur A (NE$\frac{1}{4}$, sec. 2, T. 7 N., R. 10 W.) (Plate I and Figure 8). It is very fine-grained (ϕ_{50} = 3.69 phi) and poorly sorted (s_1 = 1.30 phi). Adjacent silty mudstones are in sharp contact with the base of the unit and in gradational contact with the top of the unit. A 30-foot thick greenish-gray (5 GY 6/1) sandstone ($Tows_1$) is exposed on the ridge between Lewis and Clark River and Young's River at the end of spur 25 (SE$\frac{1}{4}$, sec. 5, T. 7 N., R. 9 W., Plate I). This sandstone is very fine-grained (ϕ_{50} = 3.0), moderately sorted (s_1 = 0.88 phi), contains faint parallel laminations, and has moderately-well-developed platy splitting. Both sandstones lack the iron-stained Liesegang rings characteristic of the other Oswald West lithologies. Stratigraphic relations suggest that $Tows_1$ lies nearer the base of the middle part than does $Tows_2$.

Unbroken molluscan fossils are locally abundant in the sandstones and siltstones of the middle part of the the Oswald West mudstones. Some of those identified by Addicott (1977, written communication) include the gastropods Perse cf. P. pittsburgensis, Perse cf. P. lincolnensis, and Neverita washingtonensis; the bivalves Nemocardium cf. N. lorenzanum, Nuculana cf. N. washingtonensis, Macoma cf. M. twinensis, and Macrocallista cathcartensis, and the shrimp Callianassa sp. (see Appendix IV for complete listing). Foraminifers from the middle part include Gyroidina orbicularis planata, Cibicides cf. C. elmaensis var. A, and Cassidulina cf. C. crassipunctata (Rau, 1977) (Appendix IV).

Faulting has precluded determination of the nature of the upper contact of the middle Oswald West mudstones but it is presumed to be gradational.

Upper. Exposures of the 500- to 800-foot thick upper part of the Oswald West mudstones are extensive in the southeastern part of the study area and are of limited extent in the southwestern part (Figure 6, Plate I). Mudstones predominate in the upper part. East of Young's River tuff interbeds are commonly observed, probably because exposures are extensive in this area. Thinly bedded, very fine-grained sandstones, and siltstones occur locally.

The mudstones are medium dark gray (N4) in fresh exposures and weather to a yellowish gray (5 Y 7/2). They are commonly structureless with blocky or conchoidal fracture. Wispy laminations formed by carbonaceous debris or silt-size detritus are present locally. These laminations and very thinly bedded white (N9) tuff layers define bedding. The mudstones are locally finely micaceous. The best exposures of these mudstones and interbedded tuffs occur along spurs 28 and 17 off the Palmer Road (sec. 12, T. 7 N., R. 9 W.).

Molluscan fossils in the upper part of the Oswald West mudstones, which were identified by Addicott (1977), include the gastropods *Turritella* cf. *T. blakeleyensis* and *T. hamiltonensis*, the bivalve *Solamen* cf. *S. snavelyi*, and the scaphopod *Dentalium* cf. *D. porterensis* (Appendix IV). Foraminifers identified by Rau (1977) include *Virgulina* sp., *Gyroidina* sp., *Anomalina californiensis*, *Pseudoglandulina inflata*, and *Nonion incisum kernensis* (Appendix IV). Silicified *Toredo* wood borings were identified by Chamberlain (1977).

Petrology

Seven samples of Oswald West lithologies were studied in thin section, including three sandstone samples which were point-counted (Appendix VI).

Very fine sand-size and coarse silt-size, angular, quartz and feldspar grains compose 10 to 50 percent of the mudstones. These grains are randomly distributed in a clay-rich matrix which shows weak to moderate aggregate extinction. X-ray diffraction analysis indicates that the matrix consists of hydroxy-interlayered montmorillonite and/or chlorite intergrades and minor amounts of chlorite, mica, and possibly kaolinite (Appendix VIII). Relatively weak diffraction peaks for most clays suggest poor crystallinity and/or the presence of amorphous material. Rare bubble wall glass shards, devitrifying to chalcedony and altering to clay minerals, are also present in the mudstones.

Tuff beds consist of an opaque very finely crystalline matrix composed of volcanic dust and amorphous clay-size alteration products. Subordinate silt-size detritus includes anhedral quartz grains, subhedral feldspars, muscovite, and glass shards.

Sandstones interbedded in the middle Oswald West mudstones classify as lithic, feldspathic, arkosic, and glauconitic wackes (Williams and others, 1954) (Figure 9 and Appendix VI). They are texturally and compositionally immature according to Folk (1954), suggesting relatively rapid erosion, deposition, and burial of these sandstones.

The mineralogy of the three interbedded sandstones studied in thin section is quite variable and an average sandstone composition is not truly representative of the entire suite. However, the

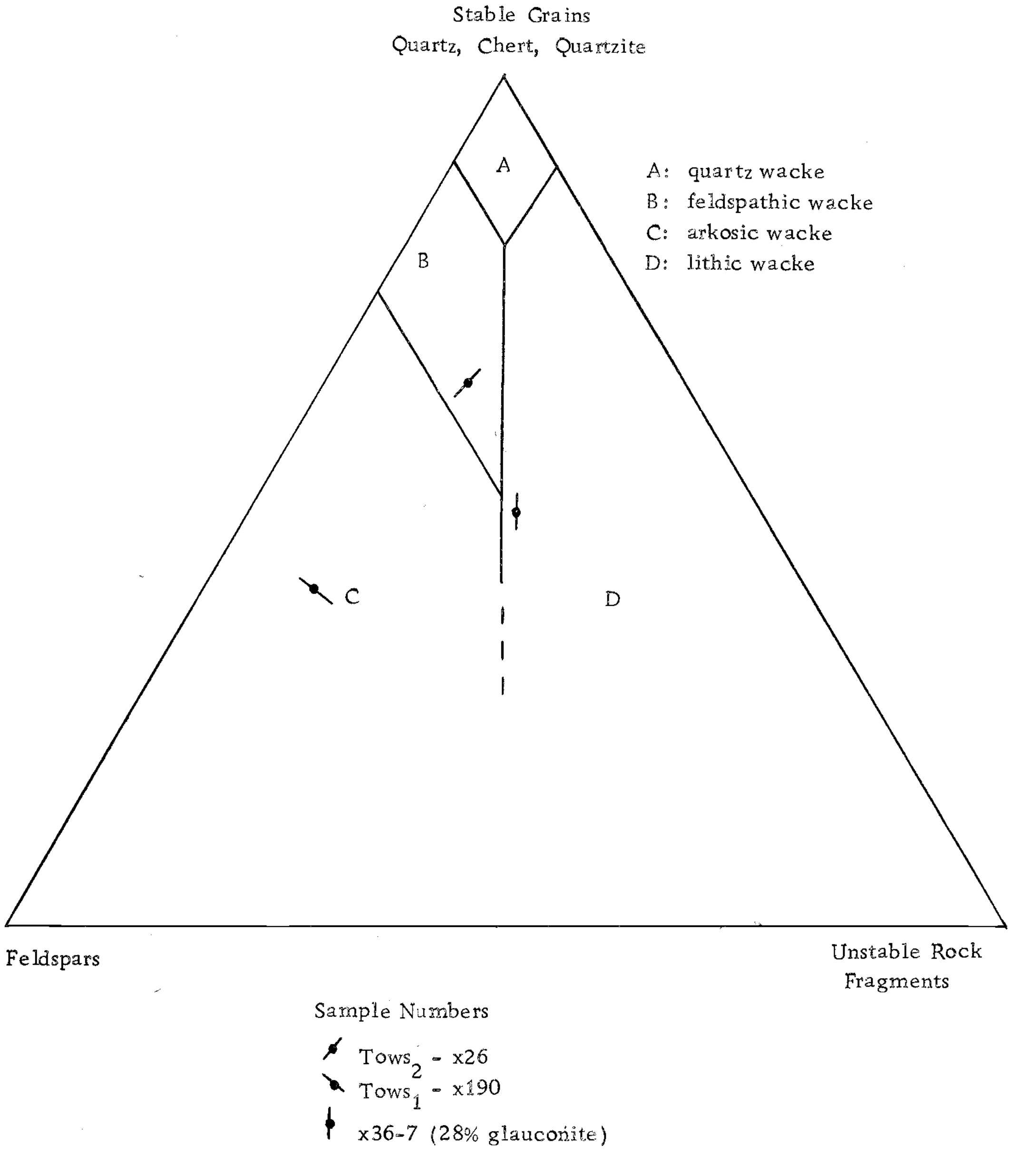


Figure 9. Classification of point-counted sandstones from the Oswald West mudstones (after Williams and others, 1954).

principal framework constituents of the sandstones studied are, in approximate order of decreasing abundance: glauconite (0-28%) and/or or quartz (16-22%), potassium feldspar (5-20%), plagioclase (2-5%), volcanic rock fragments (3-8%), micas (2-7%), opaques (1-10%), metamorphic rock fragments (1-2%), sedimentary rock fragments (1-2%), and heavy minerals (less than 1%) (Appendix VI).

The glauconite grains are well-rounded elliptical- to botryoidal-shaped bright green pellets. In many cases they appear to have formed by the glauconitization of the groundmass of mafic volcanic rock fragments, or biotite.

Monocrystalline unstrained quartz is the most common quartz type; strained monocrystalline quartz is present in minor amounts. Polycrystalline quartz types, including polygonized quartz and meta-quartzite, are rare (<2%).

Orthoclase is the most abundant potassium feldspar; sanidine is very rare. Plagioclase feldspars include oligoclase (An_{25-30}), andesine (An_{30-49}), and rare labradorite (An_{55}). The average composition is An_{34} (andesine). Plagioclase is commonly more altered and seriticized than orthoclase and is typically albite twinned.

Volcanic rock fragments are common subordinate constituents of all sandstones studied. Basalt and/or andesite clasts are predominant, or are equal in abundance to mafic (?) volcanic fragments composed primarily of altered glass. The formerly commonly display intersertal and hyalopilitic textures; pilotaxitic textures are less commonly observed. Plagioclase microphenocrysts and groundmass microlites are composed of labradorite (An_{50}) and andesine (An_{30-50}). Other groundmass constituents include opaque iron-oxides, tachylyte glass, and greenish-yellow clay mineral alteration products, probably chlorophaeite and/or nontronite. The glassy mafic (?) volcanic fragments lack plagioclase microlites and are extensively altered to clay minerals. A basaltic composition is inferred for these fragments because of the abundance of opaque iron-oxides in the groundmass of the clasts.

Phyllitic and schistose rock fragments are easily recognized by their distinctive foliation. They are composed of muscovite, quartz, and rarely graphite. Sedimentary rock fragments are predominantly very fine-grained sandstone or siltstone; they consist of angular quartz and feldspar framework grains with interstitial clay matrix. Mudstone clasts are rare.

Bubble wall glass shards are present in some sandstones. It is probable that most original tuffaceous material (shards and volcanic dust) has devitrified and altered to clay minerals (matrix). Remnants of glass shards suggest that the tuffaceous component of the sandstones is greater than is apparent in thin section.

Interstices between framework-supported grains are commonly filled with matrix (23-33%). Porosity does not exceed five percent.

The matrix (less than 30 microns) consists of a mixture of finely comminuted micas, silt-size quartz and feldspar, and green to yellow-brown clays, probably nontronite, celadonite, and/or chlorophaeite. The mica and quartzo-feldspathic portion of the matrix may be detrital, but much of the clay appears to have formed by diagenetic alteration of basaltic rock fragments and glass shards. The indistinct grain boundaries of many rock fragments, and the presence of plagioclase microlites "floating" in matrix clays, suggests that in situ decomposition of volcanic rock fragments has taken place. This post-depositional alteration of unstable detritus to form matrix is a common occurrence in volcaniclastic sandstones (Cummins, 1962; Whetten and Hawkins, 1969). Metamorphic and sedimentary rock fragments show little evidence of decomposition.

$Tows_1$ and $Tows_2$, the two thick sandstone bodies in the middle part of the Oswald West mudstones, are feldspathic and arkosic wackes, respectively (Figure 10). Unlike other sandstones in the Oswald West mudstones, glauconite is either minor or is absent.

The heavy mineral assemblages of the sandstones in the Oswald West mudstones are dominated by red-brown and green biotite, and opaques (Appendix V). Otherwise green hornblende is most abundant with pyroxenes and epidote minerals being major secondary constituents. Minor amounts of garnet, staurolite, rutile, sphene, tourmaline, zircon, monazite, and apatite are present.

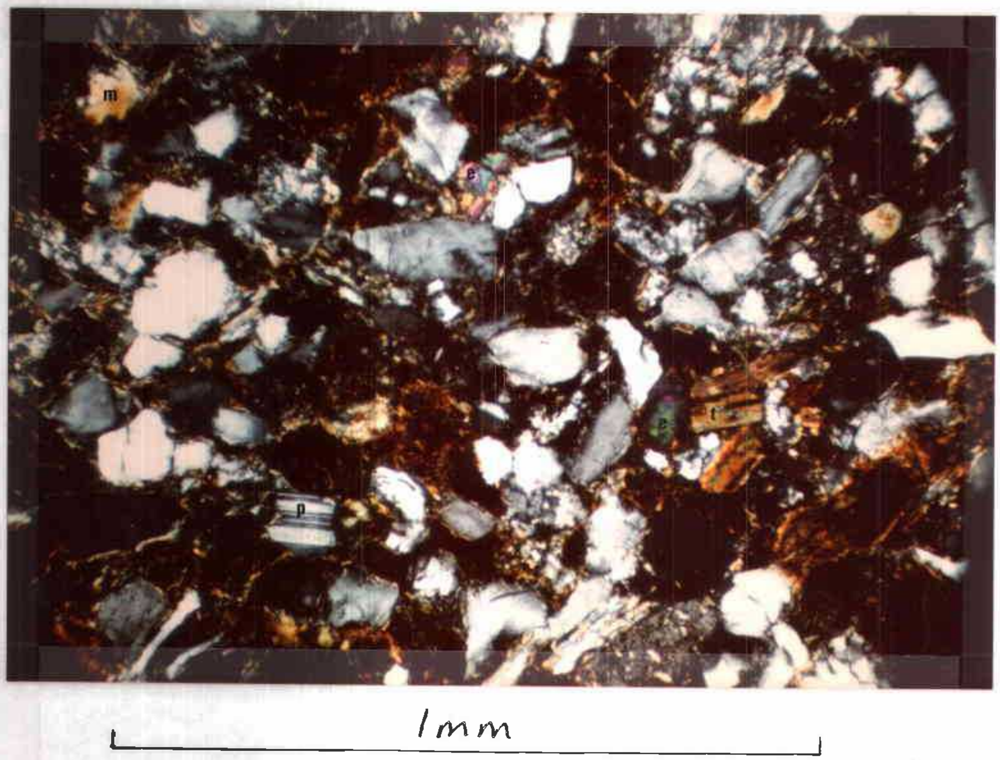


Figure 10. Photomicrograph of the sandstone, $Tows_1$, in the middle part of the Oswald West mudstones. Moderately sorted framework grains consist primarily of angular quartz and orthoclase. Plagioclase (p), epidote (e), tourmaline (t), and muscovite (m) are also present. Note biotite altering to greenish matrix clays.

Detrital grains in the sandstones are angular to subrounded (0.15-0.40) as determined by visual comparison with the roundness scale of Powers (1953). Glauconite is an exception in being very well-rounded. High sphericity characterizes detrital grains which had original spherical shape or lack cleavage or foliation, such as quartz, glauconite, and volcanic rock fragments. Metamorphic rock fragments and the feldspars have low sphericity.

Contact Relations

The lower contact of the Oswald West mudstones is not defined in this study because of the lack of any distinctive mappable litho-stratigraphic break at the base of the exposed section. However, in the subsurface, late Eocene strata similar to the Oswald West mud-stones concordantly overlie the Goble or Tillamook Volcanics at a depth of 5,000 feet (Socal #1 Hoaglund well, Plate I; Newton, 1969).

The Oswald West mudstones are overlain by the Astoria Formation. The Big Creek sandstone member of the Astoria Formation overlies with slight angular unconformity (?) the Oswald West mud-stones in the southeastern part of the study area (Figure 5 and Plate I). Fossil evidence suggests a middle early Miocene age (Pillarian Stage) for the lowermost Big Creek sandstones (Addicott, 1977) and a probable late Oligocene to early Miocene age (Zemorrian - possibly Saucesian) for the upper Oswald West mudstones (Rau, 1977). Since the Pillarian and Zermorrian Stages do not overlap (Figure 5), an unconformity may be present.

Angular unconformity is suggested by the apparent disparity in stratal dips between the two units. The dip of the Big Creek sandstones is an average of ten degrees steeper to the north than the Oswald West mudstones in the eastern part of the study area. This is suggestive of deposition of Big Creek sandstones over gently southward-dipping Oswald West strata.

The contact between the two units is not exposed, but the abrupt lithologic change between the two can be observed along the Palmer Road (N$\frac{1}{2}$, sec. 7 and NE$\frac{1}{4}$, sec. 8, T. 7 N., R. 8 W.) which crosses the contact several times.

To the west of Young's River the upper Oswald West mudstones are overlain unconformably by the Tucker Creek sandstone member of the Astoria Formation (Figure 5) (see Contact Relations of the Tucker Creek sandstone member).

Age and Correlation

A late Eocene to early Miocene age is assigned to the Oswald West mudstones based on molluscan and foraminiferal evidence, and on stratigraphic relations. Molluscan fauna near the base of the sandstone-rich middle part of the Oswald West mudstones are assigned a late Eocene to early Oligocene age (Galvinian and lower

Matlockian Stages) by Addicott (1977) (fossil samples: xf109, xf122, xf132, xf191, and xf190; Appendix IV). Considering that several hundred feet of lower Oswald West mudstones lie stratigraphically below these fossil localities, the base of the exposed Oswald West mudstone section is probably late Eocene in age.

Similar late Eocene ages have been reported for lower Oswald West strata by Penoyer (1977) and Neel (1976) in mapping to the south. In keeping with recent usage then, the stratigraphic definition of the Oswald West mudstones is expanded in this study so as to include strata older than that at the type section described by Cressy (1974).

The age of the uppermost Oswald West mudstones is late Oligocene to earliest Miocene. Foraminifera from the upper part (xf256, xf70-8) in the southeast part of the study area are referred to the Zemorrian stage by Rau (1977), indicating a late Oligocene to earliest Miocene age. To the west, molluscan fossils in the upper Oswald West mudstones underlying the Tucker Creek sandstone member (xf154c) are assigned a late Oligocene age (Matlockian Stage) by Addicott (1977). A similar age is assigned to Foraminifera from the same locale (xf154c) (Rau, 1977).

The tripartite stratigraphy established for the Oswald West mudstones in the study area correlates lithologically and chronologically with three-fold division of the unit recognized by Penoyer (1977) to the southeast. Particularly significant is the dual recognition of a sandstone-rich middle part. The upper and lower divisions of the unit defined by Tolson (1976) immediately to the south of the study area correlate best with the upper part of the Oswald West mudstones recognized in the study area.

Based on continuous mapping, and similar stratigraphic position and lithology, the upper Oswald West mudstones recognized in the study area are correlated with upper Oswald West mudstones mapped by Coryell (1978) immediately to the east.

Continuous mapping from the Oswald West type section (described by Cressy, 1974) northward to the study area (Smith, 1975; Neel, 1976; Tolson, 1976) indicates that the Oswald West mudstones in the study area are at least in part correlative with the lithologies exposed at the type section. Similarity in terms of lithology (predominantly bioturbated mudstone), age (middle Oligocene to early Miocene), and stratigraphic position (directly underlying the Astoria Formation), suggest that the upper Oswald West mudstones in the study area correlate best with the Oswald West type section. The rocks at the type section however tend to be better indurated.

The Oswald West mudstones in the study area may be correlative with all or part of the Lincoln Creek Formation mapped by Wolfe and McKee (1968, 1972) 14 miles northeast of the study area in the Gray's River area of Washington. They described a thick, late Eocene to late Oligocene sequence of tuffaceous siltstones with two zones of basaltic and glauconitic sandstone, one at the base of the formation. Either zone may be correlative with the glauconite- and sandstone-rich middle part of the Oswald West mudstones in the study area.

Formations equivalent in age to part of the Oswald West mudstones in the study area include the Scappoose, Pittsburg Bluff, and Keasey Formations of the northeastern flank of the Oregon Coast Range, and the lower part of the Nye Mudstone, the Yaquina Formation, the Alsea Formation, and the Nestucca Formation of the Newport Embayment (Figure 3).

Depositional Environment

The mudstones, siltstones, and sandstones of the Oswald West unit were deposited in an open-marine, low-energy, middle shelf to middle continental slope environment. This determination is based on fossil paleoecology, textural and mineralogical aspects of the various lithologies, and sedimentary structures.

Fossil evidence indicates that the Oswald West mudstones were deposited in water depths ranging from middle bathyal to middle sublittoral (300 to 2,400 feet). All the molluscan fossils in the middle part (Appendix IV) characterize a moderate to deep sublittoral depth facies (Addicott, 1977). In modern marine environments these depths occur in middle to outermost shelf areas.

Foraminifera and molluscan fossils from the upper part (Appendix IV) characterize a somewhat deeper depth facies, outer sublittoral to middle bathyal (Rau, 1977 and Addicott, 1977, respectively). The lithologically similar lower part of the Oswald West mudstones was probably deposited at comparable depths, though supportive fossil evidence was not obtained. These depths occur in modern outer continental shelf and middle slope areas.

The Oswald West mudstone lithologies are characterized by 1) a predominance of mudstones and muddy siltstones; 2) a lack of primary sedimentary structures including stratification, 3) soft-sediment deformational features, 4) extensive bioturbation, 5) very fine-grained and poorly sorted interbedded sandstones and siltstones, 6) randomly oriented unbroken molluscan fossils, and 7) the common occurrence of glauconite. All these features, in combination, are suggestive of deposition in outer shelf and slope environments.

Predominant silt and clay deposition suggests diminished current energy and turbulence in a low-energy environment where sediment transport is restricted to the suspension mode. Such an environment prevails today on the outer Oregon continental shelf where muds and silts are deposited by low-density turbid currents (Kulm and others, 1975).

Extensive bioturbation and concomitant destruction of primary sedimentary structures, including stratification, is common in low-energy shelf and slope environments. Bottom currents are commonly too weak to counteract the homogenization of sediments induced by extensive bioturbation. These processes and effects have been described by Reineck and Singh (1971) and Kulm and others (1975) in modern outer shelf environments in the Gulf of Gaeta, Italy and off the Oregon coast, respectively. They have also been recognized by Stanley (1975) in ancient continental slope deposits of the Gres d'Annot Formation of the Maritime Alps.

Soft-sediment deformation induced by gravity slumping or density contrasts across stratal interfaces is common in slope environments (Stanley, 1972) and in the Oswald West mudstones.

Glauconite is a marine authigenic mineral abundant in the Oswald West mudstones. It forms at depths ranging from 60 to 6,000 feet in areas of slow sedimentation where weakly reducing conditions exist (Porrenga, 1967; Pettijohn, 1975). Today it is abundant on the outer Oregon continental shelf and slope (Kulm and others, 1975).

All the evidence points to a middle shelf to middle slope depositional environment for the Oswald West mudstones as a whole, but significant variations in the depth of deposition between upper, lower, and middle parts seem likely.

The upper and lower parts of the Oswald West mudstones, dominated by bioturbated mudstones and lacking abundant sandstones, siltstones, and glauconitic strata, may be middle to upper slope deposits, as is suggested by foraminiferal evidence from the upper part (Rau, 1977).

The sandstone- and siltstone-rich middle part may be a somewhat shallower marine deposit representing temporary shoaling of the marine depositional basin in early Oligocene time, with subsequent influx of coarser grained detritus. This would approximately coincide with a short-termed eustatic sea level fall recognized by Vail and others (1976).

The extensive bioturbation and high textural immaturity of most sandstones and siltstones in the middle Oswald West mudstones indicate that there was little or no reworking following deposition. The sandstones and siltstones probably represent temporary influxes of coarser-grained detritus into a mud- and fine silt-dominated low energy middle shelf environment, as is suggested by molluscan fossil paleoecology (see above). This type of sedimentation is typical of axial prodelta-slope environments where sand and silt are periodically flushed into mud-dominated prodelta areas from shallower delta environments during floods (Fisher, 1965; Allen, 1965). Alternatively, the thin sandstone and siltstone interbeds may be storm-related middle shelf deposits which originated in a non-deltaic strandline environment. Tractive transport of strandline sands to outer shelf areas during large storms is reported by Reineck and Singh (1975).

The thick sandstones, $Tows_1$ and $Tows_2$, in the middle Oswald West mudstones, may represent extremes of basin shallowing. The faint parallel laminations, moderate sorting, thickness, and fine grain size of $Tows_1$ are features similar to those found in sands of the lower shoreface zone of modern beaches (Reineck and Singh, 1973) and on the modern inner continental shelf off Oregon (Kulm and others, 1975). The lack of argillaceous interbeds in both indicates that current energy in the depositional environment was fairly high.

Astoria Formation

The early to middle Miocene Astoria Formation differs from the older Oswald West mudstones in being composed of distinct mappable intertonguing sandstone and mudstone lithosomes. The lower formational contact is defined in the study area by the bases of the Tucker Creek and Big Creek sandstone members (Figure 5 and Plate I). The overlying Pipeline and Silver Point members occur in the upper half of the formation in the study area (Figure 5). The absence of overlying bedrock strata precludes definition of an upper contact for the formation in the thesis area. However, extrusive basalts (Depoe Bay) correlative to basalt intrusions in the study area define the upper contact of the Astoria Formation to the east of the study area (Coryell, 1977, personal communication) and to the south (Penoyer, 1977; Tolson, 1976; Neel, 1976; Smith, 1975; and Cressy, 1974).

The Astoria Formation has the most extensive outcrop area of any unit in the study area (Figure 11). The mudstones and siltstones of the formation (upper Silver Point and Pipeline (Tpm) members) tend to form low hills and valleys while the more resistant sandstones (Big Creek, Tucker Creek, and Pipeline (Tps_2) members) form topographic highs (up to 600 feet) with fairly steep slopes (Plate I). The montmorillonite-rich mudstones (Appendix VIII) in the formation are slump-prone, and landslide topography is typical of areas which they underlie.

A total thickness between 3,500 and 4,500 feet is estimated for the formation based on regional dips and outcrop distribution in the thesis area.

Tucker Creek Sandstone Member

The early Miocene Tucker Creek sandstone member crops out only to the west of Young's River in a number of small discontinuous exposures (Figure 12 and Plate I). The unit is thought to be a lateral facies of the Big Creek sandstone member which crops out in the same stratigraphic position to the east of Young's River (Figure 5).

The lack of correlative exposures along the bedding strike of individual outcrops is probably due to offsets perpendicular to strike caused by faulting. Restoration to a pre-faulting state would probably

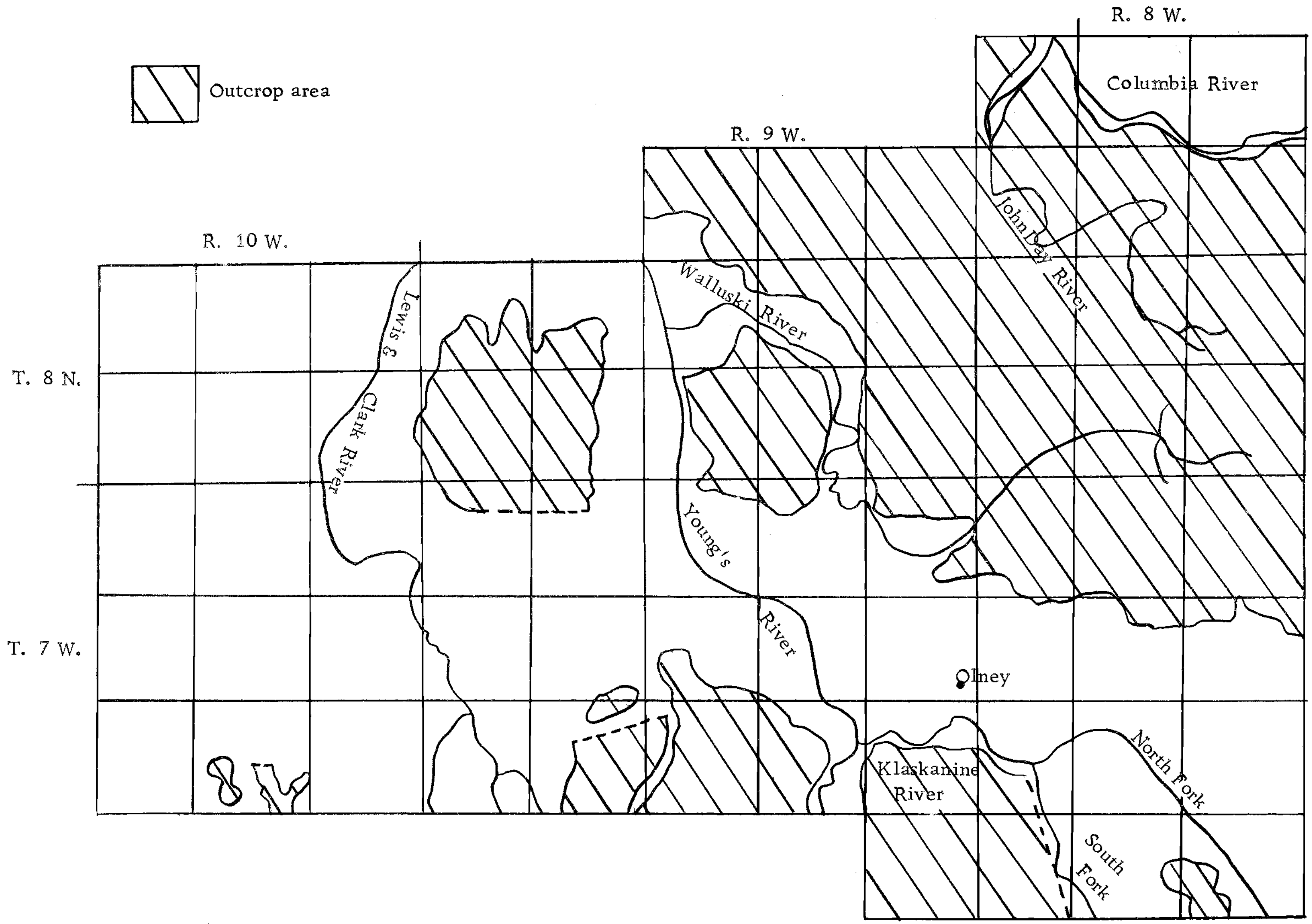


Figure 11. Outcrop distribution of the Astoria Formation.

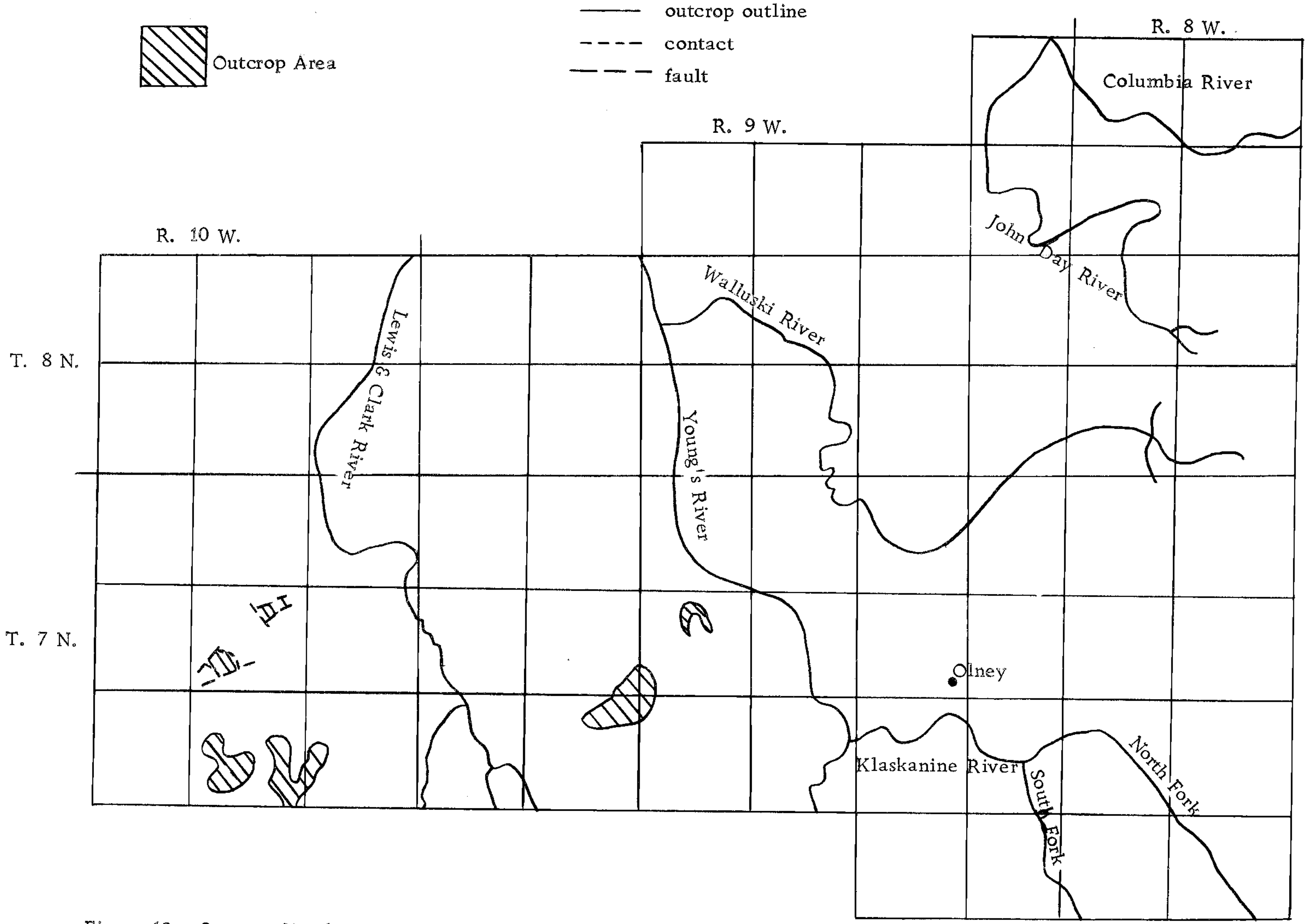


Figure 12. Outcrop distribution of the Tucker Creek sandstone.

show most exposures to line up along an east-west strike.

The well-indurated and locally calcite-cemented sandstones and siltstones of the unit tend to form topographic highs with steep slopes (Plate I). Unit thickness varies between 100 and 150 feet.

Nomenclature. Tucker Creek sandstone member is proposed as an informal name for a lithologically distinct sandstone and siltstone body which crops out in the southwestern part of the study area. The unit derives its name from a stream in close proximity to the designated type section of the unit (Plate I). The type section is located at the north end of logging spur 14L, NE$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 17, T. 7 N., R. 9 W. This unit is of limited areal extent and probably should not be given formal member status.

Lithology. The Tucker Creek sandstone member consists of thick, structureless, locally thin-bedded, bioturbated, medium- to very fine-grained, micaceous, arkosic sandstones and subordinate coarse-grained siltstones. Minor silty mudstones and glauconitic sandstones occur locally at the top of the unit (Reference Section A-B, Appendix I).

The sandstones and siltstones commonly weather to a yellowish gray (5 Y 7/2) or grayish yellow (5 Y 8/4). Rare fresh exposures are bluish gray (5 B 5/1). In outcrop, these lithologies are well-indurated and have a thick structureless appearance (Figure 13). Roadcut exposures typically have a flanking talus accumulation of fine sand and

Figure 13. Structureless, medium-grained, lowermost Tucker Creek sandstone with typical blocky fracture and yellow-brown color. Contact with underlying Oswald West mudstones above hammer. (spur 26, sec. 14, T. 7 N., R. 10 W.).

Figure 14. Samples of bioturbated, very fine-grained, well-indurated, sandstone from the middle part of the Tucker Creek sandstones. Thin vertical Trichichnus burrows suggest high-energy, shallow-marine environment (Chamberlain, 1977).

large sandstone or siltstone blocks.

The sandstones and siltstones which compose all but the uppermost Tucker Creek member are designated as subunit 1. The type section for this subunit occurs in a roadcut exposure at the north end of logging spur 14L (see above; Plate I). Subunit I is approxiamtely 80 feet thick at the type section and thins to the west, suggesting a wedge-shaped geometry for the unit.

A one foot thick highly fossiliferous "pebbly" mudstone occurs at the base of the Tucker Creek member at the type section. Silty mudstone composes more than 50 percent of this bed, but scattered pebble-size, greenish-gray mudstone ripups, coarse-grained sand, and molluscan fossils are also abundant. Overlying and in sharp contact with this basal horizon is a 25-foot thickness of fine-grained ($\emptyset_{50}$=2.81), friable, structureless, arkosic sandstone. These sandstones grade abruptly upward into well-indurated, structureless, very fine-grained sandstones and calcite-cemented coarse-grained siltstones which are approximately 55 feet thick. Vertical _Trichichnus_ burrows occur in this latter stratigraphic interval (Figure 14, see below). All lithologies overlying subunit 1 at the type section have been removed by present-day erosion (Plate I). However, in other areas subunit 1 is overlain by the finer grained lithologies of subunit 2 (see below). The pebbly mudstone at the base of the Tucker Creek member at the type locality is in sharp contact with the underlying upper Oswald West mudstones.

In some outcrops of subunit 1, the basal pebbly mudstone is absent, and the basal sandstone interval is medium-grained (ϕ_{50}= 1.75 phi) or very fine-grained.

Stratification in subunit 1 is poorly defined by the decreasing grain size upward in the unit, by rare slabby splitting parallel to bedding (Figure 15), and by the contact with the underlying Oswald West mudstones. However, in thin section, stratification is defined by a parallelism of micas and other elongate detrital grains (feldspars), and by laminae formed by varying concentrations of finely comminuted carbonaceous matter. This planar fabric is commonly disrupted by burrows (see below) which may account for the common absence of megascopically visible primary sedimentary structures in the subunit.

Distinctive one millimeter wide and up to eight centimeters long, brownish-gray, closely spaced, vertical Trichichnus burrows in the unit were identified by Chamberlain (1977) (Figure 14). They occur in the upper part of the type section of subunit 1 in a 30-foot thick interval (see above). These burrows may occur in stratigraphically equivalent intervals elsewhere, but limited exposures prevent determination of this. In thin section the burrow traces are loci of carbonaceous matter concentration and sediment homogenization. Subparallel elongate detrital grains are present around the burrow

Figure 15. Contact between fine-grained, fossiliferous Tucker Creek sandstone (left) and underlying Oswald West mudstones (right). Sandstone shows platey splitting and typical block fracture. Contact fairly sharp. (spur M, sec. 11, T. 7 N., R. 10 W.)

traces. Burrowing organisms probably destroyed enough primary fabric to cause the sandstones to appear structureless in outcrop. This bioturbation in the unit is probably more extensive than is indicated by the localized preservation of these burrows.

The sandstones in subunit 1 classify as arkosic wackes (Williams and others, 1954; Figure 30). Large muscovite flakes up to three millimeters in diameter are common in the basal sandstones. Dark disseminated carbonaceous matter imparts a salt-and-pepper appearance to some of the sandstones. Up to 0.75 percent live hydrocarbons are also present (Appendix X).

Fossils in subunit 1 occur only in the basal pebbly mudstone. Fossils from this zone at the type locality include the gastropods Turritella n. sp. ? (new species), Priscofusus medialis, the bivalves Spisula sp. and Megayoldia sp., and fish vertebrae (fossil localities: xf154a, xf154b; Appendix IV). Fossils from a similar basal bed exposed along spur M (SE$\frac{1}{4}$, sec. 11, T. 7 N., R. 10 W.) include the gastropods Priscofusus sp., and ?Acteon sp., and the bivalves Litorhadia astoriana, Nuculana calinski, and Nemocardium sp. (xf18) (all fossil identifications by Addicott, 1977).

To the west of the Lewis and Clark River, the Tucker Creek sandstone member fines upward from subunit 1 to several tens of feet of silty mudstone and glauconitic sandstone which are designated as subunit 2. Subunit 2 pinches out east of the Lewis and Clark River toward the type section. Interbedded with the mudstones in subunit 2 are three, very thickly bedded, grayish-olive-green (5 GY 5/2), partially calcite-cemented, fine- to medium-grained glauconitic sandstones (see Appendix I, Measured Section A-B). The bivalve Spisula albaria was recovered from these glauconitic strata (xf82) (Addicott, 1977).

Contact Relations. The Tucker Creek sandstone member disconformably overlies the Oswald West mudstones and is conformably overlain by the lower Silver Point mudstones (Figure 5).

A disconformity between the Tucker Creek sandstones and the Oswald West mudstones is suggested by fossil data and supported by lithologic evidence. In terms of Armentrout's (1975) molluscan zonules, the molluscan fossils in the basal Tucker Creek sandstones at the type section are referred to the Liracassis petrosa Zone (early-middle Miocene) based on the occurrence of the gastropod Priscofusus medialis in the unit (xf154b). The molluscan assemblage immediately below the contact, in the Oswald West mudstones (xf154c), contains the gastropod Turritella cf. T. blakelevensis which may be referrable to the Echinophoria rex Zone (Oligocene) (Armentrout, 1977, personal communication). The absence of fossils referrable to the intervening Echinophoria apta Zone could possibly indicate an unconformity between the two units, but the evidence is inconclusive (Armentrout, 1977).

The abrupt lithologic change from mudstones of the upper Oswald West to sandstones of the overlying Tucker Creek member, at the type section and most other localities (Figures 14 and 15), is suggestive of a rapid change in depositional environment. Molluscan fossils and Foraminifera in the underlying mudstones (xf154c) characterize a middle sublittoral to upper bathyal depth facies (Addicott, 1977 and Rau, 1977; respectively). Trichichnus burrows in the overlying sandstone are known only to occur in high-energy shallow-marine deposits (Chamberlain, 1977). The certain rapid change in depositional environment, the possible age difference, and the obvious rapid change in lithology all suggest that an erosional unconformity or hiatus occurs between the two units. The lack of angular discordance of stratal attitudes between the two units suggests that the contact is disconformable.

The Tucker Creek sandstones are conformably overlain by the lower Silver Point member (see Contact Relations of the Silver Point member).

Age and Correlation. On the basis of fossil evidence and stratigraphic relationships, an early Miocene (Pillarian Stage) age is assigned to the Tucker Creek sandstones (Figure 5). Molluscan fossils collected at the base of the unit (xf18) are middle early to middle Miocene in age (Pillarian-Newportian Stages) (Addicott, 1977). Molluscan fossils collected by Cooper (1977), apparently at the base of the unit (xf154b), are suggestive of an early to middle Miocene age based on the occurrence of the gastropod Priscofusus medialia (Addicott, 1976a; Armentrout, 1975).

The Tucker Creek member is overlain by the lower Silver Point mudstones (Figure 5). Fossils from the latter were not found in the study area but lower Silver Point strata mapped one mile to the south by Tolson (1976) are assigned an early Miocene age or older based on the occurrence of Acila gettysburgensis (M6426) (Addicott, 1976b). This bivalve was collected by Cooper (1978). Therefore, the Tucker Creek sandstone member is considered to be early Miocene in age because of the occurrence of early to middle Miocene fauna at its base, and early Miocene molluscan fauna in overlying strata (Silver Point mudstones).

The Tucker Creek sandstone member is probably correlative to and interfingers to the east with the Big Creek sandstone member of the Astoria Formation (Figure 5). The two units occupy a similar stratigraphic position in overlying with probable unconformity late Oligocene upper Oswald West strata. The westernmost exposure of Big Creek sandstone in the study area (Plate I) is middle early Miocene in age (Pillarian Stage) (xf243) which is also the age of the Tucker Creek sandstones. Both units are lithologically similar in being composed of basal, thick, fine-grained, shallow-marine, arkosic sandstones which fine upward to deeper marine siltstones, mudstones, and glauconitic sandstones. The Big Creek sandstones differ in being visibly laminated, thicker, and more continuous in outcrop.

Based on gross lithologic similarity, position in sequence, and age, the Tucker Creek sandstones are correlated with the lower part of the early to middle Miocene Angora Peak sandstone member of the Astoria Formation, mapped to the south of the study area by Cressy (1974), Smith (1975) and Tolson (1976). Both correlated stratigraphic intervals consist of sandstones of near-strandline origin, are underlain by deeper water Oswald West mudstones, and are conformably overlain by lower Silver Point mudstones. The occurrence of early Miocene (Pillarian Stage) molluscan fauna in the lower Angora Peak sandstones (Cressy, 1974; Tolson, 1976) also supports this correlation. The Tucker Creek sandstones may be a lateral strandline facies of the Angora Peak sandstones, the latter being interpreted to be fluvial-deltaic deposits (Cressy, 1974; Smith, 1975).

Depositional Environment. Subunit 1 of the Tucker Creek sandstones (see Lithology section) was deposited in a shallow-marine, high-energy, nearshore environment. The overlying subunit 2 was deposited in a deeper marine, middle to outer continental shelf environment, reflecting transgressive deepening of the marine depositional basin in the study area in early Astoria time (see Geologic History section). Environmental interpretations are based on fossil paleoecology, collectively diagnostic sedimentary structures, and vertical stratigraphic succession.

The presence of the trace fossil Trichichnus in subunit 1 indicates that deposition occurred in a high-energy, shallow-water environment (Chamberlain, 1977). Chamberlain suggests a beach, tidal flat, or fluvial origin for the sandstones. Other evidence is most compatible with an inner shelf or beach depositional model.

The lack of any argillaceous interbeds, dominance of sand-size detritus, the occurrence of parallel laminations (in thin section) as the only primary current-formed sedimentary structure, extensive bioturbation, and lack of channelization are features characterizing subunit 1 which are suggestive of nearshore, marine depositional environment. Specifically, they are most characteristic of the sediments of the upper offshore zone of Brown and Reineck (1972), which is equivalent to the lower shoreface zone of Reineck and Singh (1975), and the lower surf zone, planar facies of Clifton and others (1971). These zones occur from mean low tide level to several tens of feet of water depth. The sands in these zones are typically fine- to very fine-grained and highly bioturbated. Primary current-formed sedimentary structures are poorly preserved because of burrowing. Where preserved, parallel lamination is predominant; cross-bedding is rare (Reneck and Singh, 1973; Fisher and Brown, 1972). Argillaceous interbeds are uncommon. Jurassic shoreface sandstones of

Britain, (Davies, 1969) display similar sedimentary features and are only locally fossiliferous, similar to the Tucker Creek sandstones.

Sedimentation in the zones listed above occurs primarily during storms when suspended fine sand is transported from surf zones to nearshore areas. Suspended sand is deposited in even parallel laminations and is subsequently bioturbated (Reineck and Singh, 1973).

The siltstones and mudstones interbedded with glauconitic sandstones at the top of the Tucker Creek member (subunit 2) probably are deeper water, middle to outer shelf deposits. The bivalve Spisula albaria, collected from one of the glauconitic sandstone beds (xf82), is suggestive of middle sublittoral depositional depths (Addicott, 1977). Glauconite forms today at depths ranging from 60 to 6,000 feet (Pettijohn, 1975) and is presently abundant on the outer Oregon continental shelf (Kulm and others, 1975).

The occurrence of successively deeper water lithologies (subunit 2) up-section in the Tucker Creek member is suggestive of a transgressive depositional model for the unit as a whole. The regression preceding the transgression is represented by the disconformable contact between the shallow-marine Tucker Creek sandstones and underlying deep-marine Oswald West mudstones. The locally developed basal pebbly mudstone in the Tucker Creek sandstone member is comparable to basal Holocene transgressive strandline deposits (Swift, 1976).

Big Creek Sandstone Member

The early to middle Miocene Big Creek sandstone member crops out along an east-west-trending ridge in the east-central part of the study area (Figure 16). An additional small exposure also occurs in the southeasternmost corner of the study area (Plate I). The Big Creek sandstones tend to hold up ridges and knobs because of the presence of resistant sandstones in the lower part of the unit (Plate I).

Unit thickness ranges from approximately 1,200 feet at the eastern boundary of the study area to about 500 feet in the westernmost exposures of the unit. Thickness was calculated trigonometrically using outcrop width and average dip.

Lithology. The Big Creek sandstone member is composed of structureless to laminated, locally trough cross-bedded, fine- to very fine-grained, micaceous, carbonaceous, locally fossiliferous sandstones, and subordinate siltstones and silty mudstones. The sandstones are bluish gray (5 B 5/1) in fresh exposures but commonly weather to iron-oxide-stained yellowish gray (5 Y 7/2) and greenish gray (5 GY 6/1) (Figures 17 and 19). The finer-grained lithologies tend to be light olive gray (5 Y 6/1) and yellowish gray (5 Y 7/2 (Figure 18). Fine sand, silt, and mudstone chips accumulate at the base of most outcrops.

The vertical succession of lithologies observed in the Big Creek sandstone section begins with a 200- to 400-foot thick basal sandstone

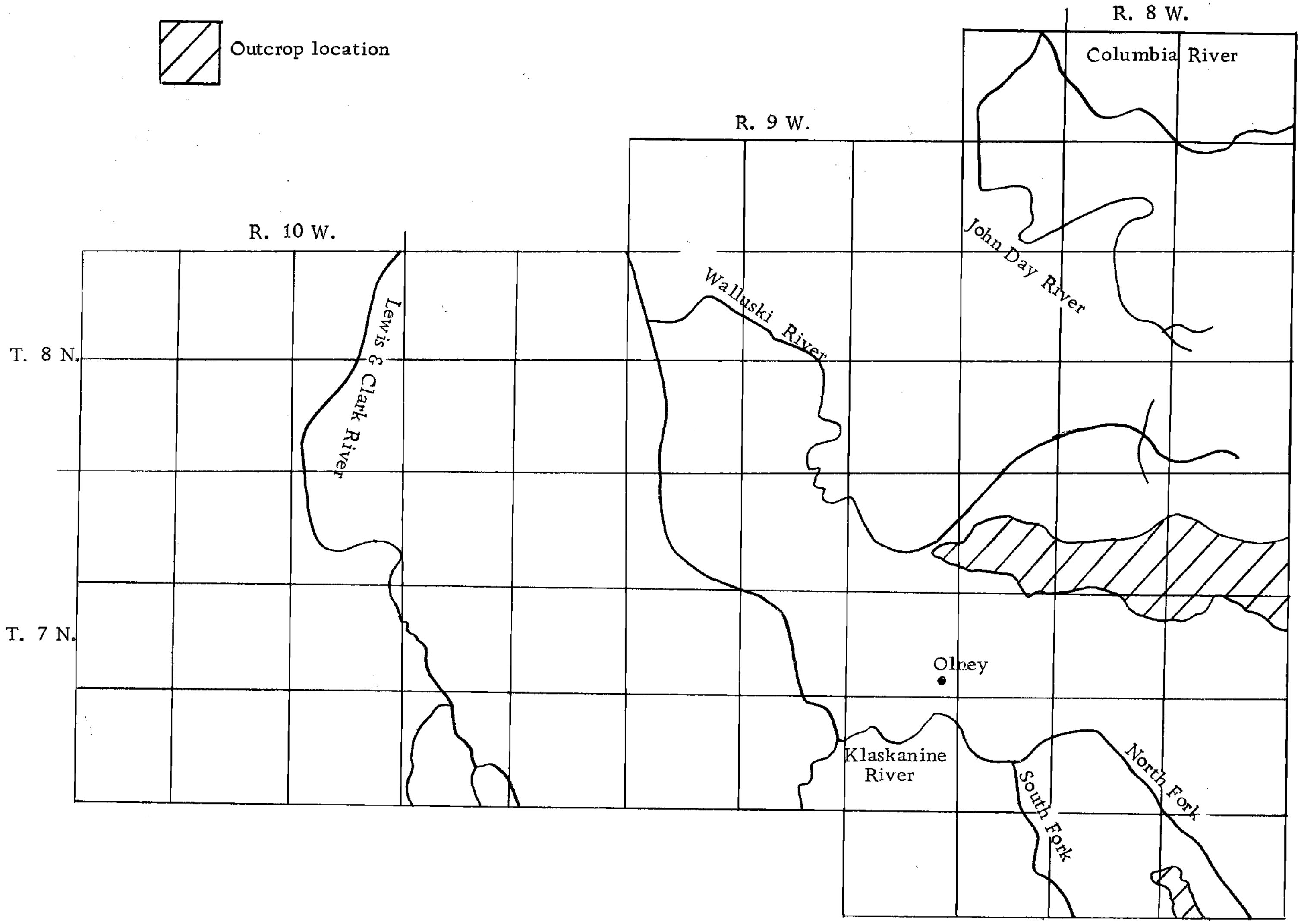


Figure 16. Outcrop distribution of the Big Creek sandstones.

Figure 17. Fine-grained sandstones of the lower Big Creek member. Note carbonaceous layer immediately below hammer, iron-oxide staining, and platey exfoliation parallel to outcrop face. (Fisher Road, sec. 8, T. 7 N., R. 8 W.).

Figure 18. Siltstones and silty mudstones in middle part of the Big Creek member. Dark layer is fossil hash bed. Hammer for scale. (spur 28, sec. 8, T. 7 N., R. 8 W.)

Figure 19. Friable, very fine-grained sandstone in the upper part of the Big Creek member. Faint parallel laminations present but not visible. Note iron-oxide staining and sandy talus. (spur 28, sec. 26, T. 7 N., R. 8 W.)

(lower part) which fines upward into a 150- to 250-foot thick siltstone and muddy siltstone interval (middle part). The upper part consists of 150 to 350 feet of muddy siltstones and interfingering discontinuous sandstones. Glauconitic sandstone occurs at the top of the unit. A small thickness of muddy siltstone lies between this glauconitic sandstone and the underlying upper sandstone.

The sandstones in the upper and lower parts of the unit are similar in being highly micaceous, locally parallel laminated but commonly structureless, thinly to massively bedded, fine- to very fine-grained ($\emptyset_{50}$=2.68-3.56 phi; M_z=2.73-3.64 phi), and moderately sorted (s_1=0.78-0.97 phi). Rare flaggy splitting occurs along bedding planes. The lower sandstones differ in being better indurated, fossiliferous, locally trough cross-bedded, more carbonaceous, and in bearing carbonized wood fragments. Rare discontinuous muddy siltstone lenses are also present. Individual sets of trough cross-strata are one to three feet wide, less than one foot thick, and cross-truncate underlying foreset beds. Individual foreset laminae are distinguished by varying concentrations of dark heavy minerals and carbonaceous debris. Overturned tops of foreset laminae also occur in the lower sandstones. This structure may be produced by "drag of strong sediment-laden currents moving across the top of a foreset lamina" (Reineck and Singh, 1973, p. 86). The sandstone in the upper part is typically very friable and heavily iron-oxide-stained (orange yellow) (Figure 19).

The upper and lower sandstones classify as arkosic wackes (Williams and others, 1954) (see Petrology of the Astoria Formation section). Carbonized plant fragments and micas (biotite, muscovite, chlorite) are common along bedding planes. Carbonate cement is lacking.

The muddy siltstones and siltstones in the middle and upper parts of the Big Creek sandstone member are locally thinly bedded but commonly structureless (Figure 18). Micas, finely comminuted carbonaceous debris, fossil hash beds, and very fine-grained, very thin-bedded, dirty sandstone lenses are present.

A light olive-gray (5 Y 5/2) fine-grained structureless glauconitic sandstone, two to three feet thick, marks the top of the Big Creek member. It crops out at the same stratigraphic position at several localities in the study area (see Plate I for locations) and to the east (Coryell, 1977, personal communication).

Molluscan fossils are locally abundant in the lower and middle parts of the Big Creek member in the study area. They are most abundant in the finer-grained facies of the Big Creek member (middle part), and are typically unbroken, suggesting low-energy depositional conditions. Fossil hash beds are common in the gradational interval between the lower and middle parts of the unit (Figure 18). Some commonly occurring molluscs are the gastropods *Turritella* oregonensis and Bruclarkia oregonensis, and the bivalves Anadara devincta, Macoma albaria, Panopea abrupta, Spisula albaria, and Katherinella augustifrons (Addicott, 1977; Appendix IV). The key index fossils Vertipecten fucanus, Patinopecten propatulus, and Patinopecten oregonensis cancellosus also occur in the unit (Addicott, 1977; Appendix IV) (see Age and Correlation section).

The lower sandstone part of the unit is well-exposed in the southeast corner of the study area (Plate I) and along Fisher Road (NW$\frac{1}{4}$, sec. 8, T. 7 N , R. 8 W.). Good exposures of the middle part occur at the north end of spur Q off the Fisher Road (SE$\frac{1}{4}$, sec. 5, T. 7 N., R. 8 W.). The upper part crops out along spur 28 (SW$\frac{1}{4}$, sec. 6, T. 7 N., R. 8 W.).

Contact Relations. The Big Creek sandstone member of the Astoria Formation overlies the Oswald West mudstones with probable unconformity. This contact is discussed in the Contact Relations section of the Oswald West mudstones.

The Big Creek sandstone member is overlain by the Pipeline member of the Astoria Formation in the study area (Figure 5). A two- to three-foot thick glauconitic sandstone bed at the top of the Big Creek member serves to definitively mark an otherwise gradational contact between the two units. Muddy siltstones occur immediately above and below the glauconitic marker horizon and represent the transition zone between the sandstones in the upper part of the

Big Creek member and the mudstones of the overlying Pipeline member. The laterally persistent occurrence of a glauconitic sandstone in this gradational interval makes this lithology an ideal marker for the contact between the two units. The discontinuous nature of the arkosic sandstones in the upper part of the Big Creek member precludes their use as a marker of the contact.

Fossil evidence, regional dips, and lithology indicate that the contact between the Big Creek and Pipeline members is conformable or possibly a diastem A diastem is a "slight disontinuity in marine sediments that indicates minor interruptions in deposition" (Krumbein and Sloss, 1963, p. 305).

A conformable relationship is indicated by fossil evidence. Late early to middle Miocene (Newportian Stage) molluscan fauna occurs in both members (Addicott, 1977; Appendix IV) (see Age and Correlation sections of both members) indicating that there is no prolonged time break between deposition of the two units.

Regional stratal attitudes in both units appear to be the same, although slumping of the Pipeline lithologies makes this determination difficult. It is possible that the bedding strike of Pipeline member strata is somewhat more northwesterly than the east-west strike of Big Creek member strata but supporting evidence is weak. Conformity of bedding attitudes is probable.

The presence of a glauconitic sandstone at the contact between the two members is suggestive of a diastem. Glauconite forms in the marine environment where sedimentation rates are very low (Pettijohn, 1975) and its presence is thought to represent a submarine disconformity (diastem) by Krumbein and Sloss (1963).

Age and Correlation. The Big Creek member contains molluscan fossils assigned middle early to middle Miocene ages by Addicott (1977). An assemblage from the westernmost exposure of the lower part of the member (xf243, Plate I) is referred to the Pillarian Stage (middle early Miocene) by Addicott (1977), based on the occurrence of the giant pectinid *Vertipecten fucanus*. Several assemblages stratigraphically higher (300-400 feet) and to the east (xf272, xf452), collected in fossil hash zones in the middle part, contain the bivalves *Patinopecten propatulus* and *Pateinopecten oregonensis cancellosus* which are restricted to the slightly younger Newportian Stage (late early to middle Miocene) (Addicott, 1977).

These data may be interpreted in two ways. The member may have been deposited uniformly over the study area during a time interval near the Pillarian-Newportian boundary (late early Miocene). Alternatively, the member may be a time-transgressive deposit with the westernmost exposures being deposited somewhat earlier than the easternmost exposures. Ten miles east of the study area at the Big Creek type-section, the upper half of the member is referred to the Newportian Stage, but the lower half may be referrable to either the

Newportian or Pillarian Stages (Coryell, 1977, personal communication). Therefore, the time-stratigraphic nature of the member is indeterminate. I favor a time-transgressive model because I believe that it is a transgressive-marine deposit (see Depositional Environment section).

The Tucker Creek sandstone member is correlative to the Big Creek sandstones in the study area. Evidence for lateral equivalence is presented in the Age and Correlation section of the Tucker Creek sandstone member. Intertonguing of the two members, though not observed in outcrop, may occur beneath the alluvial valley of the Young's River.

The lower Silver Point mudstones are time equivalent to part of the Big Creek sandstone member and interfingering of the two members may occur (see Age and Correlation section of the Silver Point mudstones).

The Big Creek member has been traced continuously from the eastern border of the study area to the Big Creek member type-section by Coryell (1977, personal communication). This lateral continuity, coupled with lithologic and chronologic equivalence, provides a basis for correlation of the Big Creek member as mapped by Coryell (1977) and myself.

The Big Creek sandstones are age equivalent to part of the Angora Peak sandstone member of the Astoria Formation, mapped south of the study area by Cressy (1974), Smith (1975), Neel, (1976), and others. Molluscan fauna referrable to the Pillarian and Newportian Stages (Addicott, 1977) occur in both members. The micaceous, carbonaceous, parallel- and cross-laminated, fine-grained marine sandstones in the Angora Peak member (Cressy, 1975) are comparable to the Big Creek sandstone lithologies in the study area. Both units occupy a similar stratigraphic position in overlying Oswald West mudstones with probable unconformity. It is suggested that the Big Creek sandstones were deposited as a lateral beach-inner shelf facies of the shallow-marine and fluvial-deltaic Angora Peak sandstones in the early to middle Miocene (see Geologic History section).

Depositional Environment. Molluscan fossil paleoecology, textural features, sedimentary structures, and vertical lithologic sequence are indicative of beach to outer continental shelf, open-marine, depositional environments for the Big Creek sandstone member.

All molluscan fossils in the Big Creek member (collected from lower and middle parts) are suggestive of deposition at middle sublittoral water depths (Addicott, 1977; Appendix IV). This depositional depth (middle shelf) is probably correct for the middle siltstone and mudstone part of the Big Creek member. However, other physical features are suggestive of substantially shallower depositional depths (beach or innermost shelf) for the lower sandstone part of the member. The middle sublittoral molluscan fossils in the lower part may possibly represent middle shelf environments that occasionally transgressed nearshore, high-energy, sand-dominated environments (Fisher and Brown, 1972).

Textural features and sedimentary structures are suggestive of a high energy, inner shelf to beach, depositional environment for the lower sandstone part of the Big Creek member, and a lower energy, deeper marine, middle to outer shelf environment for the middle and upper parts. Sandstones in the lower part are moderately sorted (Table 2), opaque-mineral-rich, and lack significant argillaceous interbeds. These features are suggestive of much reworking, concentration of heavy minerals, and winnowing of clays such as would occur in innermost shelf and beach environments. In addition, bivariant grain-size statistical parameter plots for the lower Big Creek sandstones compare favorably with those for modern Oregon inner continental shelf sands and beach deposits (see Grain Size Analysis section).

Parallel laminations, occurring in sandstones in the lower part, are typically developed in the shoreface zones of modern beaches (Reineck and Singh, 1975), in inner shelf sands of the modern Oregon shelf (Kulm and others, 1975), and may represent the outer planar facies of a non-barred nearshore high energy environment (Clifton and others, 1971). The trough cross-beds with cross-truncations in the sandstones of the lower Big Creek are formed in nearshore environments by strong longshore currents developed in the surf zone (inner rough facies of Clifton and others, 1971; Harms and others, 1975). These sedimentary structures suggest that the lower sandstones of the Big Creek member were deposited in a high-energy surf or inner shelf environment. Alternatively, if high-energy shelf conditions existed, the lower sandstones could have been deposited in a deeper inner to middle shelf environment.

The siltstone-dominated middle part of the Big Creek sandstones was probably deposited by suspension sedimentation in a relatively low-energy middle shelf environment, as is indicated by the paleoecology and unbroken nature of interbedded molluscan fossils. The lack of stratification, predominance of silt- and clay-size detritus, and poor sorting (in the middle part) are features which characterize middle shelf deposits (Reineck and Singh, 1975; Kulm and others, 1975).

The discontinuous sandstones in the upper part of the Big Creek member, which intertongue with muddy siltstones, may be relatively high-energy middle shelf deposits. These sandstones are similar in geometry (isolated lenses) and lithology (very fine-grained, parallel laminated, moderately sorted) to the sand ribbons and ridges formed in high-energy, open, inner to middle shelf areas today (Harms and others, 1975; Swift, 1976). These modern longitudinal shelf sand bodies are maintained by strong shelf bottom current reworking bottom sediment to form isolated sand bodies. Muds are deposited between sand ridges (Swift, 1976).

The glauconitic sandstone which marks the top of the Big Creek member probably reflects deepening to outer shelf conditions in late Big Creek time. Similar glauconitic sandstones are forming today on the outer Oregon continental shelf (Kulm and others, 1975).

The vertical stratigraphic succession encompassing the Big Creek sandstones includes the unconformably underlying deep-marine Oswald West mudstones and conformably overlying deep-marine mudstones of the Pipeline member. This vertical profile is suggestive of a transgressive marine origin for the Big Creek member (Visher, 1965). A typical transgressive sequence is composed of basal beach and innermost shelf sandstones (lower Big Creek) fining upward to middle shelf siltstones (middle and upper Big Creek). The basal unconformity which separates the transgressive Big Creek sequence from the underlying deep-marine Oswald West mudstones probably represents a short interval of regression and subaerial erosion before ensuing transgression.

In summary, the Big Creek sandstone member is a transgressive marine deposit consisting of high-energy beach and inner shelf sandstones, deeper water middle shelf siltstones and sandstones in the middle and upper parts, and capping outer shelf glauconitic sandstones.

Silver Point Mudstones

The Silver Point mudstone member is the most geographically widespread unit of the Astoria Formation in the study area (Figure 20). The unit is readily eroded to form low hills with gentle slopes (Plate I). The montmorillonite-rich mudstones in the unit (Appendix VIII) are slump-prone and tend to form hummocky landslide topography.

An 800-foot thickness for the lower Silver Point mudstones is suggested, based on geometric calculation of thickness using outcrop distribution and average dip. Similar calculations indicate that the upper Silver Point mudstones below the Pipeline member are about 1000 feet thick, and the upper part above the Pipeline member ($Tspu_1$) is 500- to 1000 feet thick. The total thickness of the unit ranges between 2,300 and 2,800 feet. However, because of poor exposures, slumping of the unit, and the probable presence of undetected faulting, true thicknesses may be considerably less than those suggested.

Lithology. The Silver Point mudstones are divided into lower and upper parts on a lithologic basis. Sandstone interbeds are abundant in the lower part and rare in the upper part. The lower part is discussed first.

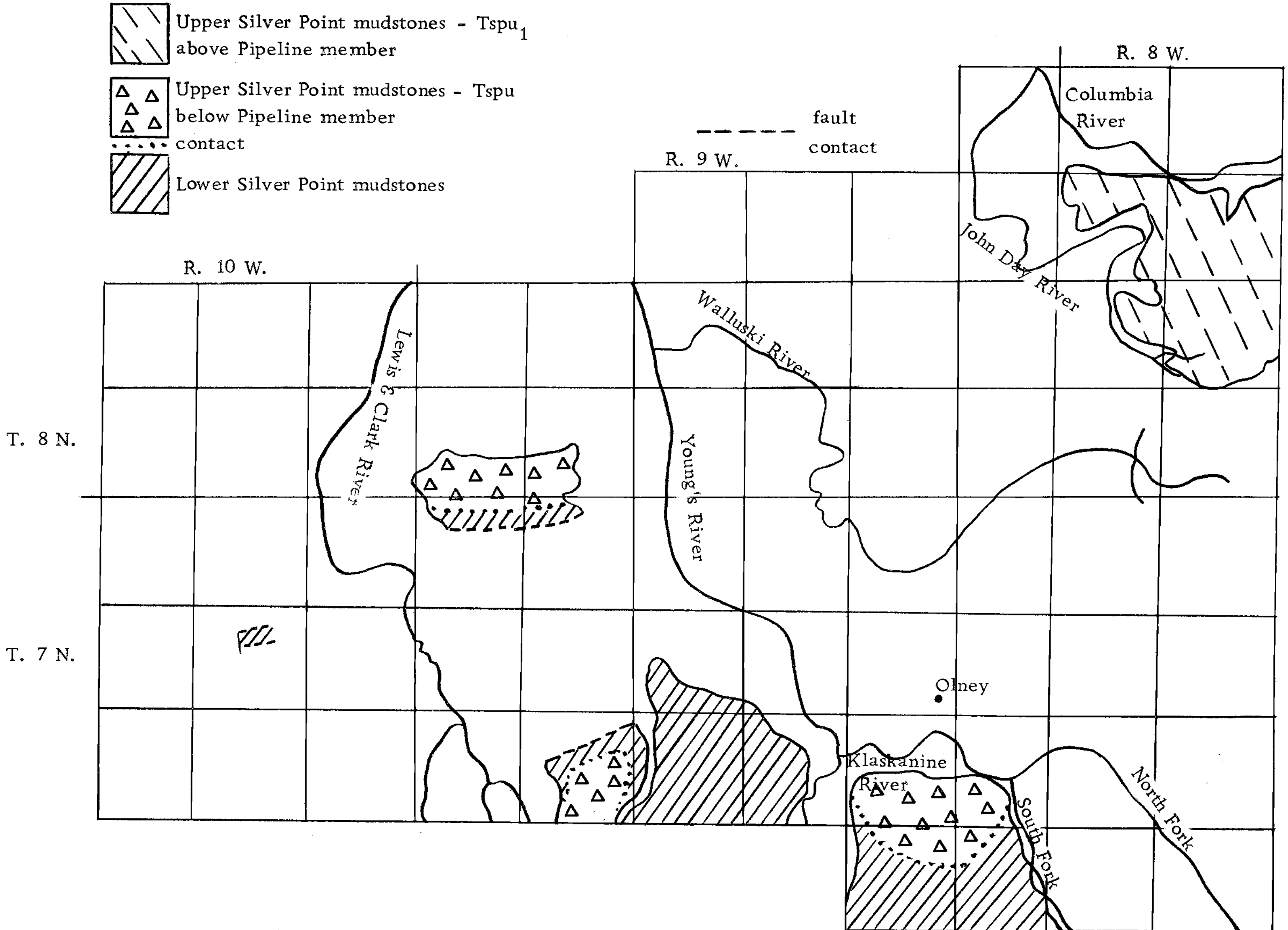


Figure 20. Outcrop distribution of the Silver Point mudstones.

The lower Silver Point mudstones are composed predominantly of laterally persistent, micaceous, carbonaceous, thinly bedded, fine- to very fine-grained sandstones and coarse siltstones, rhythmically interbedded with structureless to laminated mudstones. Sandstones and siltstones are light bluish gray (5 B 7/1) in fresh exposures and weather to a yellowish gray (10 YR 5/6). Mudstones are medium dark gray (N4) and weather to a yellowish gray (5 Y 7/2). These poorly indurated rocks are rapidly eroded in roadcut exposures to form talus accumulations of crumbly mudstone chips and silty sand. Bedding is detectable even in weathered outcrops because of the contrast between interbedded argillaceous and arenaceous lithologies.

The lower Silver Point mudstone member is generally a fining-upward unit in the sense that sandstone interbeds decrease in abundance and thickness up-section. A sandstone/mudstone ratio of about one near the base of the unit decreases to less than 0.5 in the upper part and to almost zero in the overlying upper Silver Point mudstone.

Within the overall fining-upward sequence, stratigraphic intervals dominated by mudstone or sandstone occur. Approximately 150 feet of poorly stratified to structureless mudstone, with rare interbedded thinly bedded sandstones, occur 300 to 400 feet above the base of the Silver Point member. This mudstone-dominated zone is well-exposed at the north end of spur 26-D (Plate I; NW$\frac{1}{4}$, sec. 15, T. 7 N., R. 9 W.). One-half mile to the southwest of this locality (and

100 to 300 feet higher in the Silver Point section) a 200-foot thick section of carbonaceous, laminated, fine-grained sandstones, with subordinate interstratified structureless mudstone, was measured (Appendix II, Reference Section C-D). This section displays a distinct fining-upward character as sandstone interbeds decrease in abundance and thickness up-section.

Rhythmically interbedded, thinly to very thinly bedded sandstones and mudstones compose most of the lower Silver Point mudstones (Figure 21). Beds are typically laterally persistent, parallel, and tabular. Mudstone interbeds range in thickness from two inches to two feet and are commonly structureless. Internal thin laminations are present locally where mica and carbonaceous debris are abundant. Mudstone-sandstone bedding contacts are generally sharp.

Two types of sandstone interbeds are recognized on the basis of bed geometry, lithology, and sedimentary structures. Type I sandstone beds typically have even, parallel, upper and lower contacts and range in thickness from two inches to two feet. Lenticular channel-like geometries are present locally. The sandstone channels are up to 30 feet wide, and locally have erosive bases and basal mudstone ripups (see Contact Relations section).

Type I sandstones are fine- to very fine-grained (ϕ_{50}=2.87-3.23 phi; M_z = 3.07-3.61 phi) and moderately to poorly sorted (s_1 = 0.93-1.19 phi). They are commonly highly carbonaceous and

Figure 21. Well-stratified, interbedded, fine-grained, Type sandstones and structureless mudstones of the lower Silver Point. Note sharp mudstone-sandstone contacts and well-developed splitting along parallel laminations in the upper sandstone bed. (spur 12, sec. 23, T. 7 N., R. 9 W.)

micaceous.

Locally these sandstones display pull-apart structures, and basal flame and load structures. These features are suggestive of rapid deposition of sand on a muddy substrate followed by soft-sediment deformation of the sand body by sinking into the underlying thixotropic mud (Pettijohn, 1976; Reineck and Singh, 1975).

The internal sedimentary structures of type I sandstone beds are best described in terms of the Bouma sequence (Bouma, 1962). The complete sequence includes, in stratigraphic succession, the following divisions: massive and normally graded (T_a); parallel laminated (T_b); micro-trough-cross-laminated and/or convolute laminated (T_c); parallel laminated (T_d); and structureless or laminated argillaceous material (T_e). Many type I sandstone beds display only the T_b (parallel laminated) division. Laminae are two to five millimeters thick and are defined by concentrations of mica and/or carbonized plant matter. T_{bc} sequences in the sandstones are also common. The T_c division most commonly consists of micro-trough-cross-lamination but convolute lamination is also observed. T_{abc} sequences in the sandstones are rare and only one T_{abcd} sequence was observed. Grading is commonly difficult to detect in the massive T_a division reflecting perhaps, a uniform grain size of the sediment in the source area or loss of coarser size fraction during transport. Many sandstone beds, however, display overall slight normal grading from a fine-grained base to a very fine-grained top.

The rhythmic interbedding of Type I sandstones with marine mudstones, and the characterization of these sandstones by internal sedimentary structures of the Bouma sequence, slight normal grading, locally developed channelization, lateral continuity, flame structures (locally), and basal mudstone ripups (locally) are suggestive of deposition of Type I sandstones by turbidity currents (Walker and Mutti, 1973). In terms of Walker and Mutti's (1973) turbidite facies, most type I sandstones would be described as "Facies D" classical turbidites (T_b and T_{bc}) while a few would be termed "Facies C" proximal turbidites (T_{abc} and T_{abcd}).

The less common Type II sandstone beds are characterized by lenticular bedding with connected thick lenses (classification of Reineck and Singh, 1975, p. 98). Sandstone lenticules are one- to five-centimeters long, less than one-centimeter high, and are connected by very thin sandstone laminae (Figure 22). The sandstone lenticules display the micro-trough-cross-lamination typically developed in migrating linguoid sand ripples (Reineck and Singh, 1975). These thin lenticular sandstone beds are interlaminated with mudstones in intervals between thicker Type I sandstone beds. This type of lenticular sandstone bedding in mudstones is probably produced by periodic migration of incomplete sediment-starved sand ripples across a muddy substrate followed by mud deposition (Reineck and Singh,

Figure 22. Lenticular, very fine-grained, Type II sandstone layers interbedded with mudstone in the lower Silver Point. Note micro-trough cross-laminations above and to left of ruler.

1975).

Type II sandstones are very fine-grained. In some cases the grain size approaches that of coarse siltstone. Grading is not present. Carbonaceous matter and mica are rare or lacking.

The sandstones in the lower Silver Point mudstones classify as arkosic wackes (Williams and others, 1954) (Figure 30; Appendix VI). They are typically very friable and iron-stained.

Megafossils and microfossils were not found in the lower Silver Point mudstones. However, to the south of the study area, Foraminifera were collected from the unit by Neel (1976) and molluscan fossils were collected by Cooper (1978). The latter collections include the bivalves *Portlandia* cf. *P. reagani* and *Acila gettysburgensis*.

Helminthoidia burrows (xf454, Plate I, Appendix IV) and unnamed irregular burrows (xf207) were the only trace fossils found in the interbedded mudstones of the unit (Chamberlain, 1977). The former are eurybathic but suggest deposition at outer sublittoral to upper bathyal depths. The latter is possibly of non-marine origin (Chamberlain, 1977).

Excellent exposures of lower Silver Point mudstone lithologies occur along spur 12 (SW$\frac{1}{4}$, sec. 23, T. 7 N., R. 9 W.) and at the north end of spur 26 (NE$\frac{1}{4}$, sec. 16, T. 7 N., R. 9 W.).

The upper Silver Point mudstones are composed of structureless to well-laminated, micaceous, carbonaceous mudstones, minor thin-bedded sandstones and siltstones, and rare white (N9) tuff beds. The mudstones are dark gray (N3) when fresh but typically weather to a light olive gray (5 Y 6/1) or yellowish gray (5 Y 8/1). Roadcut exposures are commonly deeply weathered and flanked by a thick talus accumulation of crumbly mudstone chips. Surface weathering is probably responsible for the structureless appearance of many mudstone outcrops.

Laterally persistent, well-defined, thin laminations and shaly splitting characterize the mudstones in the upper part of the Silver Point member (in fresh outcrop). These laminations are defined by concentrations of micas, carbonized plant debris, and coarse silt or fine sand along bedding planes. Thicker (up to one inch thick) discontinuous stringers and lenses of very fine-grained sandstone also occur in the mudstones. Rare, laterally persistent, well-indurated, parallel-laminated, thinly bedded, fine-grained to very fine-grained, sandstone interbeds are also present.

The upper Silver Point mudstones overlying the Pipeline member, in the northeast part of the study area, are designated as subunit $Tspu_1$ of the upper Silver Point mudstones. This subunit is differentiated from the Silver Point mudstones (Tspu) underlying the Pipeline member by its high stratigraphic position and locally well-laminated and highly carbonaceous character (Plate I). Complete leaf imprints are locally abundant on lamination planes. Similar leaf imprints reported by Neel (1976) to occur in the Silver Point member near Tillamook Head are suggestive of a paleoclimate comparable to the modern climate in western Oregon. Where they occur, elongate plant fragments are commonly subparallel, suggesting orientation by unidirectional current flow. $Tspu_1$ is well-exposed in roadcuts along West Twilight logging road (center of sec. 20, T. 8 N., R. 8 W.). In overall lithologic character, it is nearly identical to upper Silver Point mudstones (Tspu) below the Pipeline member.

Molluscan fossils (unbroken) collected from the upper Silver Point mudstones ($Tspu_1$) (xf423, 424) include the bivalves Delectopecten peckhami, Cyclocardia sp., Yoldia cf. Y. newcombei, and Nuculana sp. (Addicott, 1977; Appendix IV). Common Foraminifera in Tspu and $Tspu_1$ are Siphogenerina sp., Valvulineria araucana, Bulimnella subfusiformis, Bulimina cf. B. ovata, and Dentalina sp. (Rau, 1977; Appendix IV). Trace fossils were not recovered from the upper part of the Silver Point mudstones.

Contact Relations. The Silver Point mudstone member conformably overlies the Tucker Creek sandstone member of the Astoria Formation. In most of the study area the base of the Silver Point mudstone member is in fault contact with other units. However, a depositional contact with the underlying Tucker Creek member is exposed in a gently south-dipping section which crops out along

Young's River Road about one-quarter of a mile south of its junction with the Tucker Creek Road (Plate I; NW$\frac{1}{4}$, sec. 9, T. 7 N., R. 9 W.). These strata are exposed in roadcut and ditch exposures on the west side of the road. The well-indurated, cliff-forming, very fine-grained sandstones and coarse-grained siltstones at the top of the Tucker Creek member fine abruptly upward (southward) to poorly indurated lower Silver Point mudstones and interbedded fine-grained sandstones exposed in the roadside ditch. The contact is gradational over several inches. There is no disparity of attitudes between the two units.

Slightly higher in the section and several hundred feet south of this contact, turbidite sandstones and interbedded mudstones of the lower Silver Point member fill an apparent erosional channel cut into an underlying structureless mudstone horizon. This type of channelization with the lower Silver Point member has been described by Smith (1975) at Silver Point, Oregon. The lithologic similarity of mudstones above and below the channel base and the presence of interbedded sandstones and mudstones interpreted by me as being stratigraphically below the channel base (several tens of feet northward along Young's River Road), suggest that the channel base does not define the lower contact of the Silver Point mudstones. Rather, the channel occurs within the lower part of the member. However, this channel base is interpreted by Cooper (1978) to be the contact between overlying lower Silver Point mudstones and underlying Oswald West mudstones.

A depositional contact between the Tucker Creek member and Silver Point member is not exposed west of the Lewis and Clark River but the contact is presumed to be similar to that exposed along Young's River Road (fairly sharp and conformable). Fault-controlled juxtaposition of the two units occurs in the NE$\frac{1}{4}$, sec. 11, T. 7 N., R. 10 W. (Plate I).

Both the Tucker Creek member and the lower part of the Silver Point member are early Miocene in age (Pillarian Stage) suggesting a conformable age relationship between the two units (see Age and Correlation sections for both members)

The contact between the upper and lower parts of the Silver Point mudstones is gradational over several hundred feet. The contact is placed where the abundance of sandstone interbeds decreases to less than ten percent up-section. Mudstones are the dominant lithology above the contact.

The upper Silver Point mudstones, Tspu, are conformably overlain by and interfinger (?) with the Pipeline member (Figure 5). The subunit, $Tspu_1$, of the upper Silver Point mudstones conformably overlies the Pipeline member (Figure 5; Plate I). For further discussion see the Contact Relations section of the Pipeline member.

The uppermost exposure of the subunit $Tspu_1$ defines the stratigraphic top of the Silver Point member in the study area. Overlying bedrock sedimentary strata are not present. Six miles east of the study area, however, middle Miocene basaltic breccias, pillow basalts and basalt flows unconformably overlie the upper Silver Point mudstones (Coryell, 1977, personal communication). Correlative basalts in the study area occur as intrusions in the Astoria Formation.

Age and Correlation. The Silver Point mudstone member is assigned as early to middle Miocene age based on fossil data and stratigraphic relationships (Figure 5).

No fossils were recovered from the lower Silver Point mudstones in the study area. However, in lithologically and stratigraphically equivalent strata one mile to the south of the study area, the bivalves Portlandia cf. reagani (M6417) and Acila gettysburgensis (?) were collected by Cooper (1978). The latter is referrable only to the Pillarian or Matlockian Stages (Addicott, 1976b) indicating an early Miocene or older age for the lower part. This age is qualified by Addicott, however, because the state of preservation of the bivalve makes certain identification impossible. Molluscan fossils in the underlying Tucker Creek member (xf18, xf82, xf154b) are probably middle early Miocene in age (see Age and Correlation of the Tucker Creek member). Therefore, the middle early Miocene is considered to be a lower age limit for the lower Silver Point mudstones.

Molluscan fossils in the upper Silver Point mudstones (xf423, xf424) ($Tspu_1$) are late early to middle Miocene in age (Newportian Stage) (Addicott, 1977). Foraminifera from both Tspu and $Tspu_1$ (xf180, xf344, xf345, xf350) are referrable to the Saucesian Stage and possibly, in some cases, to the lower part of the stage (Rau, 1977). Since most of the Saucesian Stage is early Miocene in age (Rau, 1977) it appears that a slightly older age is assigned the upper Silver Point mudstones on the basis of Foraminifera (early Miocene) as compared with molluscan fossils (late early to middle Miocene). This discrepancy may be due to the continued survival of lower Saucesian Foraminifera (early Miocene) into the early late and middle Miocene due to favorable ecological conditions in the depositional environment in the study area. Therefore, the age of the upper Silver Point mudstones (Tspu and $Tspu_1$) is probably late early to middle Miocene.

On the basis of continuous mapping and lithologic similarity, the Silver Point mudstone member mapped in the study area is considered to be correlative to the same unit as mapped by Smith (1975), Neel (1976), Tolson (1976), Penoyer (1977) to the south of the study area. The upper and lower parts of the unit have been recognized on the same lithologic basis by these workers and myself. The upper part of the unit recognized in the study area is lithologically and stratigraphically correlative to the upper part recognized by Coryell

(1977, personal communication) in the adjacent study area to the east.

Within the study area, a partial age equivalence of the lower Silver Point mudstones and the Big Creek sandstones is probable. Both are in part middle early Miocene in age (Pillarian Stage) based on fossil evidence. The precise stratigraphic relationship between the two is not exposed in the study area. Interfingering of the two units may occur beneath the alluvial valley of the Young's River (see Geologic History section).

Chronologic correlation of the upper Silver Point mudstones and the Newport member of the Astoria Formation of the central Oregon Coast Range is indicated by the occurrence of Newportian Stage molluscan fauna in both units (Cooper, 1978).

Depositional Environment. Marine deposition of the lower Silver Point mudstones is indicated by interbedded fossils. The bivalves *Portlandia* cf. *P. reagani* and *Acila gettysburgensis* (?), collected by Cooper (1977) in lower Silver Point mudstone strata south of the study area, are suggestive of sublittoral depositional depths (Addicott, 1977). Farther to the south, Neel (1976) collected middle to outer sublittoral molluscan fossils and Foraminifera from the lower part. Trace fossils collected in the study area (xf207, xf451) and to the south (Tolson, 1976) are less definitive, suggesting non-marine to bathyal depositional environments. Overall, the fossil evidence suggests an open-marine, middle to outer shelf depositional environment for the lower Silver Point mudstones.

The poorly laminated to structureless, locally bioturbated, interbedded marine mudstones in the lower Silver Point member are typical of hemipelagic deposits in shelf and prodelta slope environments (Selley, 1970; Reineck and Singh, 1975). Randomly distributed micas and comminuted carbonaceous debris in the mudstones, and the lack of sand-size detritus, are suggestive of quiet-water sedimentation from suspension.

The two types of sandstones in the lower Silver Point member represent two modes of sand sedimentation in the lower Silver Point depositional environment. Graded Type I sandstones are interpreted to be turbidity current deposits (see Lithology section) and as such represent periodic influxes of sand into a quiet-water, mud-dominated, sublittoral environment. Similar sedimentation occurs in modern prodelta slope environments when shallow-water, nearshore, delta-front sands are re-sedimented in deeper water during down-slope slumping, storms, or floods (Allen, 1970; Gould, 1970; Visher, 1965). Allen (1960) and Selley (1970) describe distal sandstone turbidites interbedded with shelf mudstones which accumulated at the base of a steep prodelta slope at sublittoral depths (Carboniferous Mam Tor Sandstones in England). The implication is that, with sufficient steepness of a prodelta slope, a sand source (delta), and a receiving marginal shelf basin, thick sequences of interbedded marine mudstones and turbidite sandstones can accumulate adjacent to deltaic bodies. Such a deltaic model for the lower Silver Point mudstones would include, as a deltaic sediment source, the Angora Peak sandstone member of the Astoria Formation, the main body of which crops out 15 miles to the south of the study area. This unit has been interpreted by Cressy (1974) and Smith (1975) to be a fluvial-deltaic and shallow-marine sandstone deposit. The lower Silver Point mudstones have also been genetically related to the Angora Peak sandstones by Smith (1975), Neel (1976), and Penoyer (1977).

Type II sandstones in the lower Silver Point member (thin lenticular ripple-formed sandstone interbeds) are interpreted to be lower flow regime tractive current deposits (see Lithology section). Interbedding of these sandstones with marine mudstones is suggestive of fluctuating bottom current energy in the depositional environment. Intermittent strong bottom current activity, capable of transporting very fine-grained sand and coarse-grained silt, probably alternated with slack water conditions when mud was deposited. Such physical conditions may be approached in shelf areas where quiet-water mud deposition is interrupted by sand sedimentation during storms or strong tides. Sand ripples formed by bottom currents have been reported to occur in shelf areas by Komar and others (1972), Swift (1976), and Kulm and others (1975).

The fossil paleoecology, lithologies, and sedimentary structures of the lower Silver Point mudstones are then compatible with a prodelta slope or marginal-delta shelf-basin depositional model. Hemipelagic sublittoral mud deposition alternated with sand transport and deposition effected by turbidity currents and fluctuating tractive bottom currents. (See Geologic History section for further discussion of the lower Silver Point depositional model.)

Both Type I and II sandstone beds in the lower Silver Point member have been described in estuarine, tidal flat, and fluvial deposits (Stanley, 1968; Walker, 1969; and Reineck and Singh, 1975). Based on limited trace fossil evidence and the occurrence of flaser bedding, the lower Silver Point mudstones in the Young's River Falls area were interpreted by Tolson (1976) to be very shallow-marine or estuarine deposits. However, with more fossil evidence available (see beginning of this section) it is more probable that the lower Silver Point is a deeper water sublittoral deposit.

Foraminifera in the upper Silver Point mudstones (e.g. *Siphogenerina*) characterize a middle to upper bathyal depth facies (Rau, 1977, Appendix IV). This is indicative of a gradual deepening of the depositional environment up-section in the Silver Point member. The predominance of micaceous, carbonaceous, foraminiferal mudstone in the upper Silver Point is suggestive of quiet water, open-marine, hemipelagic sedimentation. The well-developed laminations in the mudstones are indicative of fluctuating low-energy sedimentation conditions. Mud laminae represent the slow settling of flocculated clay micelles. Silt, mica, finely-comminuted carbonaceous matter, and complete carbonized leaves (in $Tspu_1$), which commonly occur on mudstone laminae surfaces, may have been deposited by low density turbid currents which crossed the shelf into deeper water (continental slope) (Kulm and others, 1975).

Thin, discontinuous, very fine-grained, sandstone lenses in Tspu and $Tspu_1$ may be deposits of weak tractive currents reworking bottom sediment. Bottom current velocities as high as 1.3 ft/sec have been measured on the upper continental slope off Oregon (Kulm and others, 1975).

Overall, the lithologies in the upper Silver Point member are similar to modern continental slope deposits (Reineck and Singh, 1975).

Pipeline Member

The early to middle Miocene Pipeline member crops out in the northwestern and north-central parts of the study area (Figure 23; Plate I). Common offsetting of correlatible horizons within the unit indicates that the outcrop distribution of the unit is fault-controlled as well as strike-controlled. Restoration to a pre-faulting state would probably show the Pipeline member to crop out along an

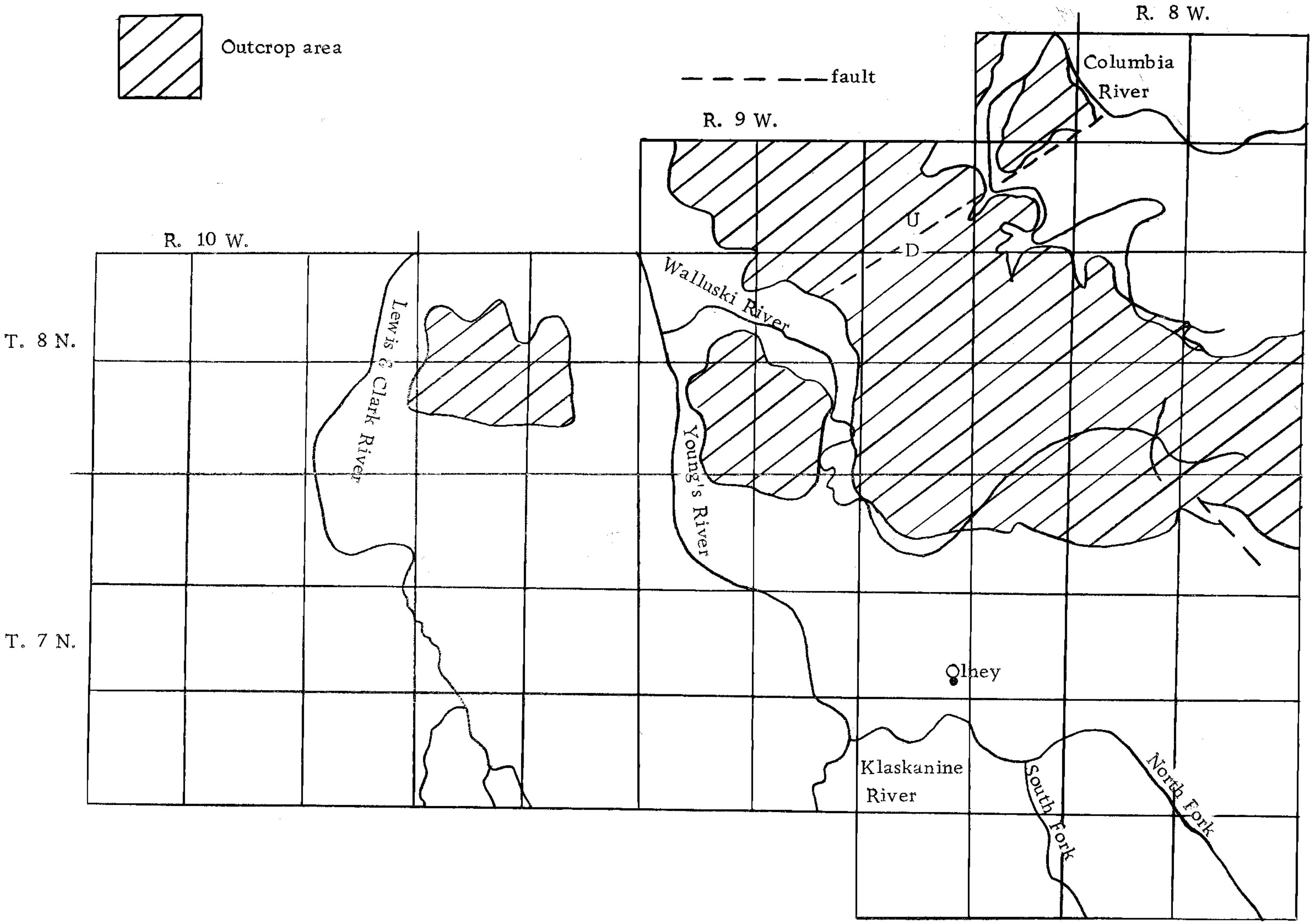


Figure 23. Outcrop distribution of the Pipeline member.

east-west belt in the northern part of the study area.

The highly friable sandstones and poorly indurated mudstones of the Pipeline member tend to form low hills of subdued relief. However, the sandstone-dominated stratigraphic interval at the top of the unit is expressed topographically as a ridge in the northwest part of the study area (Plate I). The montmorillonite-rich mudstones in the member are slump-prone and landsliding is common in areas where they occur (see slumps, Plate I).

Geometric calculation of thickness, using regional dip and outcrop distribution, suggests that the Pipeline member is 2, 000 to 2, 500 feet thick at the eastern border of the study area and thickens westward to a 3, 000-3, 500-foot thickness. However, because of poor exposures in certain areas, slumping of the unit, and the probable presence of undetected faulting, true thicknesses may be considerably less than those suggested.

Nomenclature. The name, Pipeline member, is proposed informally to designate a thick sequence of distinctive intertonguing deep-marine mudstones and sandstones within the Astoria Formation in the study area. The unit has also been mapped and described by Coryell (1978) immediately east of the study area. Coryell and I have measured two partial representative sections of the upper part of the unit (Appendix II, Reference Section E-F, Plate I; see Coryell, 1978). A complete section could not be measured because of the lack of continuous exposures of the unit in the study area.

The geographic part of the member name is that of a prominent logging road in the northwest part of the thesis area (Pipeline road) near which the best exposures of the unit occur (Plate I). This is in accordance with the Code of Stratigraphic Nomenclature (1961). This unit was previously mapped on a reconnaissance level by Cooper (1978) as a differentiated facies of the Big Creek sandstone member. Subsequent mapping by Coryell and myself indicates that the unit is lithologically distinct and stratigraphically separable from the underlying Big Creek member (Plate I).

Lithology. The Pipeline member is composed predominantly of medium-grained, thinly to very thickly bedded, structureless, very friable, clean, arkosic sandstones interbedded and intertonguing with well-laminated to structureless, micaceous, carbonaceous, deep-marine mudstones. Mudstone ripup blocks occur in the sandstones, and sandstone dikes and sills are common in the mudstones.

Pipeline sandstones are light bluish gray (5 B 8/1) in rare fresh exposures. Iron-stained yellowish gray (5 Y 8/1), grayish orange (10 YR 7/4), and white (N9) are typical weathering colors (Figure 24 and 25). The mudstones are medium gray (N5) or light olive gray (5 Y 6/1) when fresh and rapidly weather to shades of grayish orange (10 YR 7/4). Orange-yellow iron-oxide staining of all rocks is common (Figure 24). The sandstones typically have

Figure 24. Interbedded Type I sandstones and mudstones in the subunit, Tps_2, of the Pipeline member. Note lateral pinching and swelling of beds. (Spur 34, SE 1/4, sec. 25, T. 8 N., R. 9 W.)

Figure 25. Interbedded Type I sandstones and mudstones of Tps_2 of the Pipeline member. Note varying thickness of beds. (spur 32, NE 1/4, sec. 32, T. 8 N., R. 8 W.)

very steep outcrop faces and form erosion-resistant ledges when interbedded with easily eroded slope-forming mudstones (Figure 25). Talus accumulations are composed of loose sand rather than sandstone blocks because of the friability of the sandstones and lack of jointing. Mudstones yield soft crumbly mudstone chips when weathered.

In order to show lithologic variations within the unit, the Pipeline member is differentiated into sandstone-dominated (Tps_1, Tps_2) and mudstone dominated (Tpm) stratigraphic intervals (Plate I). Sandstone/mudstone ratios in Tps_1 and Tps_2 are greater than 1:1 and are typically greater than 10:1. Sandstones in these two intervals are commonly thickly to very thickly bedded; mudstone interbed thicknesses are highly variable (several inches to tens of feet) but are typically one to three feet. Sandstone/mudstone ratios in Tpm are less than 1:1 and are commonly less than 1:10. Sandstones in Tpm occur as widely scattered thick pods (up to 10 feet thick) and as numerous clastic dikes and sills.

The mudstone-dominated interval, Tpm, composes the lower half of the Pipeline member in the study area. The sandstone-dominated interval, Tps_1, is interstratified with Tpm near the base of the member. Sandstone increases in abundance near the top of Tpm and becomes predominant in the upper half of the Pipeline member, Tps_2. The contacts between these intervals are almost entirely gradational, as shown in Plate I. The sandstones and mudstones occurring in each interval listed above are identical; these intervals are differentiated only by relative abundances of sandstone and mudstone (ratios) and stratigraphic position.

The overall geometry of the Pipeline member is that of a westward-thickening wedge. Mudstone accounts for much of the increased thickness westward, but the overall thickness of sandstone increases in that direction also. Tpm increases in thickness (maximum) from about 1,500 feet to about 2,200 feet from east to west in the study area. Likewise, Tps_2 varies in thickness (maximum) from 900 feet to greater than 1,100 feet. Tps_1 pinches out to the east in the study area and thickens to 100 to 200 feet to the west. Because of poor exposures, slumping, and faulting, true thicknesses of these intervals may be considerably less than those suggested.

Mudstones in the Pipeline member are lithologically identical to laminated to structureless, carbonaceous, micaceous mudstones in the upper Silver Point member (see Lithology section of the Silver Point member). Mudstone-dominated intervals in the Pipeline member (Tpm) are differentiated from upper Silver Point mudstones only by the presence of sandstone beds, sills and dikes (see below) which are not present in the upper Silver Point member. The Pipeline mudstones (Tpm) are well-exposed along the Twilight Mainline logging road (SW$\frac{1}{4}$, sec. 32, T. 8 N., R. 8 W.).

Consideration of bedding thickness, sedimentary structures, and textural features leads to recognition of three sandstone types (I, II, III) in the Pipeline member. Only one, however (Type I), is significant in terms of widespread distribution in the member (greater than 95% of all sandstone types).

Type I sandstones are thick, clean, very friable, and medium-grained (Figures 24 and 25). This is the predominant sandstone type in all stratigraphic intervals of the Pipeline member (Tpm, Tps_1, Tps_2). These sandstone beds are commonly four- to eight-feet thick but in Tps_1 and Tps_2 these beds locally attain much greater thicknesses. Thicknesses of several tens of feet are not uncommon in these sandstone-dominated intervals; a 70-foot thick sandstone bed (without interstratified mudstone) was measured in Tps_2 (see Reference Section E-F, Appendix III; Plate I). Thick sandstones in Tps_2 are well exposed along logging road 32 ($N\frac{1}{2}$, sec. 32, T. 8 N., R. 8 W.).

Contacts of Type I sandstones with mudstone interbeds are commonly sharp but may be highly irregular, particularly at the bases of sandstone beds (Figure 24). These irregular contacts appear to have formed by penecontemporaneous differential subsidence (loading) of thick denser sands overlying a water-saturated mud substrate (Pettijohn, 1975). Some mudstone interbeds dramatically pinch and swell laterally which is suggestive of early post-depositional hydroplastic squeezing of muds.

Almost all Type I sandstones are medium-grained and poorly sorted (Appendix VIII). They classify as arkosic wackes and arenites (Williams and others, 1954; Figure 30). Locally the sandstones are calcite-cemented but commonly are poorly indurated and very friable. Mica, especially large coarse-grained flakes of muscovite, is an abundant constituent of the sandstones. Angular mudstone rip-up clasts up to seven feet long are locally abundant; more commonly they are one to two feet long.

Virtually all Type I sandstones are devoid of internal sedimentary structures; they appear to be thick structureless sandstone bodies. This may be a primary depositional feature of the sandstones or may possibly be due to post-depositional remobilization of the sandstones resulting in destruction of internal sedimentary structures. Surface weathering may also have obliterated such structures.

Several sandstones in the study area, however, which are identical to Type I sandstones in terms of grain size, mineralogy, thickness, and friability, display internal sedimentary structures. At two localities in the study area, differential iron-oxide staining of roadcut exposures (over a period of a year) resulted in apparent definition of bedding in initially structureless Type I sandstone outcrops (Figure 26). Individual bedding planes, defined by iron-oxide staining, are remarkably parallel suggesting that true bedding is represented. Individual beds are one to two feet in thickness and amalgamated to form large sandstone thicknesses without intervening mudstone interbeds. Weak coarse-tail grading in individual beds is indicated by grain-size analysis (Appendix VI). However, the mean grain size is essentially constant from bottom to top of individual beds and through a succession of beds. In these same outcrops, sets of inclined strata (4 to 5 feet thick) are interstratified with underlying and overlying horizontal layers (Figure 26). These inclined beds are thought to represent one side of a cross section of broad amalgamated channel fills similar to those pictured by Harms (1971) in deep-marine submarine-fan-channel fills in the Permian Brushy Canyon Formation in West Texas. At two other localities, thin diffuse parallel laminations formed by concentrations of carbonaceous debris and micas were observed in single one to two inch thick intervals in otherwise structureless Type I sandstones. These laminations were contorted at one locale ($\frac{1}{4}$ mile west of Twilight Mainline along logging road 32, roadcut, N$\frac{1}{2}$, sec. 32, T. 8 N., R. 8 W.) probably due to post-depositional slumping (Pettijohn, 1975). At the other locale, these parallel laminations were possibly overlain by very faint micro-trough-cross-lamination (Unit 10, Reference Section E-F, Appendix III).

Possible dish structures (Middleton and Hampton, 1973), accentuated by iron-oxide staining, were observed in a three-foot

Figure 26. Thick Type I sandstone in Tps_2 of the Pipeline member showing possible internal stratification defined by iron-oxide staining. Beds are amalgamated. (spur 32, SE 1/4, sec. 32, T. 8 N., R. 8 W.)

Figure 27. Type I sandstone bed in the Pipeline member (Tps_2) showing possible dish structures. Dishes accentuated by iron-oxide staining.

interval of an otherwise greater than five-foot thick structureless Type I sandstone (south end of spur 17, NE$\frac{1}{4}$, sec. 26, T. 8 N., R. 9 W. (Figure 27). Dishes are concave-up, less than one foot in cross section, and less than one inch deep.

In summary, Type I sandstone beds range from one foot to greater than 70 feet in thickness but are commonly five to ten feet thick. The sandstone is characteristically very friable, medium-grained, poorly sorted (framework grains), fairly clean (mostly arenites), coarsely micaceous, ungraded, and structureless. Very rarely, stratification is present in the sandstones. I suggest that many Type I sandstones may contain internal stratification which is not readily apparent in outcrop, similar to thick, commonly structureless but locally faintly thickly bedded sandstones described by Stanley (1975) in the French Maritime Alps (see Depositional Environment section). Alternatively, remobilization of Type I sandstones following deposition may have resulted in destruction of much internal stratification.

Numerous clastic dikes and sills occur in the thick mudstone-dominated interval of the Pipeline member, Tpm. The intrusions are commonly sinuous, irregular in thickness (3 inches to 1 foot), and very well-indurated. Sandstone sills pass laterally into dikes and vice versa. Some sills and dikes are observed to splay laterally into mudstones surrounding thick channelized Type I sandstones.

These clastic intrusions are particularly abundant in the upper part of Tpm (logging road 54, roadcuts, NW$\frac{1}{4}$, sec. 5, T. 7 N., R. 8 W.) but also occur in Tps_1 and Tps_2. Compositionally and texturally the sandstones in these intrusions are very similar to Type I sandstones.

Type II sandstones are several inches to two feet in thickness, fine- to very fine-grained, friable, poorly sorted, well-laminated throughout, and highly micaceous and carbonaceous. Laminae are three to five millimeters thick, moderate brown (5 YR 3/4), and defined by concentrations of carbonaceous debris and micas. Contacts with adjacent strata are usually sharp but locally are wavy. This sandstone type, in one case, directly overlies a thicker Type I sandstone bed (Figure 28). This sequence is comparable to the T_a-T_b interval of the Bouma sequence in terms of sedimentary structures and fining-upward grain size and may represent a single turbidity current deposit. However, Type II sandstones are commonly interbedded with mudstones without being in contact with Type I sandstone beds. The fine grain size of these sandstones and the abundance of constituent mica and carbonaceous debris suggest possible deposition by weak tractive currents reworking bottom sediment. Alternatively, they may be dilute distal turbidity current deposits in which only the T_d Bouma interval was formed (under lower flow regime conditions). The best exposure of this sandstone type occurs along the Pipeline Road (NE$\frac{1}{4}$, sec. 25, T. 8 N., R. 9 W.)

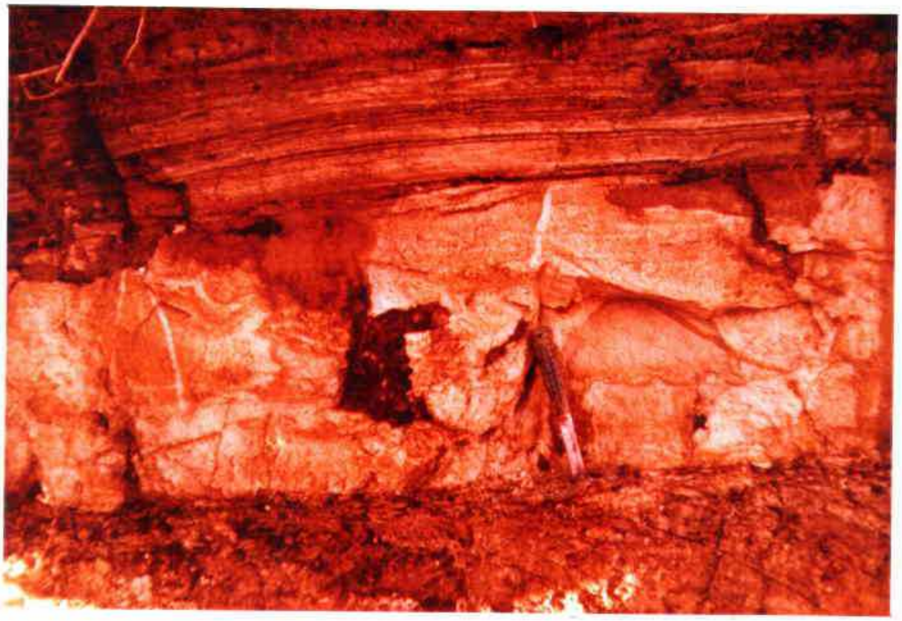


Figure 28. Very fine-grained, well-laminated, carbonaceous, Type II sandstone bed overlying structureless, medium-grained Type I sandstone bed (in Tps_2). (spur 34, SE 1/4, sec. 25, T. 8 N., R. 9 W.)

Figure 29. Fine-grained, laminated, Type III sandstone with mudstone ripups and overturned laminae in upper part. Outcrop about ten feet high. (spur 32, NE 1/4, sec. 32, T. 8 N., R. 8 W.)

(also see Reference Section E-F, Appendix III). This sandstone type was only observed in Tps_2.

Type III sandstones, unlike other sandstones in the Pipeline member, are characteristically medium bluish gray (5 B 5/1) and weather to greenish gray (5 GY 6/2) (Figure 29). At the three localities where this lithology occurs in the study area, its thickness is not more than twelve feet. Type I sandstones occur stratigraphically above and below it. Type III sandstones are always fine-grained and characteristically display distinctive micaceous and carbonaceous parallel laminations. Local trough cross-bedding is also present. These sandstones are always interbedded with very thin beds (less than several inches) of grayish black (N2) laminated, micaceous and carbonaceous mudstones which locally also occur as zones of mudstone ripups in the sandstone (Figure 29). Texturally and mineralogically the type III sandstone are most like the sandstones of the Big Creek member (see Petrology of the Astoria Formation and Grain Size Analysis sections). The genetic significance of this sandstone type is discussed in the Geologic History section. This sandstone type is well-exposed at the east edge of the study area along spur 32 (NE$\frac{1}{4}$, sec. 32, T. 8 N., R. 8 W.). This sandstone was observed only in Tps_2.

Molluscan fossils from the Tpm and Tps_2 intervals of the Pipeline member include the bivalves Delectopecten peckhami, Macoma carlottensis, and Tellina congesta (Addicott, 1977; Appendix IV). Common Foraminifera are Uvigerinella obesa impolita, Valvulineria araucana, Cassidulina crassipunctata, and Siphogenerina kleinpelli (Rau, 1977; Appendix IV). All fossils were recovered from mudstones in the member; the sandstones are apparently unfossiliferous. All fossil evidence is indicative of upper bathyal depositional depths.

Contact Relations. To the east of Young's River the Pipeline member conformably overlies the Big Creek sandstone member of the Astoria Formation (Plate I) (see Contact Relations section of the Big Creek member).

The Pipeline member conformably overlies and is inferred to interfinger with the upper part of the Silver Point member (Tspu) which crops out west of Young's River (Figure 5; Plate I). The lower part of the Pipeline member east of Young's River and the upper Silver Point mudstones to the west occupy the same stratigraphic position in the study area in that they overlie the nearly time-equivalent Big Creek and lower Silver Point members, respectively (Figure 6; see Age and Correlation section of the Silver Point member). Therefore, the two units are inferred to interfinger, the mudstones in each being identical. They are only distinguished by the presence of a distinctive Type I sandstones and dikes and sills in the Pipeline member and the lack of them in the upper Silver Point member. The interfingering is presumed to occur beneath the alluvial valley of Young's River.

The upper Silver Point member west of Young's River gradationally gives way up-section to the Pipeline member, the contact being placed at the lowermost occurrence of Type I sandstones of the Pipeline member in the mudstones (Figure 5; Plate I). There is no evidence for any significant interruption in mudstone deposition across the gradational contact. The Pipeline member above the contact and upper Silver Point member below are conformable in terms of strike and dip, and age (see Age and Correlation sections for both units).

The Pipeline member is conformably overlain by the subunit, $Tspu_1$, of the upper Silver Point member in the northwestern part of the study area (Figure 5; Plate I). The contact is well-exposed along spur 32 (SE$\frac{1}{4}$, sec. 29) and at the end of spur B (SW$\frac{1}{4}$, sec. 29; both in T. 8 N., R. 8 W.). Mudstones of the overlying subunit, $Tspu_1$, are in sharp contact with the sandstones of the underlying Pipeline member. As conformable age relationship is suggested by the occurrence of the same Newportian-Wishkahan (late early to late Miocene) molluscan fossils in both units (xf423, xf353). Concordance of bedding attitudes between the two units appears probable.

Age and Correlation. The Pipeline member is assigned a late early to middle Miocene age on the basis of fossil evidence and stratigraphic relationships (Figure 5). Newportian (late early to middle Miocene) molluscan fossils occur in the underlying Big Creek member (xf272) suggesting a lower age limit for the Pipeline member of late early Miocene.

Molluscan fossils recovered from the Pipeline member (Tps_2, xf353, xf320) and the overlying subunit, $Tspu_1$, of the upper Silver Point mudstones (xf423) are referred to the Newportian or Wishkahan Stages (late early to late Miocene) (Addicott, 1977). However, the presence of Saucesian Foraminifera in both of these units (xf356, xf314, xf345, xf344, xf350) (Rau, 1977) suggests an upper age limit no younger than middle Miocene (Figure 5). This is substantiated by the occurrence of middle Miocene basalt intrusions in the lower part of the Pipeline member (Plate I; see Age and Correlation of the Depoe Bay Basalt). Therefore, the age of the Pipeline member is considered to be late early to middle Miocene (Figure 5).

The Pipeline member may be correlative with all or part of Unit III of the Astoria Formation as mapped by Wolf and McKee (1968, 1972) in the Grays River area of Washington, 14 miles northeast of the study area. Both units are similar in terms of overall lithology (interbedded thick sandstones and mudstones), stratigraphic position, and age.

Similarity in terms of interbedded mudstone lithologies and stratigraphic position suggests that the Pipeline member may be laterally correlative to part of the upper Silver Point mudstones mapped to the south of this study area by Tolson (1976), Neel (1976), Smith (1975), and Penoyer (1977). Continuous mapping of the upper Silver Point mudstones (Tspu) into the study area from the south, probable interfingering of the upper Silver Point member and the Pipeline member in the study area, and similar ages of the two units are all supportive of this correlation. However, sandstones of the Pipeline member have not been recognized to the south of the study area, possibly because they were never deposited there or have been removed by erosion.

Depositional Environment. Fossils in the mudstones of the Pipeline member are indicative of a deep-marine depositional environment. The low diversity of molluscan fossils in the mudstones and the presence of thin-shelled unbroken bivalves such as *Delectopecten peckhami* and *Macoma carlottensis* are suggestive of deep outer sublittoral to bathyal depositional depths (Addicott, 1977). Foraminifera (e.g. *Siphogenerina*) characterize a middle to upper bathyal depth facies (Rau, 1977; Appendix IV).

If the Pipeline member comprised only mudstones, the development of a deep-water depositional model for the unit would be relatively simple. Clays and fine silts slowly diffusing seaward from nearshore areas of terrigenous sediment input would gradually accumulate in quiet-water, deep-marine, offshore areas. This sediment input, along with the pelagic rain of organic material and hard parts of marine organisms, would account for most mud layers in the member. Coarse-grained silt, very fine-grained sand, micas, comminuted carbonaceous debris, and large plant fragments occurring on mud laminae surfaces, may have been carried into deeper water by low density turbid currents (Kulm and others, 1975) generated in nearshore areas during storms. Discontinuous lenses of sandstones in the mudstones may have been formed by tractive currents reworking bottom sediment.

The depositional model for the Pipeline member must also account for the interbedding of large volumes of relatively clean, medium-grained, friable sandstones with mudstone in a deep-marine environment. Thick sandstone accumulations in modern deep-marine environments occur in submarine canyons, submarine fans, and deep-sea channels (Nelson and Kulm, 1973; Stanley and Unrug, 1972; Griggs and Kulm, 1970). It is now recognized that submarine canyons heading in shelf areas play a major role in the transfer of coarse terrigenous sediment to deep-marine environments (Stanley, 1975). Steep canyons incised into shelf margins funnel fluvial and nearshore marine sands to deeper waters via sediment gravity flows (Middleton and Hampton, 1973). Some deposition occurs in submarine canyons but most sediment is deposited in base-of-slope regions (continental rise) forming thick fan-shaped clastic wedges called submarine fans (Nelson and Kulm, 1973). Deep-sea channels receive and transport sediment from submarine canyons and fans to abyssal plain environments (Griggs and others, 1970). With this understanding of some of the possible depositional environments in which modern deep-marine sands occur, a depositional model for the sandstones in the Pipeline member can be developed.

If all the salient features of submarine canyon, submarine fan, and deep-sea channel deposits are considered, it is apparent that the sandstones of the Pipeline member bear remarkable similarity to deposits of submarine canyons (Stanley, 1967, 1975; Stanley and Unrug, 1972; Walker and Mutti, 1973) and upper submarine fan-channels (Walker and Mutti, 1973; Nelson and Nilsen, 1975). The sandstones in such deposits occur as thick (tens of feet) amalgamated beds; lack grading or are weakly graded; display poorly developed to no internal stratification; may show diffuse parallel lamination, convolute lamination, and dish structures; are poorly sorted; and contain mudstone ripup clasts. Mudstone-sandstone bedding contacts are sharp but commonly irregular due to soft-sediment deformation and channelization of the sandstones. Sandstones cannot be traced laterally for any significant distance and are complexly intertongued with surrounding mudstones bearing deep-marine fauna. All these features essentially describe the Type I sandstone in the Pipeline member. Additionally, most Type I are classified as "Facies B" sandstones (massive sandstones with and without dish structures; Walker and Mutti, 1973) which are associated with submarine canyon and inner-fan-channel deposits. However, inner-fan-channel deposits, unlike submarine canyon deposits, typically have an adjacent associated levee facies composed of rhythmically interbedded, thinly bedded, fine-grained sandstones and siltstones (Nelson and Nilsen, 1974). Since this facies is not present in the Pipeline member, the member is more likely a submarine canyon deposit. Additionally, the paleobathymetry of fossils in the Pipeline member suggests middle bathyal to deep outer sublittoral depositional depths (Addicott, Rau, 1977); these depths are more typical of modern submarine canyons than upper submarine fan areas (Shepard and Dill, 1966).

All the features associated with Type I sandstones, such as medium-grain size, poor sorting, weak to no grading, common structureless appearance, rare presence of diffuse parallel laminations and possibly dish structures, mudstone ripups, and clastic dikes and sills, are suggestive of deposition by fluidized flow and/or grain flow (Middleton and Hampton, 1973; Nelson and Nilsen, 1975; Stanley, 1975). A turbidite origin for most of the Type I sandstones does not seem probable since they rarely display any sedimentary structures of the Bouma sequence, are not laterally continuous, and lack well-developed grading. However, post-depositional remobilization of the sands may have destroyed diagnostic turbidite sedimentary features.

The suggested flow mechanism for deposition of Type I sandstones, grain flow and fluidized flow, are thought to be most active in submarine canyons and upper-fan channels. Sediments accumulated in the canyon head are periodically flushed down-canyon during down-flank slumping (Stanley, 1975) as high-viscosity, non-turbulent sediment gravity flows (fluidized and grain flow). Mixing of water with these flows down-canyon and on the submarine fan theoretically leads to development of high-density turbidity currents (Middleton and Hampton, 1973). The lack of turbidite deposits in the Pipeline member is not surprising then if most deposition took place in submarine canyons or inner-fan channels, where turbidity currents are less common. However, rare Type I sandstones showing faint laminations, and well-laminated Type II sandstones may be turbidity current deposits.

Strong tractive bottom currents are also active in submarine canyons and inner-fan valleys (Stanley, 1975; Shepard and others, 1969). Type II sandstone beds, which are non-graded, thin, and parallel laminated throughout, may be deposits of such currents (see Lithology section).

The sedimentologic features and the mode of deposition of the sandstones in the Pipeline member are compatible with a submarine canyon or upper-fan-channel depositional model. A third consideration is geometry.

Because of the confinement of submarine canyon and channelized upper fan deposits to linear depocenters, an overall shoe-string-like geometry is typically developed. Deposits are lenticular in cross-section and, in longitudinal section, thicken down-channel and pinchout up-channel toward the canyon head (Stanley and Unrug, 1972). The geometry of the sandstones in the Pipeline member is somewhat similar. Comparison is difficult, however, since down-dip variations in sandstone geometry cannot be observed in the study area. In terms of overall regional distribution, the Pipeline member is restricted to exposures flanking the present day axis of the lower Columbia River (Plate I; Coryell, 1977, personal communication; Wolf and McKee, 1968, 1972, Unit III of the Astoria Formation). This distribution is partly controlled by regional structure but may also reflect confinement of deposition of the member to a linear depression subparallel to the present river axis. The lack of sandstones of Pipeline lithology in extensive correlative exposures south of the study area (upper Silver Point) tends to confirm this. The total thickness of the sandstone-dominated intervals in the Pipeline member, Tps_1 and Tps_2, is 900 to 1,400 feet which is comparable to the approximately 1,000-foot thickness cited by Stanley (1975) for submarine canyon deposits (sandstones) of the Gres d'Annot Formation in France.

The sandstone-dominated intervals in the Pipeline member, Tps_1 and Tps_2, tend to pinch out along bedding strike to the east and thicken to the west (Plate I; Coryell, 1978). It is possible that these two-dimensional geometries represent oblique (?) longitudinal sections of submarine canyon and upper-fan-channel deposits which would pinchout up-channel and thicken down-channel. If so, the successively westward exposures of each subunit would be progressively farther down-canyon or down-channel deposits, and a westerly paleocurrent dispersal pattern would be inferred. The lack of westward fining of grain size in each subunit is compatible with this interpretation since submarine canyon and inner-fan-channel deposits show little or no down-axis fining.

Alternatively, the westward-thickening and eastward-pinching-out outcrop patterns of the subunits, Tps_2 and Tps_1, could represent one half of an oblique channel cross section, the channel axis being oriented northeasterly-southwesterly, implying a source area in southwestern Washington (Plate I).

Fossil evidence is also compatible with a submarine canyon depositional model for the Pipeline member. The middle bathyal to deep outer sublittoral paleobathymetry indicated by fossils is similar to water depths occurring in the upper reaches of the La Jolla Submarine Canyon off southern California (Shepard and others, 1969), the Astoria Canyon off Oregon (Nelson and others, 1970), and the Congo Submarine Canyon off Zaire (Shepard and Emergy, 1973). It is important to note that these canyons head in outer shelf, inner shelf, and river south areas, respectively, and that bathyal depths are attained in the canyons in these areas. Consequently, while the

Pipeline member was deposited at upper bathyal depths, it need not have been deposited on a continental slope where these depths are typically. Deposition could have occurred in a deep submarine canyon cut into a continental shelf.

The predominance of mudstones with minor interbedded sandstones in the lower half of the Pipeline member suggests that the main sandstone depocenter was outside the study area or that little sand was being delivered to the depositional basin. The thin sandstone-dominated interval, Tps_1, interstratified with Tpm, represents a temporary influx of sand in a mud-dominated environment, perhaps due to channel shifting within a submarine canyon environment. The abundance of sandstone in the upper half of the member (Tps_2) suggests that the depositional axis of the submarine canyon was located at or within the northern border of the study area.

Petrology of the Astoria Formation

Twenty-three sandstone samples from the various members of the Astoria Formation were studied in thin section; modal analysis was performed on 15 of these samples (Appendix VI). Only one mudstone sample from the Astoria Formation in the study area was sufficiently well indurated to be prepared as a thin section.

Almost all the sandstones in the Tucker Creek, Silver Point, Big Creek, and Pipeline members are classified as arkosic wackes and arenites (Figure 30) (Williams and others, 1954). This overall mineralogic uniformity is not surprising in light of the close temporal and spatial relationship of the various members in the study area. Variations in mineralogy among the members are detailed below. In terms of Folk's (1954) maturity indices, the sandstones in the Astoria Formation are compositional and texturally immature.

There is little variation among the sandstones of the Astoria Formation in terms of types of minerals and rock fragments present (Table I). The same detrital grains appear in most sandstones. Common framework constituents are, in approximate order of decreasing abundance, quartz (21-32%), feldspar (13-19%), rock fragments (5-14%), mica (3-9%), opaques (1-5%), and heavy minerals (trace-1%) (range in percent based on average mineralogies listed in Table I).

Monocrystalline unstrained quartz is commonly twice as abundant as all other quartz types combined. Grains are typically clear but acicular and gas inclusions may be present. Monocrystalline strained quartz and polycrystalline (polygonized) quartz are approximately equal in abundance (2-6%). The latter is composed of individual equant quartz units with straight boundaries whereas the less abundant metaquartzite grains are composed of elongate quartz units with sutured boundaries. Rare micas are crenulated along these sutured boundaries. Chert is rare to absent in most sandstones

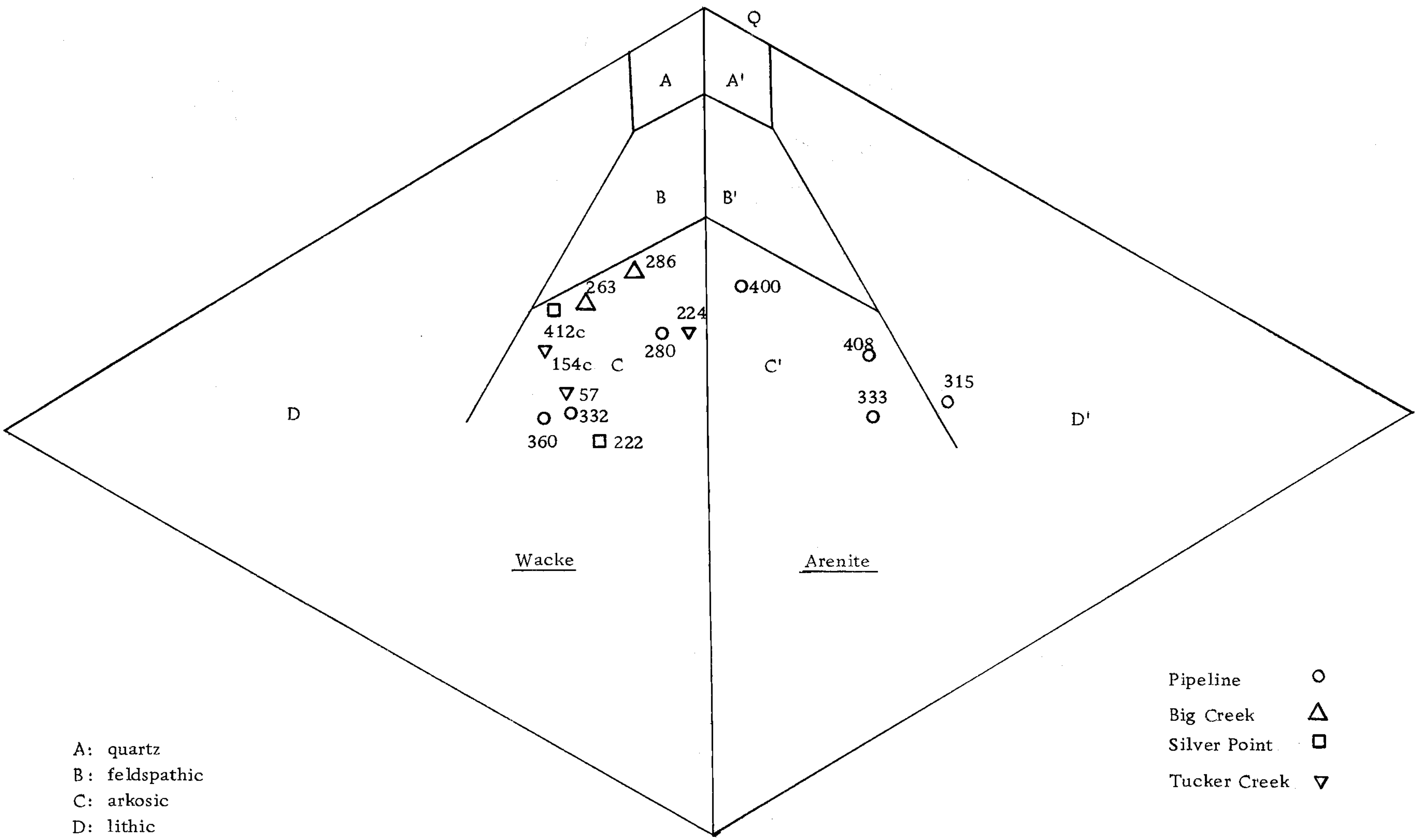


Figure 30. Classification of the Astoria Formation sandstones (after Williams and others, 1954).

Table 1. Average mineralogies of sandstones in the Astoria Formation.

	Tucker Creek	Big Creek	Silver Point	Pipeline
Quartz				
Monocrystalline	17	25	15	24
Polycrystalline	3	3	5	5
Quartzite	1	tr	1	3
Chert	1	-	tr	tr
Feldspar				
Plagioclase	4	6	3	5
Orthoclase	11	7	15	13
Sanidine	1	tr	-	1
Rock Fragments				
VRF	6	4	4	8
MRF	tr	1	3	4
IRF	tr	tr	1	1
SRF	1	-	2	1
Mica				
Muscovite	1	2	2	2
Biotite & Chlorite	2	7	5	2
Opaques	3	5	3	1
Mafics	tr	1	-	tr
Glauconite	tr	-	-	tr
Others	5	4	3	tr
Cement				
Hematite	tr	-	-	3
$CaCO_3$	5	-	-	-
Zeolite	-	-	-	3
Porosity	8	6	8	10
Matrix	28	28	29	14
Grain Size	f-m	f	vf-f	m

Tr = less than 1%   vf - very fine   f - fine   m - medium

Modal analyses used in computing average mineralogy listed by sample no. below (see Appendix VI for modal analysis of each sample).

Tucker Creek - sample no. 57, 154c, 224
Big Creek - sample no. 263, 286
Silver Point - sample no. 222, 412c
Pipeline - sample no. 280, 315, 400, 360, 408, 333

(Appendix VI).

The average abundance of monocrystalline quartz appears to vary among the members of the Astoria Formation (Table I), but it is doubtful that these averages are based on a sufficient number of samples to make the differences observed significant. Additionally, quartz abundances overlap among individual sandstones of different members (Appendix VI). In making any comparison of grain types between sandstones of the various members, the effect of grain size must be considered. Substantial variations in the abundances of mineral constituents can occur between finer-grained and coarser-grained sandstones of the same unit (Odom and others, 1976). Generally, coarser sandstones are richer in unstable lithic fragments while finer-grained sandstones have higher percentages of quartz and feldspar. The finer grained character of sandstones in the Big Creek and Silver Point members relative to those in the Pipeline member must, then, be kept in mind when differences in mineral abundances between the sandstones of these members are observed. The differences may be real or may be a result of grain-size differences. The effect of grain size is perhaps seen in the variations in mineral abundances between the coarser-grained and finer-grained sandstones of the Tucker Creek member (samples no.'s 57 and 154c, and 224, respectively; Appendix VI).

Orthoclase is the dominant feldspar in sandstones of the Astoria

Formation in the study area. Mixtures of unaltered grains and grains with dusty brown coatings of kaolinite (?) are common in all sandstones, although fresh grains are quite abundant in the Pipeline member. Rare myrmekitic intergrowths of orthoclase and quartz occur in some sand grains (Figure 31). Plagioclase grains tend to be more altered with sericite and rare calcite forming along cleavage surfaces. Some grains are completely seriticized. However, mixtures of both fresh and altered plagioclase grains are typical in most sandstones.

Plagioclase grains commonly display albite twinning and less commonly pericline and Carlsbad twinning. Rare zoned plagioclase is present in sandstones of the Pipeline member. Untwinned plagioclase was observed in a number of sandstones, particularly in the Pipeline sandstones. Since the latter is difficult to identify, it may be more prevalent in these sandstones than is commonly thought. Plagioclase compositions (as determined by the Michel-Levy method; Kerr, 1959) range from oligoclase (An_{23}) to labradorite (An_{62}) but andesine is most common (An_{30-50}). Plagioclase grains in the Big Creek sandstones tend to be more calcic than those in other members in the Astoria Formation (An_{42} versus An_{30-35}, respectively (average An values)). The Big Creek sandstones also tend to have less orthoclase than sandstones in other members (Table I; Appendix VI). Plagioclase, however, is fairly evenly distributed among the sandstones of the formation (approx. 4%). A relatively low

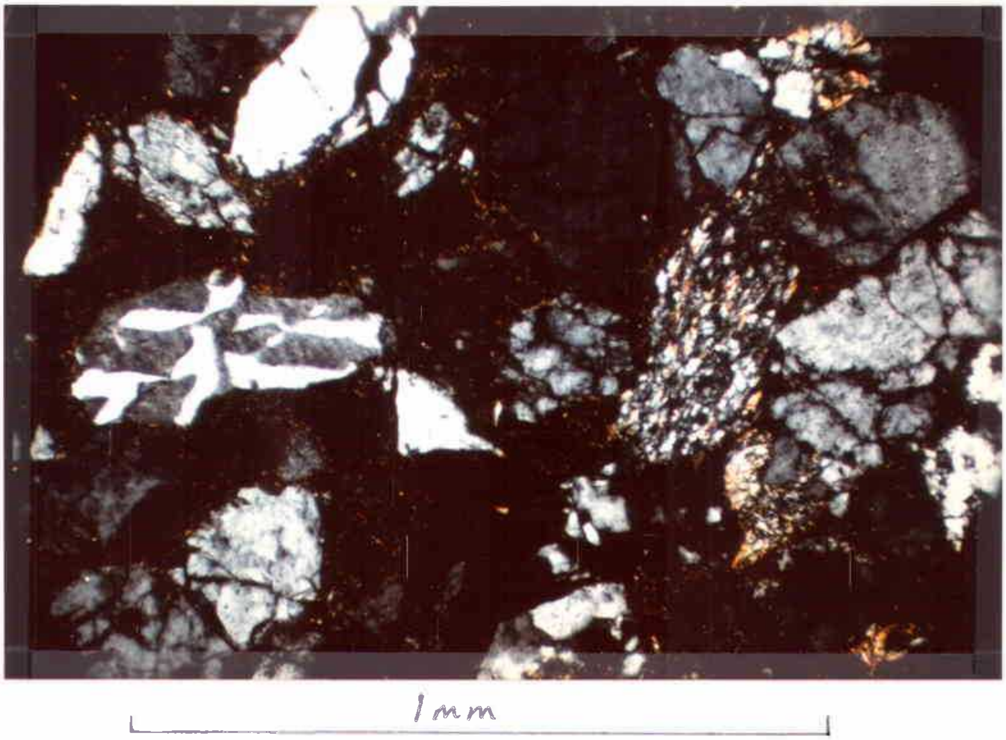


Figure 31. Photomicrograph showing typical schistose rock fragment in a Pipeline sandstone. Quartz, orthoclase, and myrmekite also present. (crossed nicols)

orthoclase/plagioclase ratio (approx. 1:1) in the Big Creek member is substantiated by the work of Coryell (1978) immediately east of the study area. Sanidine is significant only as a constituent of the sandstones of the sandstones of the Pipeline member (up to 2%; Appendix VI).

Volcanic rock fragments are present in subordinate amounts in all sandstones in the Astoria Formation (Table I). Basaltic and/or andesitic fragments are most common (Figures 32 and 34). These fragments display hyalopilitic and intersertal textures. Plagioclase microlites are commonly randomly oriented, but pilotaxitic textures are observed. Plagioclase microphenocrysts are rarely present. Plagioclase compositions range from An_{36} (andesine) to An_{54} (labradorite). The groundmass typically consists of dirty brown glass altering to magnetite, hematite, and greenish to orangish clay minerals (probably chlorophaeite, nontronite, and saponite). Rarely, olivine and/or pyroxene occurs in the groundmass. Possible dacitic rock fragments contain microphenocrysts of quartz and orthoclase, and lack opaques in the groundmass. Overall, volcanic rock fragments are more abundant in the sandstones of the basal Tucker Creek member (16%) and the Pipeline member (8%) than in the finer grained Big Creek and Silver Point members (4%), probably because of the preferred destruction of rock fragments below medium grain size (Pettijohn and others, 1973).

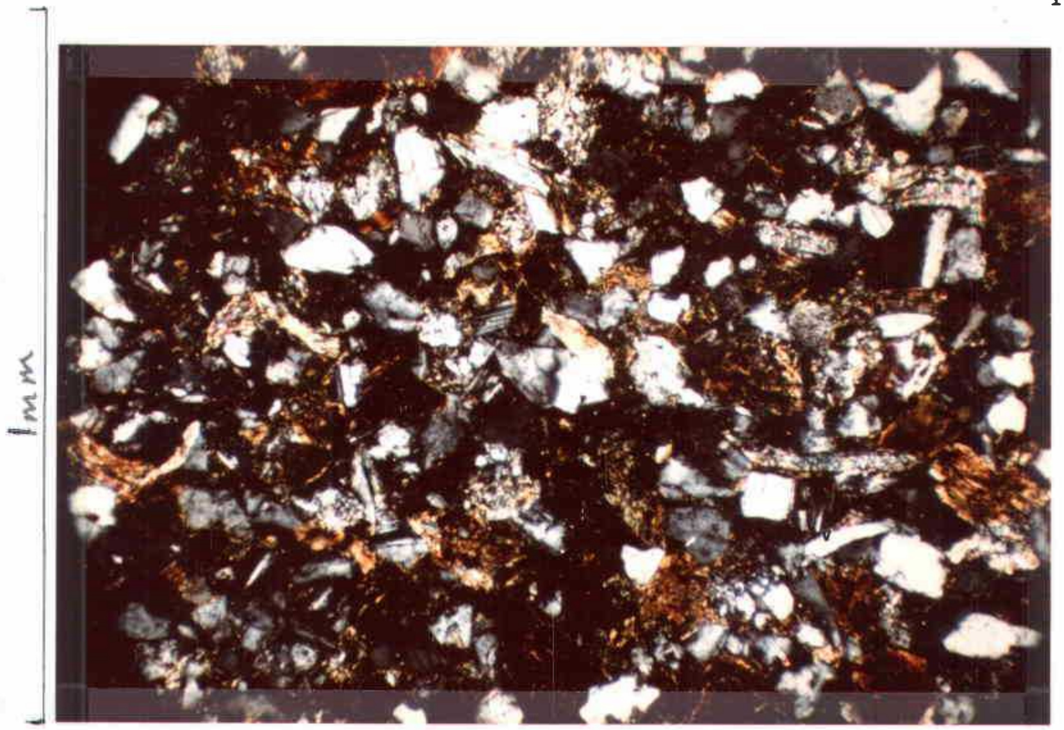


Figure 32. Photomicrograph of Big Creek sandstone, lower part. Moderately sorted, angular framework grains consist primarily of quartz with lesser amounts of orthoclase, plagioclase, and volcanic rock fragments (v). (crossed nicols)

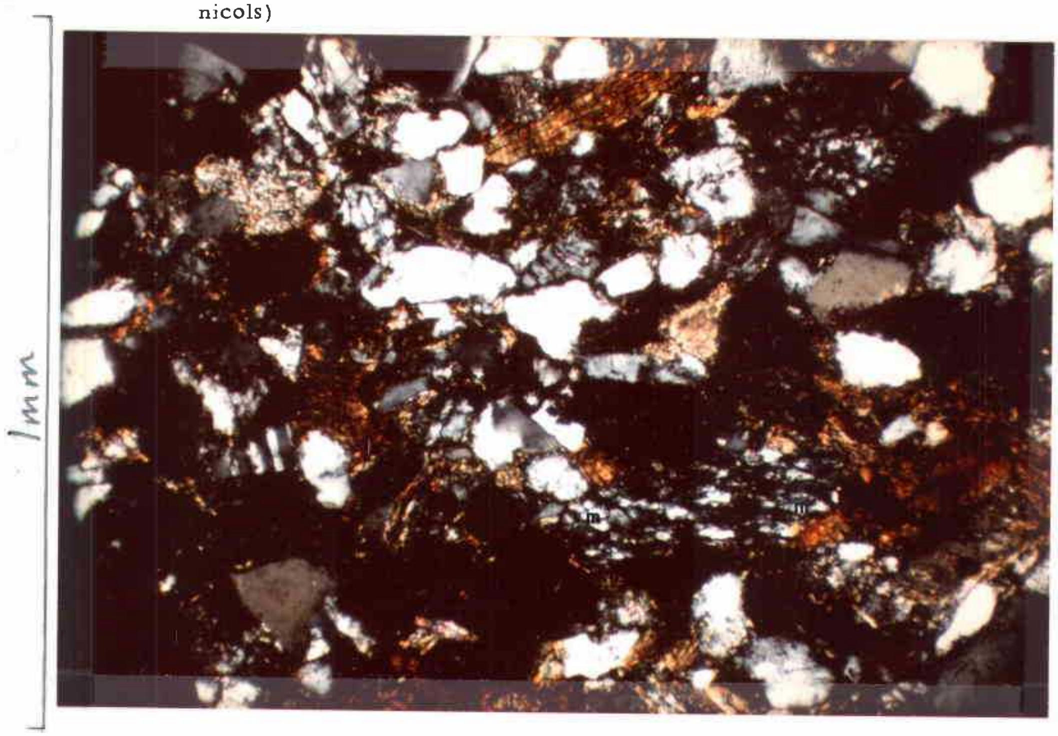


Figure 33. Photomicrograph of lower Silver Point turbidite sandstone. Poorly sorted, angular framework grains consist of quartz, orthoclase, plagioclase, muscovite, biotite and schistose rock fragments (m). Abundant clay matrix. (crossed nicols)

At least minor amounts of metamorphic rock fragments are present in most sandstones. Schistose rock fragments are most common (Figures 32 and 35) and are typically composed of foliated quartz and mica. Quartz grains are elongate, sutured to polygonized, and display undulose extinction. Muscovite is the most common mica; biotite and chlorite may also occur. Rarer gneissic rock fragments show well-developed foliated mineral segregations of quartz and micas (muscovite). Phyllitic rock fragments are least common. They are composed of abundant micas (mostly muscovite), silt-size quartz grains and rare carbonaceous matter. The Pipeline member sandstones, in particular, have locally high abundances of metamorphic rock fragments (up to 7%, Appendix VI; mostly schistose) (Figure 31).

Acidic plutonic rock fragments occur in trace amounts in sandstones from each member (Appendix VI), but significant abundances are largely confined to sandstones of the Pipeline member (Appendix VI). These fragments typically consist of an interlocking mosaic of equant quartz crystals with straight to undulose extinction, subhedral to anhedral orthoclase, and muscovite. Microcline is a rare constituent. These minerals are suggestive of a granitic composition for most of these rock fragments. However, some fragments contain plagioclase crystals of oligoclase or andesine composition (An_{22-36}), which possibly indicates a derivation from a quartz monzonite source.

Sedimentary rock fragments are rare in all sandstones studied (tr-2%); coarse-grained siltstone is the most common type observed. Framework grains consist predominantly of angular quartz; feldspars and micas are subordinate constituents. Clay matrix content is high and the clasts display no planar fabric. Rare mudstone clasts also occur in some sandstones. The difficulty of identifying the commonly poorly-defined sedimentary rock fragments in thin section precludes comparison of abundances between members.

Micas are a common constituent of all sandstones studied (Table I). Muscovite is typically unaltered (Figures 31 and 34). Biotite characteristically is red-brown or green and shows alteration to magnetite and chlorite (Figures 32 and 33). Micas bent or wrapped around quartz grains are fairly common in sandstones of the Pipeline member (Figure 35). Big Creek and Silver Point sandstones have relatively high abundances of biotite and chlorite (Figure 32) (5-7%, Table 1).

Opaque minerals include magnetite, hematite, ilmenite, leucoxene, and limonite. Ilmenite grains are typically partially or completely altered to leucoxene. Magnetite occurs as discrete detrital grains, and along fractures and between detrital grains as minute clustered granules. The latter appear to have originated by decomposition of biotite to chlorite and magnetite (Heinrich, 1965). Alteration of magnetite to hematite and limonite is common. The opaque

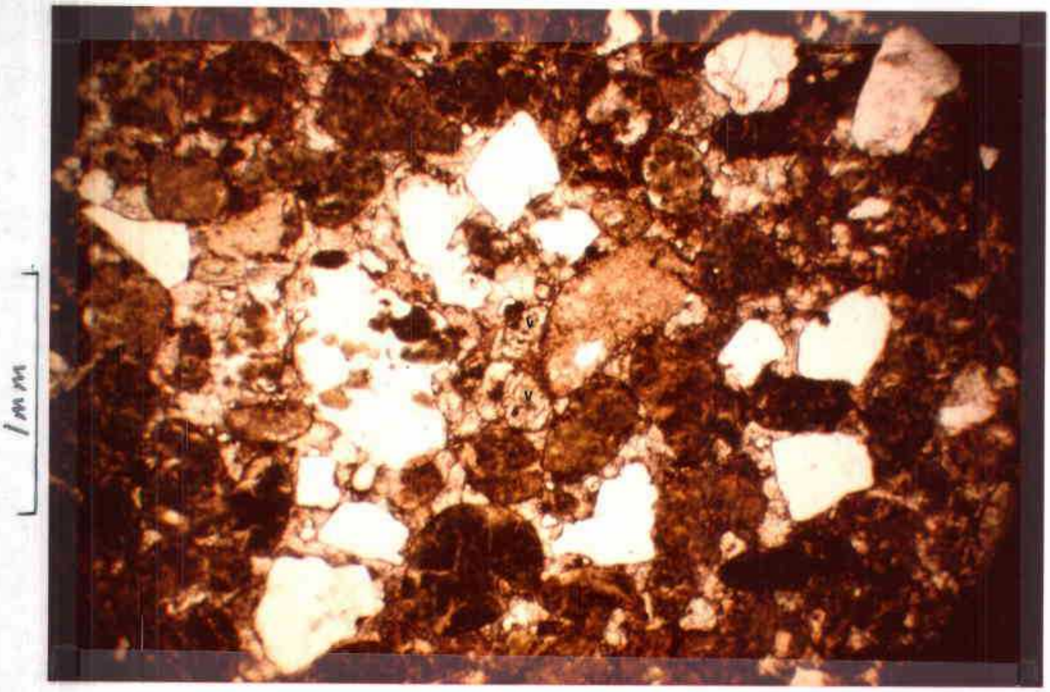


Figure 34. Calcite-cemented glauconitic sandstone at the top of the Tucker Creek member. Colorless grains are quartz and orthoclase. Note incipient glauconitization of volcanic rock fragments (v).

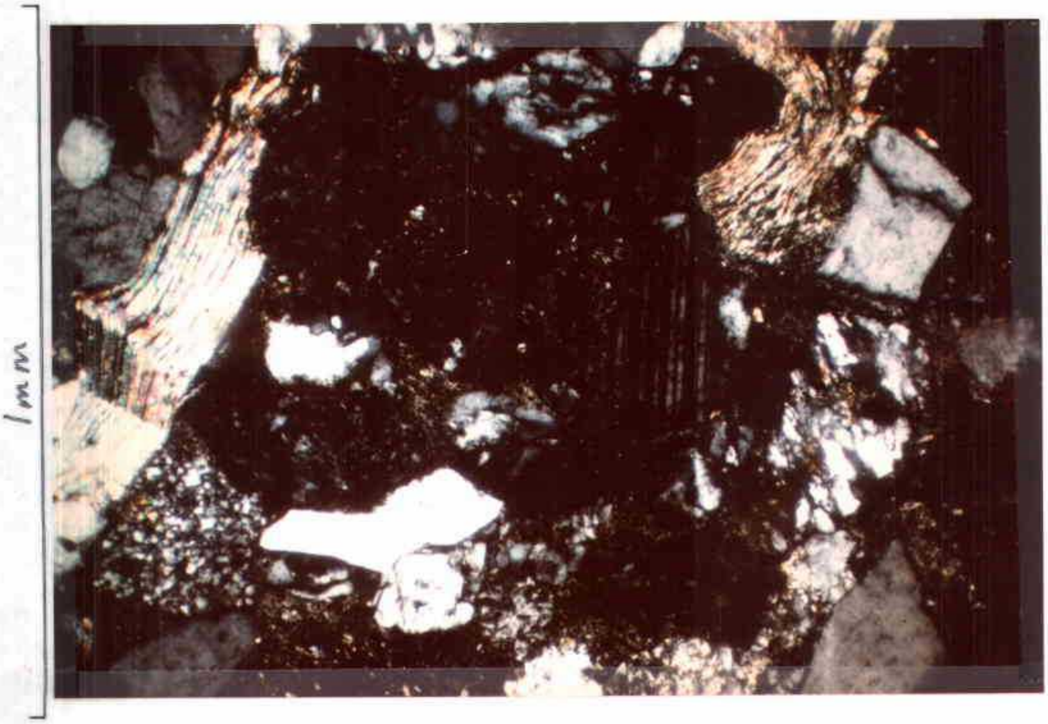


Figure 35. Photomicrograph of Pipeline sandstone, Type I, in Tps_2. Quartz, orthoclase, and plagioclase present. Note bent muscovite and altered biotite. (crossed nicols).

mineral content may be slightly higher in the Big Creek sandstones compared with other members.

Heavy minerals are present in trace amounts in all sandstones studied (Appendix V). Amphiboles, pyroxenes, epidote minerals, and other accessory heavies are common to all sandstones (see Geologic History section for further discussion).

Additionally locally significant constituents of the sandstones in the Astoria Formation include glauconite and carbonaceous matter. Glauconite is abundant in the sandstones at the top of the Tucker Creek and Big Creek members. Glauconite grains are bright green in thin section, fine- to medium-grained, and appear to have formed by the glauconization of the groundmass of volcanic rock fragments, or biotite (Figure 34). Carbonaceous matter occurs as discrete dark brown carbonized plant or wood fragments in the Big Creek member. Orange-brown, kerogen-like, disseminated carbonaceous material occurs in sandstones of the Tucker Creek member (sample no. 154c; Appendix VI). This material contains between 0.5 and 1.0 percent live hydrocarbons (Appendix X).

Almost all sandstones studied in thin section are in framework support. Inter-framework areas are dominated by silt and clay matrix. Cement and void space are present in subordinate amounts (Table 1; Appendix VI).

Matrix is present in variable amounts in all sandstones studied

(8-39%) and typically appears as a greenish to brownish paste (Figures 32 and 33). It is typically composed of angular silt-size (<30 μ) quartz and feldspar grains, finely comminuted micas, and abundant very fine finely crystalline material. The latter consist of greenish isotropic clays (probably chlorophaeite) and yellowish-green to orangish clays of variable birefringence (probably saponite or nontronite). X-ray diffraction analysis of the less-than-two-micron size fractions of the Big Creek and Pipeline sandstones indicates that chlorite (chlorophaeite ?) and hydroxy-interlayered montmorillonite (nontronite or saponite ?) are the dominant clay constituents (Appendix X).

The quartzo-feldspathic portion of the matrix and some of the micas are probably detrital in origin, but much of the clay-size matrix appears to have originated by in situ decomposition of unstable framework detrital grains, particularly volcanic rock fragments. Alteration of volcanic rock fragments to form matrix is indicated by: the presence of plagioclase microlites floating in matrix clays between framework grains; the alteration of the groundmass of volcanic grains to greenish and orange-yellow clays; and the lack of matrix and preservation of volcanic rock fragments in rare calcite-cemented sandstones. The post-depositional decomposition of volcanic rock fragments to form clay matrix is a common occurrence in volcaniclastic sandstones (Cummins, 1962; Whetten and Hawkins, 1969). Matrix clays also have probably formed by alteration of biotite to chlorite and by alteration of feldspars to sericite.

The Pipeline sandstones have relatively low matrix contents (14%, ave.) and high porosities (10%, ave.) (Table 1) and as such are the best potential petroleum reservoirs in the study area. All sandstones in other members of the Astoria Formation have high matrix contents (Table 1) and would be relatively impermeable potential reservoir rocks.

Authigenic cementation of sandstones in the Astoria Formation in the study area is rare. Sandstones in the upper part of the Tucker Creek member are locally cemented by sparry calcite (Figure 34). The calcite appears to have formed, in part, by alteration of plagioclase grains, but dissolution and re-precipitation of calcareous shell material is also a possible source. Hematite cement derived from detrital magnetite, mafic volcanic rock fragments, or biotite is the main cementing agent in sandstones of the Pipeline member (Table 1). Local zeolite cement is also present in the Pipeline sandstones. In a paragenetic sequence, it is typically the last pore-filling material. The zeolites display the optical properties of heulandite and stilbite (Kerr, 1959). Derivation from volcanic rock fragments is probable.

In an overall comparison of the sandstone mineralogies of the Astoria Formation in the study area, it is evident that great differences are not present (Figure 33). However, subtle differences can perhaps be considered valid awaiting further substatiative petrologic work. The Big Creek sandstone member may have a distinctive-enough mineralogy to be used as a criterion for separation from other members. Its relatively low orthoclase/plagioclase ratio, generally high opaque mineral content, and more calcic character of its constituent plagioclase can perhaps be used as distinguishing criteria. The interpretive value of these criteria is apparent in study of the lithologies of the Pipeline member. The anomalous mineralogy of the Type III sandstones (sample no. 332; Appendix VI) of the Pipeline member, in comparison to Type I sandstones, is similar to the mineralogy of the Big Creek sandstones. Type III sandstones have a relatively low orthoclase/plagioclase ratio, high opaque-mineral content, and a more calcic plagioclase content, in comparison to Type I sandstones (An_{42} versus An_{33}, respectively (averages)). The implication is that Type III sandstones were derived from a Big Creek type source area rather than a Type I sandstone source area (see <u>Geologic History</u> section).

One laminated mudstone sample from the lower Silver Point mudstones was examined in thin section. Mud laminae are composed of finely crystalline clays and subordinate larger discrete muscovite flakes. The parallel-oriented clays and micas show well-developed aggregate extinction. Angular silt-size quartz and feldspar grains are scattered throughout the clay matrix. X-ray diffraction analysis indicates that the clays are composed of hydroxy-interlayered montmorillonite and/or chlorite intergrade, subordinate mica, and possibly chlorite (Appendix VIII). Alternating with mud laminae are silty mudstone layers which display weak grading. Angular quartz and feldspar grains are abundant in these layers and aggregate extinction is weak.

Correlation of the Astoria Formation

The purpose of this section is to suggest correlations between members of the Astoria Formation in the study area and informal units of the Astoria Formation recognized by Howe (1926) at the type locality, Astoria, Oregon. The City of Astoria is located immediately north of the study area (Figure 1).

At the type locality, Howe (1926) divided the Astoria Formation into a greater than 150-foot thick lower sandstone, an approximately 1000-foot thick middle mudstone, and an upper sandstone of undetermined thickness. Top and bottom contacts of the formation were not defined by Howe.

Based on similarity in terms of stratigraphic position and gross lithology, the Tucker Creek and Big Creek sandstones in the study area (Figure 5) are correlated with the lower part of Howe's (1926) lower sandstone. These correlated stratigraphic intervals consist primarily of structureless, fine-grained sandstone overlain by finer grained lithologies (interbedded sandstones and mudstone) and underlain by mudstone (see Lithology of the Tucker Creek and Big Creek sandstones and descriptions of the lower sandstone by Howe, 1926, and Carter, 1976). The ages of these correlated intervals are early to middle Miocene (see Age and Correlation sections of units in the study area and discussions of the age of the Astoria Formation type locality by Moore, 1963, and Addicott, 1976b). These correlated sandstone intervals all occur at the base of the Astoria Formation.

"A curious succession of alternate thin beds of sand and thin beds of shale" occurs in the upper part of the lower sandstone as described by Howe (1926). This is essentially a description of the lower Silver Point mudstone unit mapped in the study area (see Lithology section). Additionally, both these stratigraphic intervals overlie thick structureless sandstones (Tucker Creek in the study area; lower part of the lower sandstone at Astoria) and are overlain by a thick sequence of mudstones (upper Silver Point mudstones in the study area, Figure 5; middle mudstone at Astoria, Howe, 1926; Carter, 1976). Therefore lithostratigraphic correlation of Howe's upper part of the lower sandstone and the lower Silver Point mudstones in the study area is suggested.

The upper Silver Point mudstones, Tspu (Figure 5), in the study area and the lower part of Howe's middle mudstone are correlated on the basis of similar stratigraphic position and lithology.

Both intervals consist of laminated to structureless mudstone and lack clastic intrusions and beds of Pipeline sandstone lithology (see Lithology of the upper Silver Point mudstones, and Carter's (1976) description of the middle mudstone).

The Pipeline member (Figure 5) is considered to be lithostratigraphically correlative to the upper part of Howe's middle mudstone and the upper sandstone. Supporting evidence includes 1) the continuous mapping of the Pipeline member from the study area to the City of Astoria showing these correlated intervals to occur at the same stratigraphic position (Plate I; Carter, 1976; Howe, 1926) and 2) the presence of nearly identical mudstone and sandstone lithologies in these correlated intervals (see Lithology of the Pipeline member; Carter, 1976; Howe, 1926).

The upper Silver Point mudstones, $Tspu_1$, overlying the Pipeline member in the study area (Figure 5, Plate I), do not have a lithostratigraphically equivalent counterpart at the Astoria Formation type locality.

Grain Size Analysis

Thirty-three grain-size seive analyses were performed on sandstones from the Oswald West mudstones and the Astoria Formation (Appendix VII). Percentages of sand versus silt and clay, and the statistical parameters of Folk and Ward (1957) were calculated for each sample.

A verbal summary of quantitative size-analysis data (listed in Appendix VIII) for each unit in the study area is presented in Table 2. The purpose of the table is to show the overall textural characteristics of sandstones in each unit and to facilitate rapid comparison of sandstone textural features between units. Percentages of silt and clay fractions are not listed because they can be obtained by taking the difference between the percentage of sand fraction listed and 100 percent. Grain sizes coarser than sand size are not present in any of the sandstones analyzed.

Important sandstone textural differences between units indicated in the table are: 1) Pipeline sandstones are generally coarser and have less silt and clay matrix than other sandstones; 2) the Big Creek sandstones are better sorted and less positively skewed; 3) the Tucker Creek sandstones have relatively low peaked size distributions compared with other sandstones; and 4) the Oswald West sandstones tend to have a higher matrix content and are finer-grained than other sandstones. None of the textural features of the Silver Point sandstones are distinctive alone but in combination may be characteristic of that unit.

Statistical grain-size parameters were plotted on the environmentally-sensitive graphs of Friedman (1962), Moiola and Weiser (1968), and Passega (1957) to aid in the interpretation of depositional

Table 2. Verbal summary of textural features of sandstones in the Oswald West mudstones and the Astoria Formation.

	Sand fraction	Grain size	Sorting	Skewness	Kurtosis
Pipeline member					
Type I sandstone (16)	A (B)	med (fn)	pr (mod)	v. pos.	v. lept.
Type II sandstone (1)	B	fn	pr	v. pos.	v. lept.
Type III sandstone (3)	B (A)	fn	pr (mod)	pos (v. pos.)	v. lept.
Silver Point member (2)	B-C	vf-fn	mod-pr	v. pos.	v. lept. -lept.
Big Creek member (4)	B (C)	vf-fn	mod	pos. (v. pos)	v. lept (lept.)
Tucker Creek member (2)	B-C	fn-med	pr	v. pos.	lept.
Oswald West mudstones					
Middle part (5)	C (B)	vf (fn)	mod-pr	v. pos.	v. lept. -lept.

From size analysis data in Appendix VII; descriptive terminology after Royse (1970).

Sand fraction: A - greater than 90%; B - between 80 and 90%; C - less than 80%

Grain size: med - medium-grained; fn - fine-grained; vf - very fine-grained

Sorting: mod - moderately sorted; pr - poorly sorted

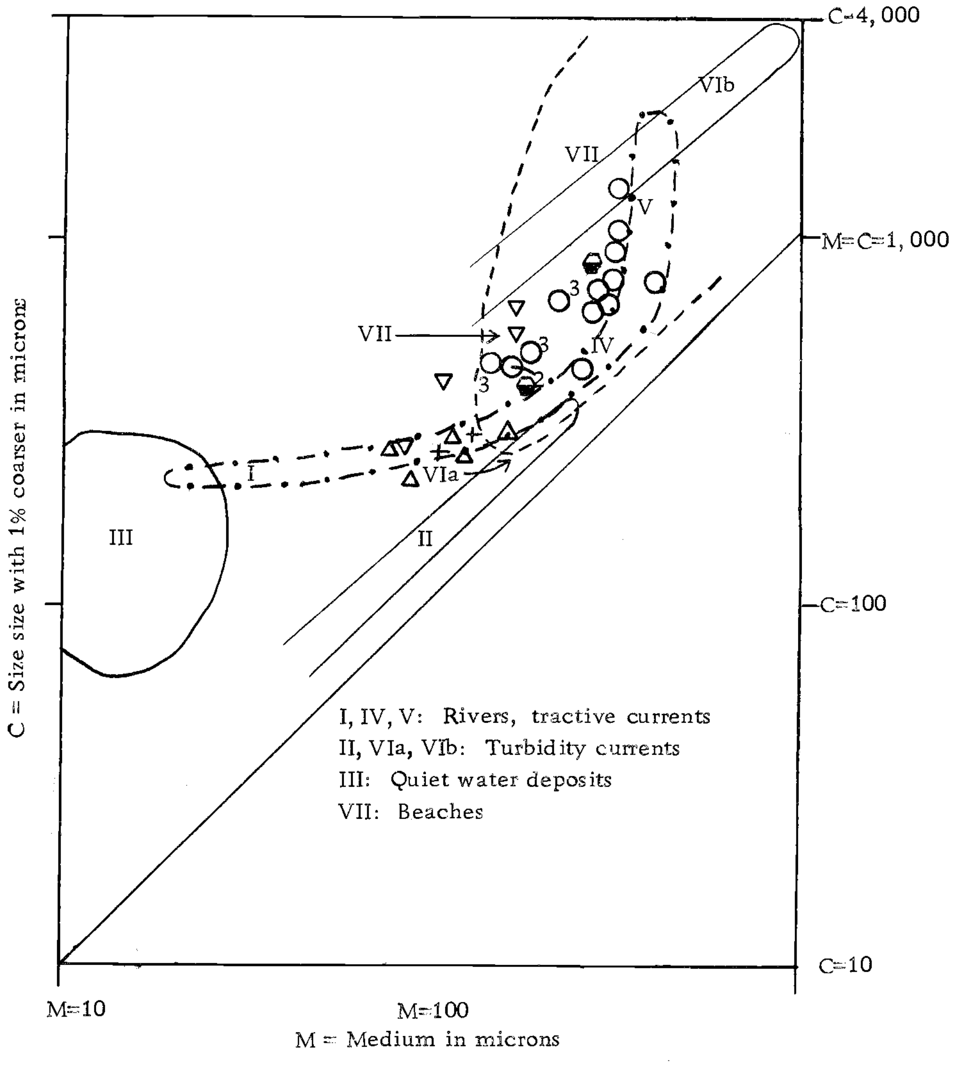
Skewness: pos. - positively skewed; v. pos. - very positively skewed

Kurtosis: lept. - leptokurtic (excessively peaked); v. lept. - very leptokurtic

Textural features listed in parentheses are present but less common than those listed without parentheses. A range in texture where neither end-member is predominant is indicated by a dash.

Number in parentheses following unit name - number of analyses environments for each unit. However, most sandstones invariably plotted within a single environmental field on these graphs, usually river, tractive current, or eolian. Fluvial, tractive current, or eolian origins, which imply deposition in subaerial environments, are considered unlikely for most sandstones in the study area since other evidence is suggestive of a variety of marine depositional environments (see Depositional Environment sections for units in the study area). It is probable that the original size distributions of most sandstones have been altered by the addition of diagenetic matrix through decomposition of unstable sand-size detrital grains (see Petrology sections on the Astoria Formation and the Oswald West mudstones). Consequently, the interpretation of depositional environments utilizing statistical parameters plots is of limited value. Diagenetic alteration of size distributions is substantiated by the consistent plotting of most sandstones in graphical fields where relative enrichment in fines is typical, i. e. fluvial.

The "basic patterns" CM diagram of Passega (1957) is of possible interpretive value for these sandstones because this graphical plot utilizes statistical size parameters that are relatively unaffected by matrix content (the median and coarsest 1%). In this graphical plot, (Figure 36), most of the Pipeline sandstones plot near the higher turbulence end of the river or tractive current field (V); the Big Creek and Tucker Creek sandstones plot predominantly

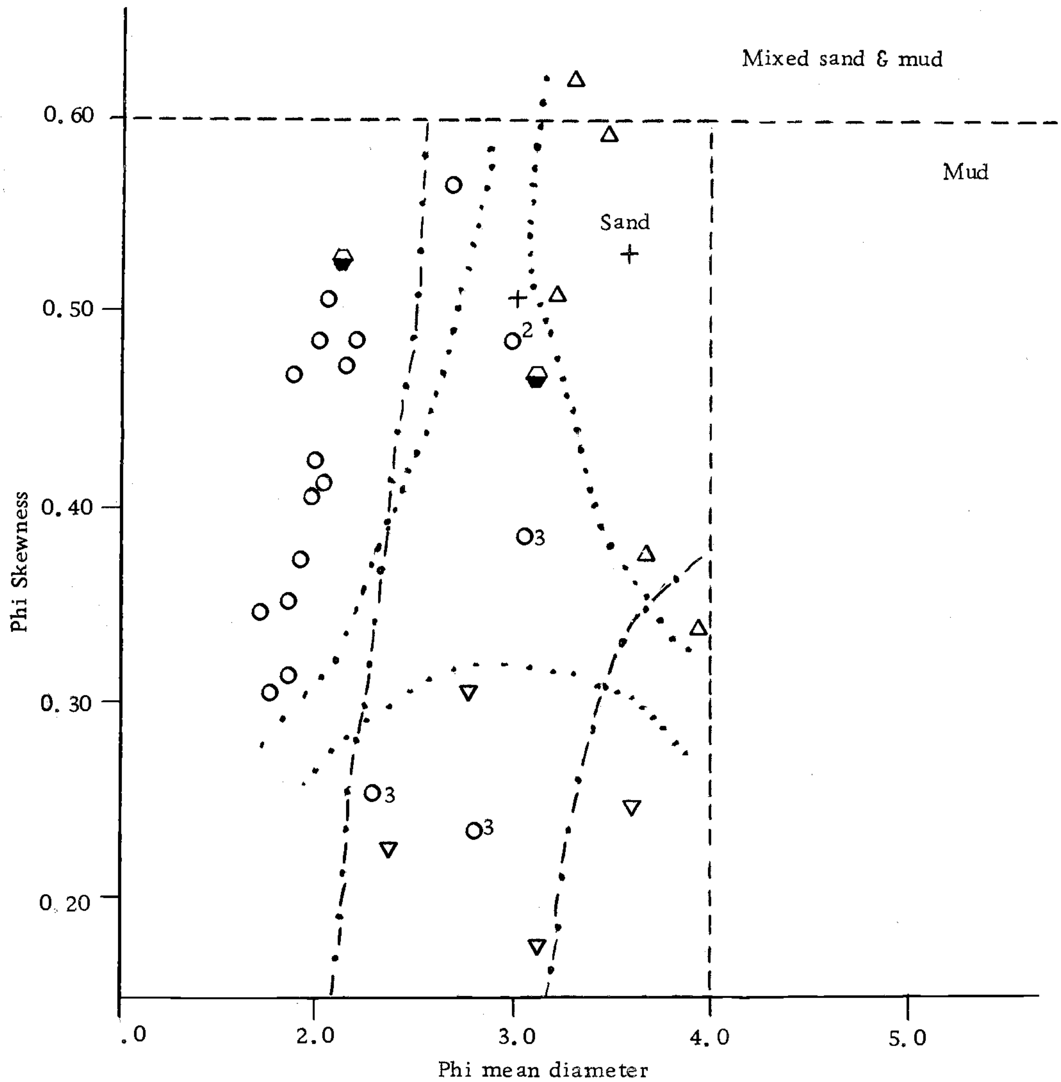


See figure 37 for explanation of symbols.

Figure 36. Plot of sandstones from the Astoria Formation and the Oswald West mudstones on a Passega CM diagram using statistical parameters from size analyses (after Passega, 1957).

within the beach environment field (VII); and virtually all the Silver Point and Oswald West sandstones plot within the low energy end of the river or tractive current field (I). The suggestion of decreasing energy in the depositional environment from Pipeline to Big Creek to the latter members (Silver Point and Oswald West) is corroborated by a corresponding sequential general decrease in grain size (Figure 37; Appendix VII). The plotting of most Pipeline sandstones (Type I) near the high-energy end of the river field suggests that the textural features in these sandstones were inherited from a previous period of fluvial transport. Rapid deposition of these sandstones in a deep-marine environment would result in preservation of these fluvial textural features. This is supportive of a hypothesized direct derivation of Type I Pipeline sandstones from an ancestral Columbia Rivers source (see <u>Geologic History</u> section). The plot of Silver Point sandstones (Type I) on the Passega diagram is somewhat anomalous since these sandstones are interpreted to be turbidity current deposits (see <u>Depositional Environment</u> section).

Statistical grain-size parameter plots were found to be most useful as a criteria with which to differentiate sandstones of the various units and members in the study area. The most effective separation of the units in the study area, into different fields of a bivariant graphical plot, occurred in a plot of sandstone mean diameter versus skewness (Figure 37). The sandstones of the Pipeline



O Pipeline member
- O Type I sandstone
- O2 Type II sandstone
- O3 Type III sandstone

Tucker Creek member

+ Silver Point member

▽ Big Creek member

△ Oswald West mudstones

Size statistics after Folk and Ward (1957)

Dotted lines show fields of Pipeline, Big Creek, and Oswald West mudstones.

Dashed lines show definition of sedimentary facies on modern Oregon shelf (after Kulm and others, 1975)

Dash-dot lines - concentration of sand facies.

Figure 37. Bivariant plot of textural parameters of sandstones in the Astoria Formation and Oswald West mudstones.

member, Big Creek member, and the Oswald West mudstones are well-separated in this plot; those in the Tucker Creek and Silver Point members are not resolved into distinct fields in this plot or most others. Separation of the Big Creek and Pipeline members in a bivariant graphical plot is also reported by Coryell (1977, personal communication). An interesting feature of this graphical plot is the occurrence of Type III Pipeline sandstones in or near the Big Creek sandstone field (Figure 37, see dotted lines). The textural similarity of these two sandstones and their mineralogic similarity (see Petrology of the Astoria Formation section), is suggestive of derivation of Type III Pipeline sandstones from a Big Creek-type source area (see Geologic History section).

Since many of the sandstones of the different units in the study area are inferred to be marine shelf and nearshore beach deposits, except the Pipeline member (see Depositional Environment sections of each unit), a quantitative textural comparison with modern Oregon shelf sediments was made to further substantiate these interpretations. The various sedimentary facies of these modern shelf sediments, defined on a plot of mean diameter versus skewness, are shown in Figure 37 (after Kulm and others, 1975). Virtually all the sandstones from the study area plot within the sand facies field on this graph (Figure 37). Furthermore, almost all the sandstones, except those in the Pipeline member, plot within an area of the sand facies field in which modern inner shelf sands are concentrated (shown by dash-dot lines, Figure 37). It is evident in this comparison that the textural features of modern inner shelf sands and beach sands off Oregon are similar to those of sandstones in the study area which are interpreted to be marine middle or inner shelf deposits, i.e. sandstones in the Big Creek and Tucker Creek members, and the middle part of the Oswald West mudstones. Silver Point sandstones, even though turbidite in origin, are also similar to modern Oregon shelf sands. In a general way, then, Oregon inner-shelf sands may be considered modern analogues of sandstone in these units. The deep-marine Pipeline sandstones are coarser grained than all modern shelf sands (Figure 37) suggesting that they were derived from an alternate source. It is postulated that the Pipeline sandstones (Type I) were derived directly from a fluvial source (see Geologic History section).

Depoe Bay Basalt

The middle Miocene Depoe Bay Basalt occurs as two sills and three dikes in the southwestern part of the study area (Figure 38, Plate I). The basalts tend to form topographic highs with fairly steep slopes as less well indurated Tertiary sedimentary strata around them are eroded away (Plate I). It is probable that the highest point in the study area (NE$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 6, T. 8 N., R. 8 W.)

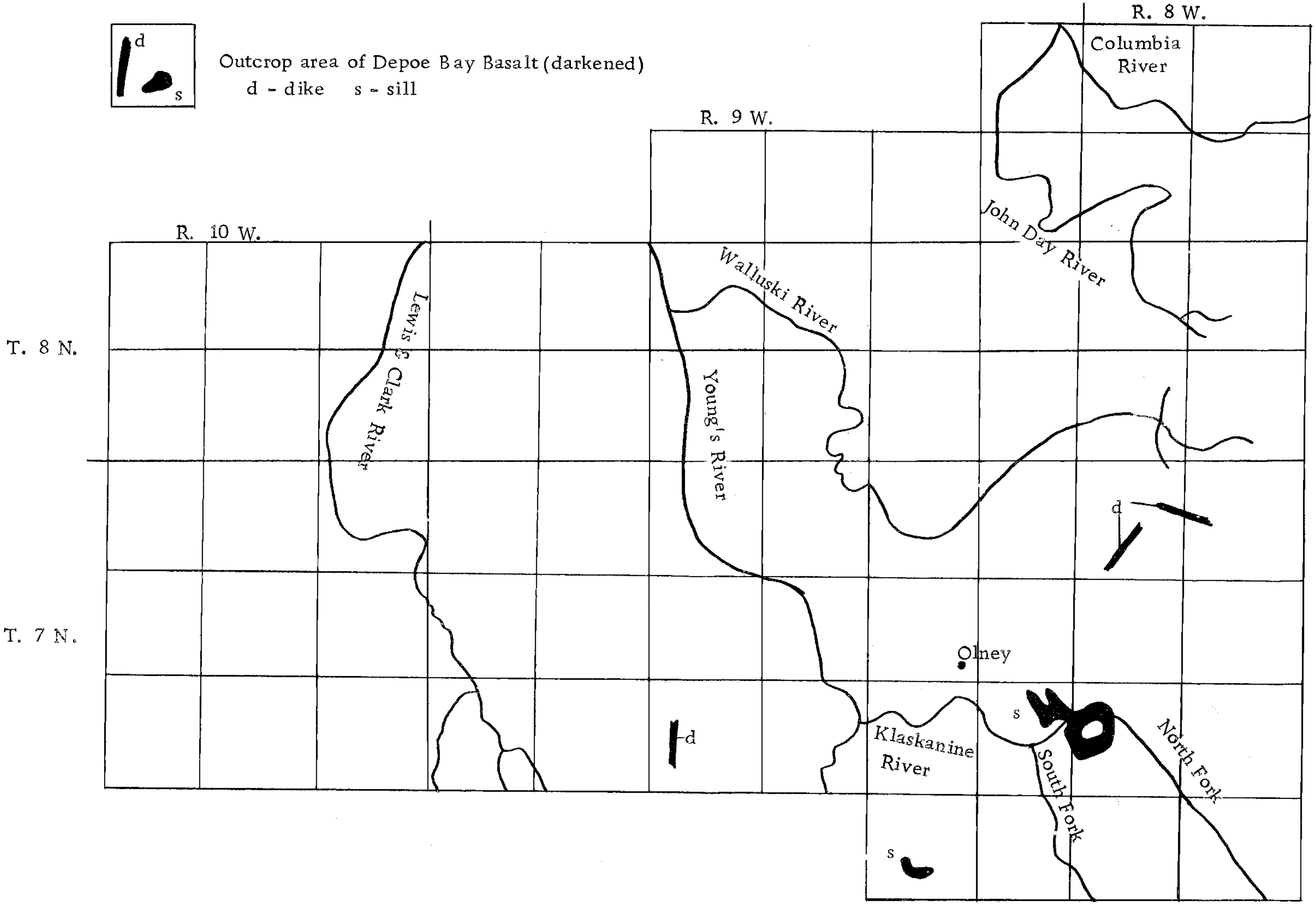


Figure 38. Outcrop distribution of the Depoe Bay Basalts.

is underlain by a basalt dike (Plate I).

Lithology, Petrology, and Chemistry

The Depoe Bay Basalts in the study area are typically finely crystalline (aphanitic) and non-porphyritic. In the central portions of thick intrusions the grain size may be somewhat coarser (up to 1 mm) and rare tiny phenocrysts of plagioclase may be present. Glassy, brecciated basalt occurs locally along the margins of intrusions. The basalts are typically dark gray (N3) and weather to shades of dark yellowish orange (10 YR 6/6). Crude columnar jointing is locally present; structureless basalts are more common.

The three dikes in the study area are eight to ten feet wide. Dike margins are planar and sharp to highly irregular and poorly defined. The sill in section 23 (T. 7 N., R. 9 W.; Plate I) is about ten feet thick. The sill southeast of Olney (Plate I) has a maximum thickness over 100 feet (Figure 39) and is the largest intrusion in the study area. Sill margins are typically sharp and planar to irregular. It is well exposed in a quarry and roadcut on U.S. 202 where it displays wide columnar joints.

Petrographic study indicates that the intrusive basalts in the study area are holocrystalline to hypocrystalline. Glass content is high in the thin dikes and sills in the thesis area (sample 278, Appendix IX). These hypocrystalline basalts typically display

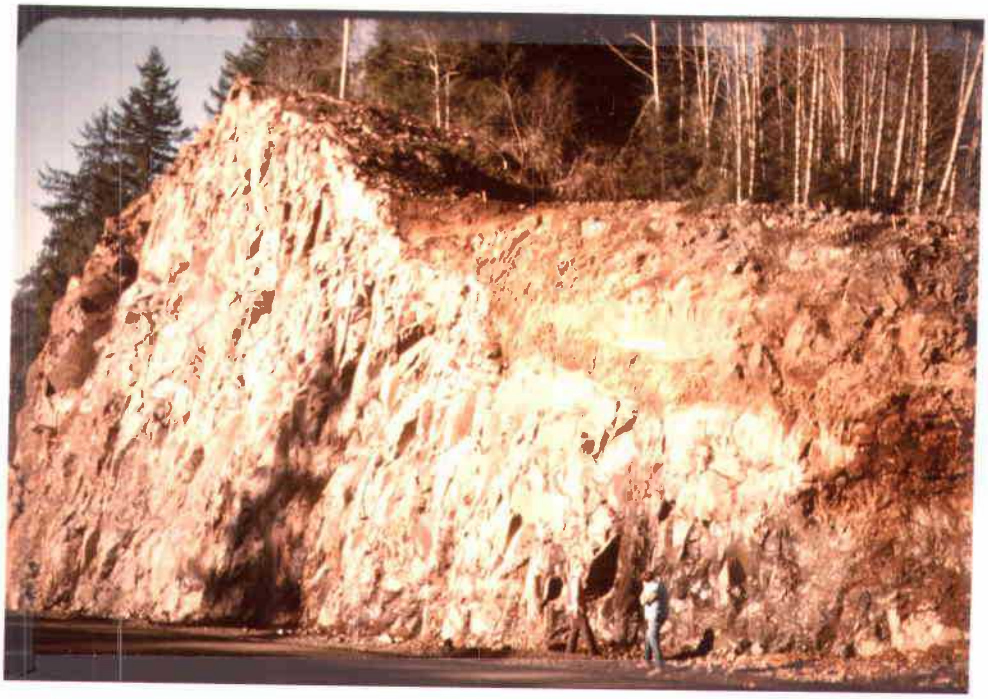


Figure 39. Thick sill of Depoe Bay Basalt intruding upper Oswald West mudstones. Crude columnar jointing and baked contacts present. (Location in text.)

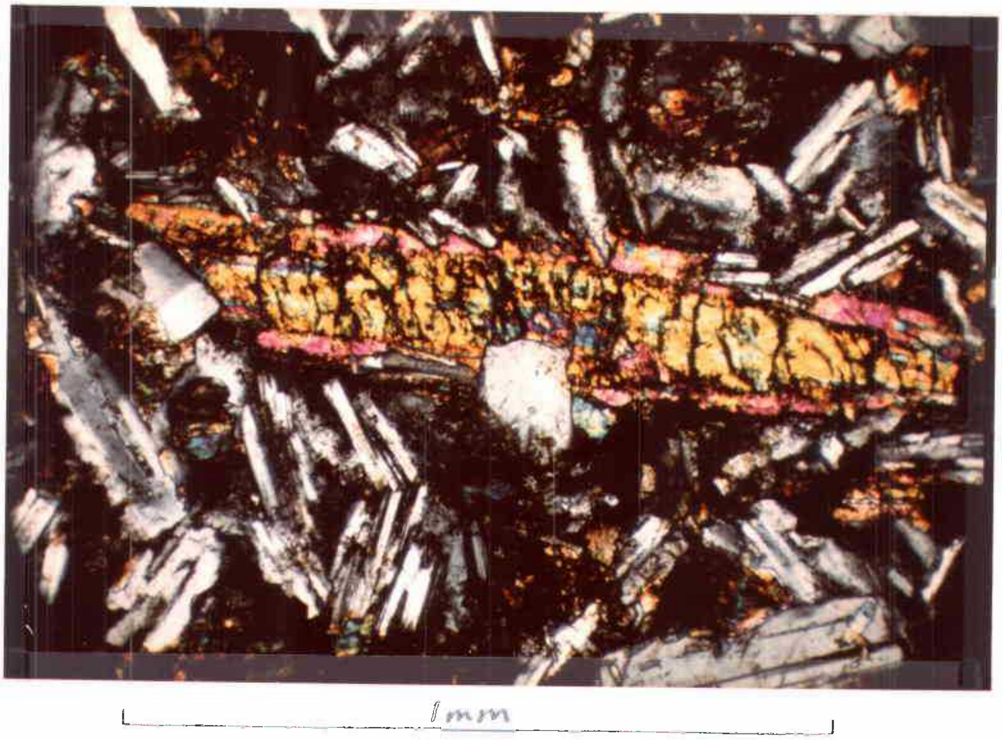


Figure 40. Photomicrograph of Depoe Bay Basalt (from sill, above). Groundmass consists of anhedral plagioclase and clinopyroxene augite microphenocryst intergrown with quartz (?) in center of field of view. (crossed nicols)

intersertal textures in thin section. Holocrystalline basalt composes the center of the thick sill southeast of Olney (Plate I) and displays a diabasic texture in thin section (Figure 40; sample no. 8-9-1, Appendix IX).

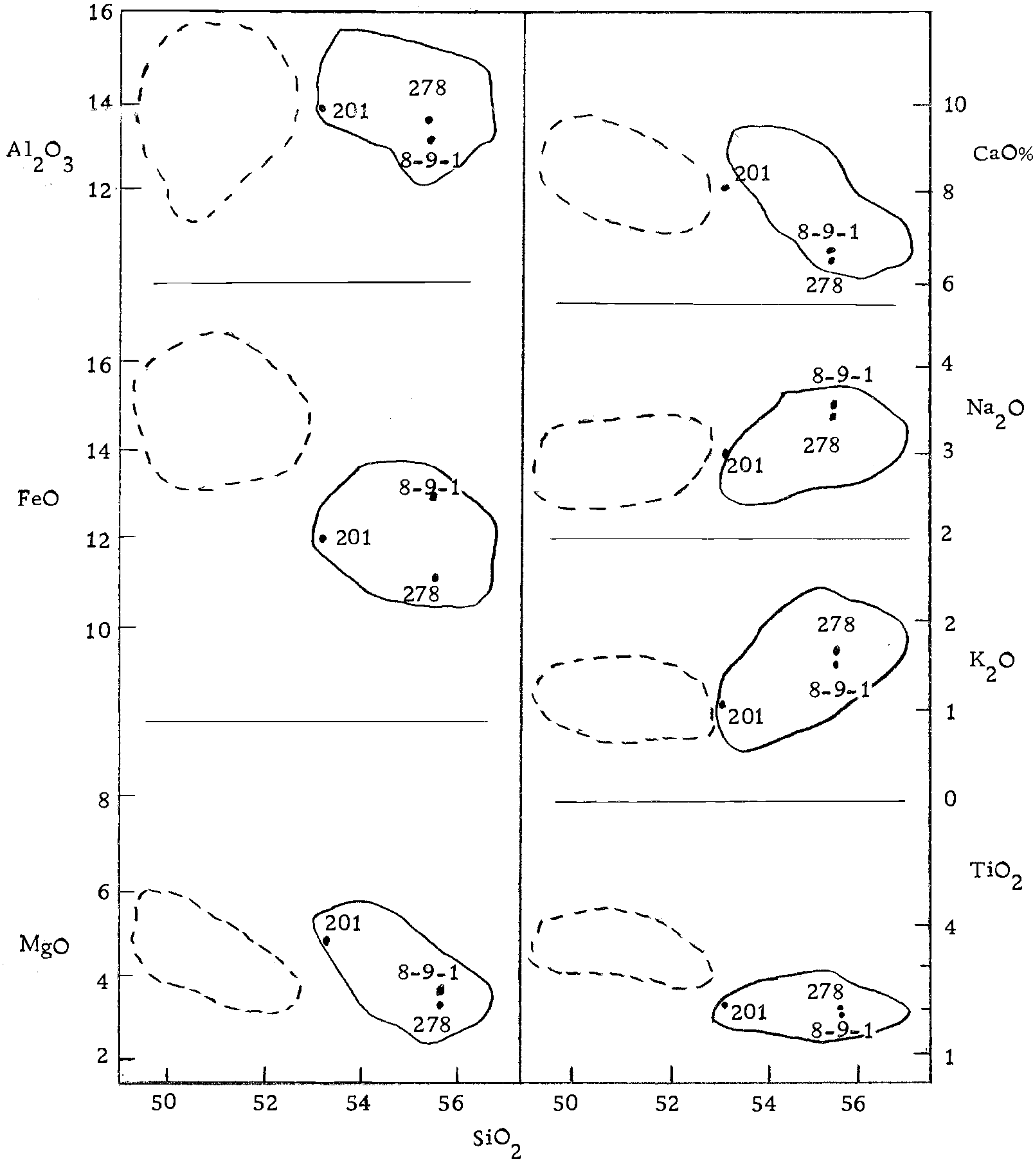
The basalts are composed predominantly of calcic plagioclase (31-48%), clinopyroxene (24-28%), and opaques (12-16%) (Figure 40; Appendix IX). Albite-twinned plagioclase crystals are subhedral to anhedral and range in composition from An_{55} to An_{62} (labradorite). Rare zoned plagioclase is also present. Clinopyroxene crystals (mostly augite) are typically anhedral and, in holocrystalline basalts, may be zoned. They rarely occur as microphenocrysts (Figure 40). Anhedral iron oxides (magnetite and/or ilmenite) fill interstices between plagioclase and pyroxene crystals. In hypocrystalline basalts dirty brown tachylyte glass, containing minute scattered opaques, fills interstices along with iron oxides. Calcite occurs as an alteration product of plagioclase crystals. Anhedral quartz grains are fairly common in the holocrystalline basalt studied in thin section (sample no. 8-9-1, Appendix IX). Most of the grains are probably secondary, but intergrowth of quartz and clinopyroxene observed in the thin section (Figure 4) is suggestive of a primary magmatic origin.

Plots of chemical analyses of basalts from the study area (analyses listed in Appendix IX) on a silica variation diagram are within the compositional range of the Depoe Bay Basalt chemical-type as defined by Snavely and others (1973) (Figure 41). These basalts are characterized by relatively high SiO_2 and low TiO_2 contents in comparison with other middle Miocene coastal basalts of the Oregon and Washington Coast Ranges (e. g. Cape Foulweather). Depoe Bay Basalts are also typically non-porphyritic as are the basalts in the study area. Therefore, the basalts in the study area are termed Depoe Bay Basalt to indicate chemical and lithologic equivalence with the type Depoe Bay Basalts at Depoe Bay, Oregon (Snavely and others, 1973).

Contact Relations

In the study area, the Depoe Bay Basalt intrudes the upper Oswald West mudstones, the lower Silver Point mudstones, and the mudstones of the Pipeline member (Tpm) (Plate I). Baked sedimentary strata marginal to the basalt intrusions (mudsones in all exposures) are typically bleached and well-indurated. Locally, finger-like apophyses of basalt extend into the surrounding mudstones (Figure 39).

Six miles to the east of the study area, extrusive Depoe Bay Basalts, chemically and petrologically correlative to intrusions in the study area, unconformably overlie older strata of the Astoria Formation and Oswald West mudstones (Coryell, 1978). This



--- Cape Foulweather compositional limits

——— Depoe Bay compositional limits

Samples listed in Appendix IX, locations given in Appendix XI and on Plate I.

Figure 41. Comparison of Cape Foulweather and Depoe Bay petrologic types variation limits with basalt samples in thesis area. (after Snavely and others, 1973)

relationship is also observed directly south of the study area (Penoyer, 1977; Tolson, 1976).

Age and Correlation

The Depoe Bay Basalt intrusions in the study are middle Miocene in age. The occurrence of these intrusions in the subunit, Tpm, of the Pipeline member (Plate I) fixes a lower age limit for the intrusions of late early Miocene (see Age and Correlation section of the Pipeline member). However, more precise ages for the Depoe Bay Basalts have been obtained to the south of the study area.

The type Depoe Bay Basalts at Depoe Bay, Oregon were determined by Snavely and others (1973) to be middle Miocene in age based on K/Ar dates and foraminiferal evidence. Depoe Bay Basalts in the Tillamook Head area were dated (K/Ar) at 15.5 ± 0.4 m.y. by Niem and Cressy (1973). Neel (1976) obtained a Foraminiferal age for the Depoe Basalts of middle Miocene in the Sugarloaf Mountain area. The Depoe Bay Basalt intrusions in the study area are probably of similar age (middle Miocene) since they are equivalent to the dated basalts in terms of chemistry, lithology, and stratigraphic position.

The Depoe Bay Basalts are chemically, petrologically, and age equivalent to the Yakima-type basalts of the Columbia River Basalt Group in eastern Oregon and Washington (Snavely and others, 1973).

Quaternary Deposits

For mapping purposes, Quaternary deposits in the study area were divided into beach ridge and inter-ridge deposits (Qb), and alluvial terrace ($Qual_1$) and modern floodplain deposits ($Qual_2$) (Plate I).

Alluvial terrace and floodplain deposits are extensive along the Lewis and Clark, Young's, Walluski, and John Day Rivers in the study area (Plate I). Terrace deposits ($Qual_1$) typically form prominent benches about 50 feet above younger modern floodplain deposits ($Qual_2$). These benches are easily recognized on topographic maps and in aerial photos. Terrace deposits are restricted in occurrence to the flanks of modern river valleys.

Terrace deposits ($Qual_1$) consist of two sedimentary facies. The first consists of unconsolidated, poorly sorted, framework-supported, rounded to subrounded, pebbles and cobbles set in a matrix of medium- to coarse-grained, friable, dirty, lithic and quartzose sand. Basaltic cobbles and pebbles are predominant but mudstone and sandstone lithologies also occur. These clasts display thick weathering rinds on freshly broken surfaces. Grayish orange (10 YR 7/6) is the predominant color of this lithology due to pervasive iron-oxide-staining. The localized occurrence of this facies and its coarseness are suggestive of a river channel origin. This facies is well-exposed along the Lewis and Clark Road, NW$\frac{1}{4}$, sec. 7, T. 7 N., R. 9 W.

The second and more common terrace facies consists of bluish-gray to brownish gray, well-laminated, sandy, cohesive muds interbedded with subordinate amounts of thinly bedded, muddy, fine- to medium-grained sand. Rare carbonized plant fragments and mica occur on mud laminae surfaces. These muds and sands are rhythmically interbedded in exposures along the road at the northwest edge of the study area (SW$\frac{1}{4}$, SW$\frac{1}{4}$, sec. 27, T. 8 N., R. 10 W.). These lithologies are similar to deposits in modern levee and flood-basin environments marginal to river channels (Allen, 1970).

River entrenchment destroyed most of the old floodplain represented by present terrace deposits along river valley margins. As rivers approached new base levels, younger floodplain deposits were developed ($Qual_2$, Plate I) in the study area. These deposits consist of a down-stream-thickening surficial veneer of fine sands, silts and clays, which overlie river gravels interbedded with fine-grained sediments (Schlicker and others, 1972). Prominent levees along the Lewis and Clark and Young's River are probably of natural and man-made origin.

Beach ridge and inter-ridge deposits (Qb, Plate I) of the Clatsop Plains occur in the southwesternmost part of the study area. The Clatsop Plains consist of a series of north-south-trending, arcuate, beach ridges composed of fine- to medium-grained sand with heavy mineral placers (Cooper, 1958). The ridges are thought to be storm-wave and dune deposits formed on a wave-cut marine terrace 6,000 to 18,000 years B.P. during coastal plain progradation (Cooper, 1958). Sand was probably derived from the Columbia River by long-shore drift input. Inter-ridge swales are sites of peat formation (Schlicker and others, 1972) and lacustrine sedimentation (Cullaby Lake, southwest corner of study area; Plate I).

Structural Geology

Regional

The northern Oregon Coast Range is structurally a northward-plunging anticlinorium consisting of a core of Eocene volcanics with flanking accumulations of younger Tertiary sedimentary and volcanic units (Snavely and Wagner, 1964; Figure 2; see Regional Geology section). Numerous broad open folds on the east flank of the anti-clinorium have a north-northwesterly trend which becomes more westerly in folds on the anticlinorium nose (Wells and Peck, 1961). High-angle normal and reverse faults generally have northwesterly and northeasterly trends. Offshore structures are generally discord-ant with onshore structures which is suggestive of major faulting at the coastal periphery of the northern Oregon Coast Range (Zietz and others, 1971).

Several major unconformities in the northern Oregon Coast Range Tertiary strata (see Regional Geology section) record periods of active tectonism and/or eustatic sea level changes (Snavely and Wagner, 1964). Local unconformities are also present in the rock records preserved in structural embayments of the west side of the Oregon Coast Range. These downwarped marginal basins include the Newport, Tillamook, and Astoria embayments. Strata in the study area were deposited in the Astoria embayment, the axis of which approximately parallels the lower Columbia River (Bromery and Snavely, 1964). The sedimentary rock sequence within the embayment is between 5,000 and 10,000 feet thick (Braislin and others, 1971).

Thesis Area Structure

The major structural features in the study area include the two north-northwest-trending faults concealed by the alluvial valleys of the Lewis and Clark River and Young's River (Figure 41; Plate I; dotted lines). Though not exposed, these faults are inferred to be present based on the marked lack of structural and stratigraphic continuity across these river valleys.

The regional stratal strike (east-west) remains constant across each river valley but major dip reversals are striking. Consistently northward-dipping strata to the east of Young's River strike into northward- and southward-dipping strata on the central ridge to the west of the river (Plate I). This ridge is structurally a faulted east-west-trending anticline (Plate I). Structural discordance across Young's River is also indicated by the lack of continuity of faults across the river (Figure 43; Plate I). Stratigraphic discontinuities a are typified by the juxtaposition of early to middle Miocene Big Creek sandstones and late Eocene to early Oligocene middle Oswald West mudstones when each unit is projected across Young's River along strike (Plate I). The position of the Young's River fault in the north central part of the study area is clear (in the Young's River alluvial valley) but its continuation in the south central part is uncertain. It may continue along Young's River (slightly southeasterly) or it may trend slightly southwesterly across the alluvial valley of Tucker Creek and along the alluvial valley of an unnamed river which is a tributary to Tucker Creek (Plate I). Major faulting is certainly present along either trend based on the occurrence of structural and stratigraphic discordances across each trend.

Substantial evidence supports the existence of a major fault along the Lewis and Clark River. The anticlinal structure on the central ridge (to the east of the Lewis and Clark River) strikes westward into almost entirely southward-dipping section of strata on the ridge to the west of the river (Figure 42; Plate I). Projection of strata along strike across the northern part of the Lewis and Clark

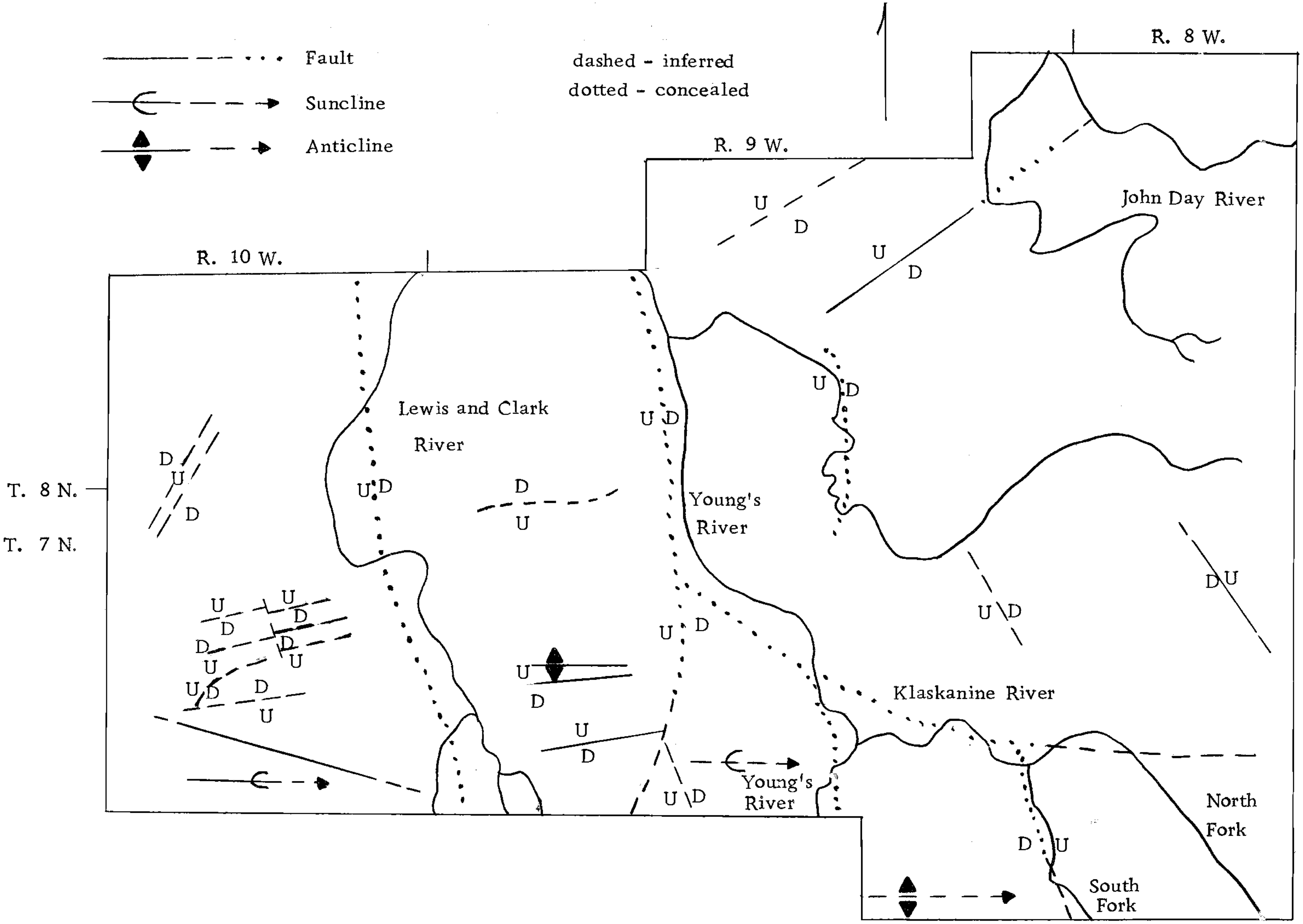


Figure 42. Structure map of the study area.

River shows juxtaposition of late Eocene to early Oligocene, lower and middle, Oswald West mudstones and early to middle Miocene Silver Point and Pipeline strata (Plate I). These large structural and stratigraphic discordances across the Lewis and Clark River suggest that the river valley conceals a major fault.

Because strata to the east of each of these faults is generally younger than strata to the west of each (Plate I), the upthrown block is presumed to be on the west side of each fault. This would account for the overall differences in ages of strata on each side of the Young's River and Lewis and Clark River valleys. However, the major dip reversals across the river cannot be explained in terms of simple translational block faulting. The major anticlinal axis on the southern part of the central ridge in the study area (sec. 8, T. 7 N., R. 9 W.) has possibly been offset northward from the anticlinal axis to the east of Young's River at the southeastern border of the study area (Figure 42; Plate I). Realignment of these two anticlinal axes would result in conformance of stratal dip direction on both sides of Young's River. If these two anticlinal axes have been offset, the displacement mechanism would require some strike-slip right-lateral motion along the Young's River fault (approx. $1\frac{1}{2}$ miles of offset). This type of displacement appears to be the simplest explanation for the dip reversals across Young's River. Similar right-lateral strike-slip motion has been postulated by Penoyer (1977) in faults to the southwest of the study area. Alternatively, complex rotational block faulting may have resulted in these dip reversals.

The southward dip of strata on the westernmost ridge in the study area (west of the Lewis and Clark River) is remarkably discordant with the overall northward stratal dip in the eastern half of the study area (to the east of Young's River) (Plate I). Large-scale strike slip displacement along the Lewis and Clark River fault could be invoked to explain this, but is not necessary. Dip reversals such as this can result from rotational block faulting. Assuming an original northward dip, strata on the ridge west of the Lewis and Clark River could have been rotated upward and southward along the Lewis and Clark River fault relative to other areas, resulting in a dip reversal (southward-dipping) with sufficient rotation. The rotational axis would presumably be south of the study area. This type of rotational faulting implies that displacement along the fault plane becomes greater with increasing distance from the rotational axis. This effect is perhaps seen in the juxtaposition of successively older strata on the west side of the fault with successively younger strata on the east side of the fault proceeding northward along the Lewis and Clark River (Plate I).

Since faulting along the Lewis and Clark River and Young's River faults is complex, is difficult to determine the amount of effect along each. Based on the juxtaposition of Oswald West strata and Pipeline member strata along each fault (projected along strike), dip-slip displacements of more than a 1,000 feet (perhaps several 1,000) along each fault are possible.

A third major fault trends subparallel to the Klaskanine River and its north fork (Figure 42). Northward-dipping upper Silver Point mudstones (Tspu) on the south side of the fault are down-faulted against northward-dipping upper Oswald West mudstones on the north side. Since approximately 900 feet of intervening strata occur between these two units (Figure 5), this distance is the minimum dip-slip displacement along the fault.

Folds in the study area consist of two east-west-trending anticlines and two small synclines. The plunges are generally at low angles in the east. Most of the smaller faults in the study area generally trend northwest-southeast and northeast-southwest. However, many faults to the west of Young's River tend to have more of an east-west component of strike than faults in the eastern half of the study area. This difference is perhaps genetically related to the major faulting along Young's River and the Lewis and Clark River.

The most significant faulting in the study area, other than along the Young's, Lewis and Clark, and Klaskanine Rivers, occurs in the northwest part of the study area. The northwest-trending fault in sections 23, 24, 26, and 27 (T. 8 N., R. 9 W.) separates southward-dipping Pipeline strata on the west from northward-dipping Pipeline strat on the east (Plate I). The sandstone-dominated interval, Tps_2, of the Pipeline member, has been offset a mile or more along the fault. The dip reversal across the fault suggests that rotational faulting has occurred to produce this offset. Pipeline strata to the west of the fault dip southward all the way to the city of Astoria (2 miles) while Pipeline strata to the east dip southward almost to the town of Svensen, four miles east of the study area (Coryell, 1978). This suggests that this fault is a major control on the dip reversal of strata between Astoria and Svensen.

With the possible exception of the middle Miocene Depoe Bay Basalts, faulting affects all bedrock units in the study area. Therefore, faulting is probably middle Miocene or younger in age. A northwest-trending fault at the eastern boundary of the study area (sec. 5, T. 7 N., R. 8 W.) has offset early to middle Miocene Big Creek sandstone strata but does not appear to offset a Depoe Bay Basalt dike intersecting the fault. This suggests the possibility of post-Astoria and pre-Depoe Bay (middle Miocene) faulting. Pre-Depoe Bay Basalt faulting has been reported by Penoyer (1977), Cressy (1974), and by Coryell (1978).

TERTIARY GEOLOGIC HISTORY

Paleocurrent Data

Orientations of axes of channelized sandstone bodies are the only indicators of paleocurrent directions in the late Eocene to earliest Miocene Oswald West mudstones in the study area. Current-formed internal sedimentary structures are lacking, probably due to bioturbation and soft-sediment deformation. Channel-axis orientations are suggestive of northwest-southeast and northeast-southwest lines of paleo-sediment dispersal (Figure 43). Paleogeographic reconstructions of the Coast Range area by Snavely and Wagner (1963) show land areas to be present only to the east, southeast, and northeast of the study area during Oswald West time, so paleo-sediment dispersal was probably westerly.

Micro-trough-cross-laminations in turbidite sandstones (Bouma C interval) serve as paleocurrent indicators in the early to middle Miocene Silver Point mudstones. These unidirectional indicators of current flow are suggestive of a northwesterly paleo-sediment dispersal pattern (Figure 43). This is supportive of a hypothesized derivation of the turbidite sandstones in the unit from the early to middle Miocene Angora Peak delta (Cressy, 1974; Smith, 1975), located 19 miles to the south of the thesis area.

Trough cross-bedding was the only indicator of paleocurrent

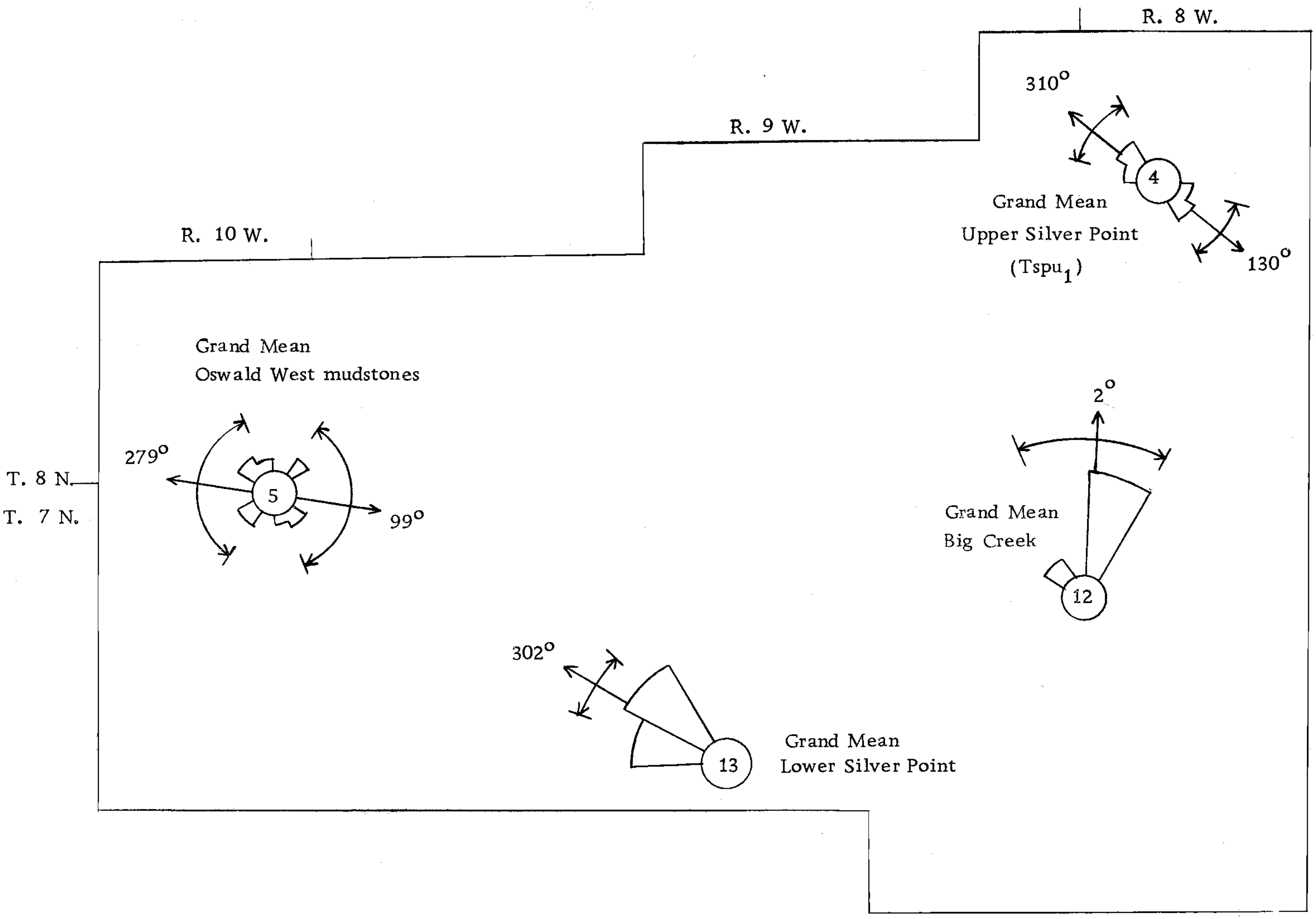


Figure 43. Rose diagrams showing paleocurrent directions of units in the study area.

direction in the early to middle Miocene Big Creek sandstones. Unlike other units in the study area, a distinct northward component of paleo-sediment dispersal is indicated (Figure 43). This substantiates a hypothesized derivation of some of the detritus in the Big Creek sandstones from the Angora Peak delta by northward longshore drift. Similar paleocurrent directions in the Big Creek sandstones are reported by Coryell (1978) in work to the east of the thesis area.

The geometries of the sandstone-dominated intervals (Tps_1, Tps_2) in the Pipeline member are suggestive of a westerly to southwesterly paleo-sediment dispersal pattern (see Depositional Environment section of the Pipeline sandstones).

Oriented elongate carbonized plant fragments were utilized as paleocurrent indicators in the youngest sedimentary bedrock unit in the study area, $Tspu_1$ (early to middle Miocene), an upper subunit of the upper Silver Point mudstones. These indicators suggest a northwest-southeast line of paleo-sediment dispersal (Figure 43). Dispersal to the northwest along this bidirectional orientation is inferred because of the general westerly or northerly paleocurrent directions obtained in other units.

Provenance

The volcaniclastic and tuffaceous character of much of the detritus in the Oswald West mudstones and in members of the Astoria

Formation is a reflection of the predominance of the volcanics in potential proximal source areas. From the Eocene to the Miocene, basalt highlands in the ancestral Coast Range area, and pyroclastic and intermediate to basaltic volcanic buildups in the ancestral Cascades, shed large volumes of volcanic detritus into adjacent marine basins of the Oregon and Washington Coast Range geosyncline (Snavely and Wagner, 1963). In addition to predominant volcanic input, more distal sediment sources such as the acid igneous and metamorphic terrains of north-central Washington and eastern Oregon probably contributed non-volcanic detritus to local areas of the geosyncline (Cressy, 1974; Smith, 1975; and see below).

The predominance of montmorillonite in the clay fractions of mudstones and siltstones in the study area (Appendix VIII) is suggestive of a volcanic provenance (Deer and others, 1962). Abundant epiclastic and pyroclastic volcanic deposits of the ancestral western Cascades, such as the Oligocene to early Miocene Little Butte Volcanic Series, are possible sources of the montmorillonite-rich detritus in these fine-grained lithologies. Numerous tuff beds in the Oswald West mudstones, and a lesser number in the Silver Point mudstones, probably represent contemporaneous explosive dacitic (?) volcanic input from eruptions in the ancestral western Cascades.

Basaltic and andesitic rock fragments are the predominant lithic constituents of the sandstones in the Oswald West mudstones;

and the Tucker Creek, Big Creek, Silver Point, and Pipeline members of the Astoria Formation (see petrology sections). This aspect of composition is indicative of an important volcanic provenance for these units. Basaltic rock fragments were probably derived from locally uplifted basaltic highlands marginal to the study area (Snavely and Wagner, 1963; Wolfe and McKee, 1972). Specific basaltic provenances would include the Eocene Tillamook and Goble Volcanics which form the core of the northern Oregon Coast Range. Andesitic, and some basaltic detritus, probably originated farther to the east in the ancestral western Cascades of Oregon and Washington. Possible sediment sources in these areas include the andesites and basalts of the Oligocene to Miocene Little Butte Volcanic Series (Wells and Peck, 1961) (in Oregon) and the Oligocene Ohanapecosh Formation of the southern Washington Cascades (Fiske, 1963). These sources may have supplied the hornblendes and hypersthenes which commonly occur in the heavy mineral fractions of sandstones in the study area (Appendix V). Local basalt highlands (Tillamook and Goble Volcanics in Oregon; Crescent Formation in Washington; all Eocene) along with western Cascade sources may have supplied augite which is also a common heavy mineral (Appendix V). Local Eocene basalts and the andesites of the western Cascades have been suggested as provenances for the Oswald West mudstones and the Astoria Formation by previous workers (Penoyer, 1977; Neel, 1976; Smith, 1975; and

Cressy, 1974).

The presence of non-volcanic detritus in all sandstones studied indicates that provenance areas are not limited to the Oregon and Washington Cascades or Coast Ranges. Metamorphic rock fragments (schists, metaquartzite, phyllites, gneisses) (see petrology sections) and the heavy minerals tremolite, epidote, clinozoisite, garnet, andalusite, staurolite, and kyanite (Appendix V) are indicative of a high- and low-rank metamorphic provenances. Such metamorphic terrains are absent in the Oregon Coast Range and of limited extent in the southern Oregon Cascades. Additionally, acid plutonic source terrains are suggested by the presence of granitic rock fragments (Appendix VI) and detrital grains of monazite, muscovite, rutile, orthoclase, tourmaline (schorlite), zircon, and sphene (Appendix V). Possible sources of these non-volcanic detrital grains include the pre-Tertiary metamorphic and acid igneous terrains of north-central Washington (e.g. Darrington Phyllite, Cretaceous granitic batholiths), northeastern Washington and southeastern British Columbia (e.g. Precambrian Belt Series, gneisses and schists of the Shuswap Complex, Cretaceous granitic batholiths), eastern Oregon (e.g. schists, gneisses, and granites of the Blue Mountains Province), and Idaho (e.g. Ordovician quartzites, Cretaceous Idaho batholith).

Transport of detritus from such areas to the study area implies that a large-scale drainage system existed, perhaps comparable to that of the modern Columbia River. The Columbia River (and its tributaries) receives sediment from all these areas (Whetten and others, 1969) and the mineralogy of its transported sands is similar to that of the sandstones in the study area. An ancestral Columbia River, similar to the present day river in terms of drainage area, may have been a significant source of the non-volcanic dettritus in the study area. An ancestral Columbia River sediment input is consistent with the general east to west paleocurrent dispersal pattern suggested gy paleocurrent indicators in units of the study area (Figure 43). Additional evidence suggesting provenances to the east of the Cascades for the Oswald West mudstones and the Astoria Formation is presented by Penoyer (1977), Neel (1976), Smith (1975), and Cressy (1974).

The Cretaceous and Jurassic metamorphic and acid igneous terrains of the Klamath Mountains in southwestern Oregon are possible sources of non-volcanic detritus. Such detritus may have been transported northward by longshore drift toward the study area, similar to modern sediment dispersal patterns in the Oregon offshore (Scheidegger and others, 1971). A northward transport direction is suggested by paleocurrent indicators in the Big Creek sandstones (Figure 43).

Geologic History, Summary, and Conclusions

Six major rock units were mapped in the thesis area. They are, in approximate stratigraphic order: the Oswald West mudstones; the Tucker Creek sandstone, Big Creek sandstone, Silver Point mudstone, and Pipeline members of the Astoria Formation; and the Depoe Bay Basalts (petrochemical type). Quaternary alluvial and beach-ridge deposits are also present.

The bedrock sedimentary units in the study area record nearly continuous conditions of marine sedimentation from the late Eocene to middle Eocene. This record is punctuated by a possible minor hiatal or erosional unconformity between the Oswald West mudstones and the overlying Astoria Formation. A major post-middle Miocene angular unconformity separates all bedrock units from overlying Quaternary deposits.

According to Snavely and Wagner (1963), a geosynclinal trough was present in western Oregon and Washington in the early Tertiary. The trough was delimited on the north by Vancouver Island, on the south by the Klamath Mountains, on the east by the Cascades, and on the west by the offshore of Oregon and Washington. In terms of a plate tectonic model, the geosyncline may have been a fore-arc basin in an arc-trench system (Dickinson, 1974), the magmatic arc being located near the axis of the present Oregon Cascades and the subduction zone in the Oregon and Washington offshore (Niem, 1976). An arc-trench system in western Oregon and Washington may have been initiated by subduction of the Farallon Plate beneath the North American Plate 40 to 60 m.y. B.P. following northward migration of a triple plate junction along the west coast of North America (Atwater, 1970).

Initial infilling of the Tertiary geosyncline (fore-arc basin?) occurred in the early and middle Eocene (?). Over 10,000 feet of pillow basalts and basaltic breccias (Tillamook and Siletz River Volcanics), complexly intertonguing with deep-marine tuffaceous siltstones and sandstones, accumulated in the axis of the geosyncline (Snavely and Wagner, 1963). Presumably equivalent Eocene basalts and overlying sedimentary rocks are present in the subsurface of the study area, based well records from the Standard "Hoaglund" and Lower Columbia "Brown" wells in the western part of the study area (Newton, 1969; Plate I). The sedimentary rocks consist of foraminifera-rich, pyrite-bearing, mudstones and siltstones which were probably deposited in a deep-marine, reducing continental slope environment (Tolson, 1976).

The late Eocene to early Miocene Oswald West mudstones are the oldest strata exposed in the study area. As a whole the unit is distinguished by a predominance of hemipelagic mudstones and siltstones, common soft-sediment deformational features, extensive bioturbation, abundant glauconite, and constituent deep-water fossil assemblages. These features are indicative of deep-marine, low-energy, depositional conditions such as occur in outer shelf and slope environments (Stanley and Unrug, 1972; Kulm and others, 1975; Reineck and Singh, 1975). However, the abundance of sandstones in the middle part of the Oswald West mudstones ($Tows_1$ and $Tows_2$), with interbedded middle sublittoral molluscan fossils, is suggestive of a short-termed basin shoaling in the late Eocene and early Oligocene. A westward shift of coarse clastic depocenters, from the eastern margin of the Coast Range geosyncline in the late Eocene, is noted by Snavely and Wagner (1963) and attributed to the shoaling effect of local upwarping of volcanic basement in the geosyncline. This shoaling would also coincide in time with a short-termed world-wide eustatic sea level fall recognized by Vail and others (1976). I postulate that, as a result of a short-termed late Eocene to early Oligocene regression, the shallower marine (middle shelf) middle Oswald West mudstones in the study area were deposited as a westward-facies equivalent of the shallow-marine Pittsburg Bluff Formation of the northeast flank of the northern Oregon Coast Range (Figure 3).

The middle Oligocene to earliest Miocene upper Oswald West mudstones represent a return to deep-marine sedimentation (outer shelf-upper slope) following deposition of the middle part of the unit.

Few coarse clastics are present in the upper part. Late Oligocene to early Miocene deep-marine sedimentation in the Coast Range geosyncline (upper Oswald West) was limited to local subsiding basins as broad uplift and westward shift of the strandline occurred in most of the geosyncline (Snavely and Wagner, 1963).

The early to middle Miocene Astoria Formation overlies the upper Oswald West mudstones with possible minor angular unconformity in the study area. An unconformity is suggested by the abrupt transition from deep-marine mudstones of the upper Oswald West mudstones upward to the shallow-marine Tucker Creek and Big Creek sandstones of the Astoria Formation and by the possible discordance of bedding attitudes between the Big Creek sandstones and the Oswald West mudstones in the eastern part of the study area. These features are suggestive of regression accompanied by mild tectonism in the early Miocene. I believe that, as a continuation of the general upwarping trend in the Coast Range geosyncline in the late Oligocene, uplift in the study area occurred in the early Miocene resulting in a westward shift of the paleo-strandline to a point west of the study area. Concomitant with this apparent regression a eustatic rise in sea level occurred (Vail and others, 1976), implying that the regression was caused by local tectonic upwarping. This local upwarping may have been related to changes in plate motion in the circum-Pacific area in the early Miocene (Dott, 1969).

Evidence for an early Miocene regression, resulting in an unconformity between the Oswald West mudstones and the Astoria Formation, is also cited by Penoyer (1977), Tolson (1976), Neel (1976), and Cressy (1974).

It has been postulated by several workers (Penoyer, 1977; Neel, 1976) that the early to middle Miocene Angora Peak sandstone member of the Astoria Formation, located 19 miles south of the study area (Cressy, 1974), represents a deltaic depocenter of an ancestral Columbia River. The depocenter is thought to have shifted from the east to the Angora Peak area by deltaic progradation during an early Miocene regression (above). The Angora Peak delta may have significantly influenced early to middle Miocene sedimentation in the study area (see below).

Early to middle Miocene sedimentation in the study area (Astoria Formation) occurred in an elongated downwarped basin (Astoria embayment) which trended parallel to the present axis of the lower Columbia River (Bromery and Snavely, 1964; Snavely and Wagner, 1963). Except for several other coastal marine embayments, most of the Coast Range geosyncline was subaerially exposed during this time. These marine embayments have varying Miocene histories of marine transgression and regression suggesting that deposition in each embayment was partly controlled by local tectonics.

Following early Miocene regression, a general transgression ensued, depositing the deepening-upward Astoria Formation over the upper Oswald West mudstones in the study area. Basal shallow marine deposits of the transgressive sequence include the Tucker Creek sandstone and the Big Creek sandstone members of the Astoria Formation. Eastward shifting of the early Miocene strandline across the study area during transgression resulted in sheet-like deposition of the Big Creek and Tucker Creek sandstones. Their marked fining-upward character and the occurrence of glauconitic sandstones at the top of each unit is suggestive of continual deepening up-section as transgression progressed (Visher, 1965; Kulm and others, 1975). I interpret these shallow-marine sandstones to be a lateral transgressive strandline facies of the deltaic Angora Peak sandstones based on their close relationship in time and space. The Angora Peak sandstones are interpreted to be fluvial-deltaic and shallow-marine deposits of an ancestral Columbia River by Cressy (1974) and Smith (1975). Discontinuous basal shallow-marine sandstones of the Astoria Formation, interpreted to be lateral beach and barrier-bar facies of the Angora Peak delta, have been described in continuous mapping from Angora Peak (Cressy, 1974) north to the study area (Smith, 1975; Neel, 1976; Tolson, 1976; Penoyer, 1977). I believe that these outlying basal sandstones of the Astoria Formation (including the Tucker Creek and Big Creek sandstones in the study area) were deposited by northward longshore drift redistribution of Angora Peak delta-front sands. This is substantiated by the northward paleocurrent directions obtained in the Big Creek sandstones in the study area (Figure 43).

Lower Silver Point mudstones conformably overlie the Tucker Creek sandstones in the western half of the study area. They are composed predominantly of rhythmically interbedded fine-grained, micaceous, carbonaceous turbidite sandstones and structureless mudstones. The mudstones probably are normal marine-shelf hemipelagic deposits based on their lithology and fossil paleoecology. I interpret most of the sandstones to be turbidity current deposits which originated by oversteepening and slumping of delta-front sheet sands of the Angora Peak delta, located to the south and southwest of the study area. This is compatible with the northwesterly paleo-sediment dispersal pattern in the lower Silver Point mudstones (Figure 42). Confinement of these turbidity current flows to low areas on an irregular shelf topography in the study area may be an explanation of the lack of occurrence of this facies in the eastern half of the study area. It is possible that, while shallow-marine inner-shelf Big Creek sandstone deposition took place in the eastern half of the study area, deeper-marine deposition of lower Silver Point mudstones occurred in topographically lower, middle and outer shelf areas in the western half of the study area.

The lower Silver Point mudstones and the Big Creek sandstones fine upward to the deep-marine upper Silver Point mudstones and Piepline member, respectively. The mudstones in these latter units are micaceous, carbonaceous, well-laminated to structureless, and contain abundant deep-marine (bathyal) Foraminifera. Either due to continual downwarping of the Astoria embayment or continued eustatic sea level rise, the early to middle Miocene transgression reached a maximum at this time. Within this deepening marine environment, the thick, medium-grained, friable, arkosic sandstones of the Pipeline member were deposited in the northwestern part of the study area (Plate I). Based on outcrop distribution, overall geometry, sedimentary structures, and textural features, I interpret these sandstones to have been deposited by sediment gravity flows (grain flow and/or fluidized flow) in a submarine canyon which was approximately coincident with the present axis of the lower Columbia River (see Depositional Environment of the Pipeline member).

Given a submarine canyon depositional model, two modes of coarse clastic sediment input are possible; direct fluvial (Trimonis and Shimkus, 1968) and longshore drift (Shepard and others, 1969). I believe that both modes are represented by sandstones in the Pipeline member. The predominant Type I sandstones of the Pipeline member are characterized by relatively high abundances of metamorphic rock fragments, hornblende, and orthoclase. These constituents are suggestive of derivation from source areas outside the volcanic terrain of the Oregon Coast Range and Cascades. I speculate that in the late early to early middle Miocene differential downwarping of the Astoria embayment, perhaps related to formation of a submarine canyon, caused a northward shift of the ancestral Columbia River depocenter from the Angora Peak area to a point east of the study area near the present course of the river. The Pipeline sandstones may then have been derived directly from a Columbia River source which could supply the high quantities of non-volcanic detritus present in these sandstones. Longshore drift input into the submarine canyon is, I believer, represented by the rarer Type III Pipeline sandstones, which are texturally and mineralogically similar to the Big Creek sandstones (see Petrology of the Astoria Formation and Grain Size Analysis sections). Though the Big Creek sandstones are older than the Pipeline member in the study area, it is probable that a Big Creek-type inner shelf-strandline facies, shifted to the east of the study area as a continuation of the early Miocene transgression, existed during Pipeline time and could input Big Creek-type sand into the submarine canyon by longshore drift.

The Pipeline member is overlain by the subunit, $Tspu_1$ (middle Miocene), of the upper Silver Point member. The latter consists of well-laminated to structureless, locally highly carbonaceous and micaceous, hemipelagic, deep-marine (bathyal) mudstones. The absence of Pipeline sandstones in this lithology is possibly due to shifting of the axis of the submarine canyon northward out of the study area (Gray's River area of Washington (?); Wolfe and McKee, 1972, Unit III).

In the middle Miocene several dikes and sills of Depoe Bay Basalt were intruded in the Astoria Formation and Oswald West mudstones in the study area. In surrounding areas, Depoe Bay Basalt and younger Cape Foulweather Basalt were extruded as submarine pillow basalts and breccias, and subaerial flows; and intruded as dikes and sills. Since these basalts unconformably overlie the Astoria Formation, a short-termed regression and folding event is thought to have preceded middle Miocene basalt volcanism (Penoyer, 1977; Neel, 1976; Coryell, 1978).

Since no bedrock units younger than middle Miocene are present in the study area, post-middle Miocene marine regression and uplift are presumed to have occurred, coincident with a broad regional uplift of the Coast Range in the late Tertiary (Baldwin, 1976). Middle Miocene to Pleistocene (?) deformation is indicated by the east-west-trending folds and northwest- and northeast-trending faults which affect all bedrock units in the study area. Middle Miocene faulting and possibly folding, prior to basaltic volcanism (Depoe Bay and Cape Foulweather), is reported by Coryell (1978), Penoyer (1977), and others.

Continued uplift of the Coast Range into the Quaternary is indicated by the presence of terrace deposits along river valley margins in the study area. Uplift of the present Coast Range has been attributed to isostatic re-adjustment related to imbricate thrusting in a subduction zone at the Oregon and Washington continental margins (Kulm and Fowler, 1974).

ECONOMIC GEOLOGY

Crushed Rock and Gravel

Dikes and sills of Depoe Bay Basalt are the only potential sources of crushed rock in the study area. All the intrusions, except one, are of very limited extent and probably have little economic value. The single large intrusion in the study area, a Depoe Bay Basalt sill which crops out southeast of Olney (sec. 13, T. 7 N., R. 9 W.; Plate I), is currently being quarried by the City of Astoria as a source of road gravel and landfill.

Untapped resources in the study area include the Quaternary alluvial basaltic terrace gravels which crop out along the alluvial valleys of the Lewis and Clark River and Young's River. These poorly consolidated deposits could be easily quarried for use as road fill and surfacing material. Fairly extensive gravel deposits crop out along the Lewis and Clark River Road (sections 6 and 7, T. 7 N., R. 9 W.).

Petroleum

The only reported major oil seep in Oregon occurs in the southeastern part of the study area (Plate I, Figure 44; NW$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 14, T. 7 N., R. 9 W.). It is located on the thickly forested floodplain-tidal flat of the Klaskanine River about one-third of a mile southwest

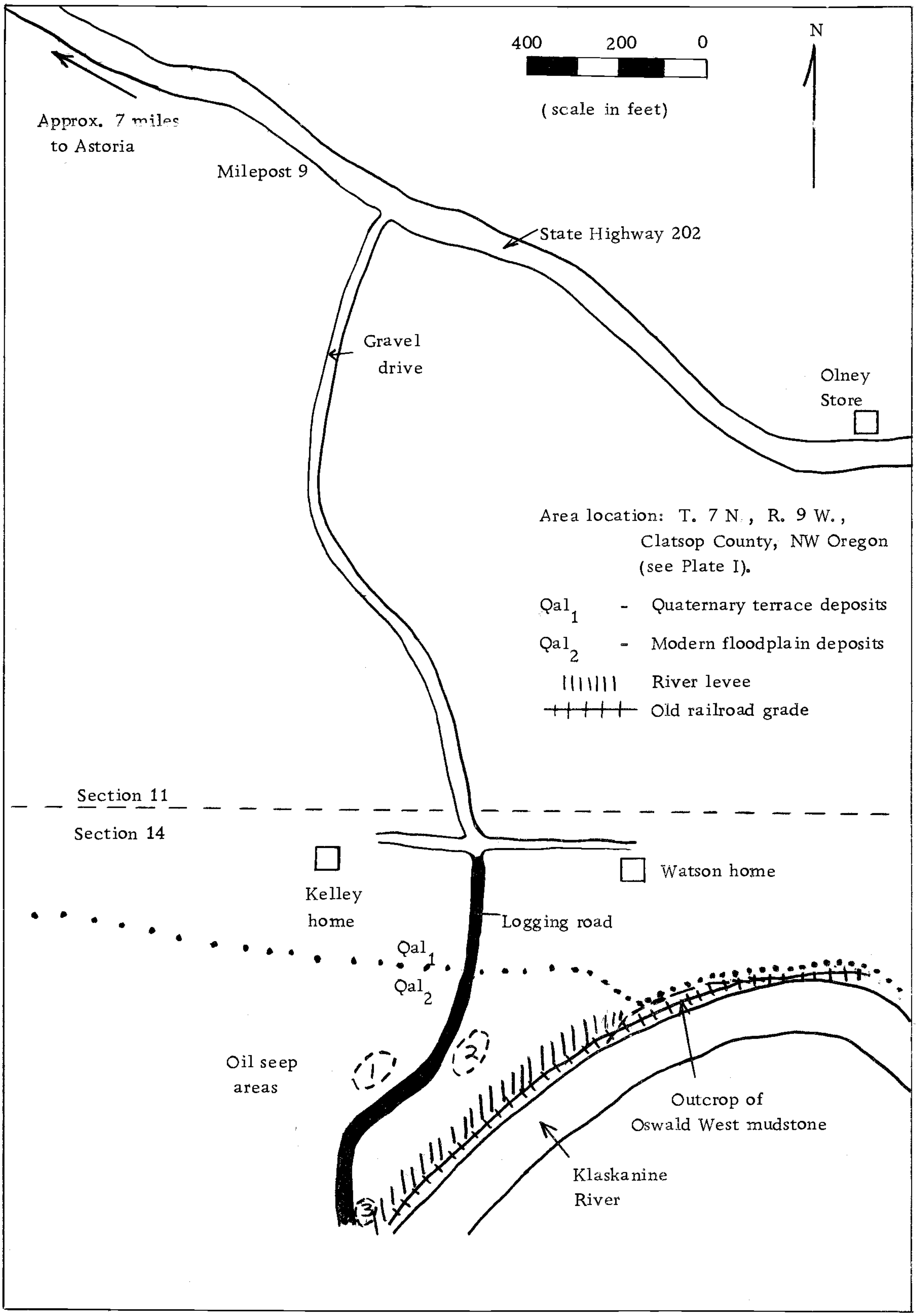


Figure 44. Sketch map showing location of Olney oil seep in the study area (see Plate I).

of Olney (Figure 44). Access, with permission, to the oil seep is afforded by an old logging road which intersects a gravel drive off State Highway 202 (Figure 44). The property on which the oil seep is located is owned by Mr. and Mrs. Alfred Watson.

Oil is present in scattered patches over a densely foliated, several hundred square-foot area centered on the logging road access. The major surficial concentration of oil occurs in a two- to five-foot deep groundwater-filled depression (10 feet by 12 feet) flanking the west side of the logging road (oil seep locality #1, Figures 44 and 45). The pond is six to ten feet above the level of the Klaskanine River (Figure 44). The oil is present in dull black, thick tarry patches and as a thin lightly irridescent film on the surface of the pond water and has impregnated soil on the banks of the pond. Combustible gas bubbles (methane ?) are observed to occasionally break the surface of the pond water. These may be genetically related to the oil seep or may originate from the slow decay of organic matter in the flood-plain muds. No bubbles of oil appear to break the surface. During backhoe excavation at one end of the pond (A. Watson, 1977, personal communication) a tree stump was uncovered at a depth of six feet.

Oil seep locality #2 (Figure 44) is about 100 feet northwest of the pond on the east side of the logging road in a densely vegetated area. Bulldozer removal of six to twelve inches of top soil, over an area of 50 to 100 square feet at this locality, revealed the presence

Figure 45. Olney oil seep #1. Oil is present as thick, pitch-black, tarry patches on the water surface of a water-filled depression (see Figure 44).

of three small oil seeps (6 to 12 inches wide) where fresh oil was either coming up gradually or was moving laterally from adjacent oil-saturated soil. Traces of oil-saturated soil (at a depth of 2 feet) were also observed by A. R. Niem (1977, personal communication) several hundred feet south of these localities on the logging road in surficial levee deposits of the Klaskanine River (oil seep locality #3, Figure 44).

Two shallow holes (15 to 25 feet) were drilled with a portable gasoline-driven auger by V. C. Newton of the Oregon Department of Geology and Mineral Industries, with assistance by Alan Niem, George Coryell, and myself, in July, 1977 adjacent to oil seep localities #1 and #2. Drilling showed subsurface deposits to consist of blue cohesive silty clay which possibly contained traces of oil. The silty clay is probably a floodplain or tidal flat deposit of the Klaskanine River since it is lithologically dissimilar to the Oswald West mudstones which crop out along the bank of the Klaskanine River several hundred feet to the west (Figure 44). The tree stump uncovered in oil seep #1 also indicates the clay is probably a Recent floodplain deposit. The depression in which oil seep #1 occurs may be part of a long, swampy, highly vegetated, abandoned slough or tidal channel of the Klaskanine River (Niem, 1977, personal communication).

A few days later, oil seep localities #1 and #2 were redrilled to a depth of 26 feet with a coring device by V. C. Newton. Well cuttings from these holes consisted of silty clay containing some light brown globules of oil that fluoresced under ultraviolet light. Black specks of oil in cuttings obtained at a depth of 26 feet in one hole may have originated by natural upward migration of petroleum or by sloughing of oil-saturated mud into the drill hole (Newton, 1977, personal communication).

Samples of oil from oil seep #1, collected in May, 1976, were sent to several petroleum companies for chemical analyses. Analysis performed by Union Oil Company of California was inconclusive due to the weathered nature of the sample, but in their opinion it was a highly oxidized crude-like oil (Braislin, 1976, written communication to Niem). Amoco Production Company, however, determined from a different sample that the oil is genuine crude with a gravity 11.7 API (Furer, 1977, written communication to Niem). Standard Oil of California later confirmed this crude oil identification in analysis of a sample collected by D. Hastings (1977, written communication to Mrs. Watson). Oil samples were re-collected from oil seep #1 in July, 1976 following backhoe excavation by Alfred Watson and sent to Mobil Oil Corporation for analysis. Evidently, fresh oil seepage had occurred following excavation because Mobil Oil reported the sample sent to be unweathered crude oil. Their analysis showed the following composition for the oil sample: saturated hydrocarbons - 74%, naptha-aromatics - 16%, and asphaltics - 10% (Parsons, 1977, written communication to Niem). They also reported that the Olney oil is chemically unlike any other crude oil from California examined by Mobil but is somewhat similar to crude oil from the Ocean City field near Aberdeen, Washington (Appendix XII). The paraffin content of the Olney oil is relatively high, and the infrared absorption spectrum of the heavy aromatic hydrocarbons is quite different from other West Coast crudes (Parsons, 1977, personal communication to Niem).

These analyses establish that the Olney oil is genuine crude oil. However, the source of the oil is uncertain. Since the oil seep occurs in floodplain deposits and drilling to date has not penetrated to bedrock strata, a genetic relation between the oil seep and the subsurface bedrock geology cannot be established. The possibility of the oil being brought in and dumped by man cannot be ruled out. Crude oil could have been used during the logging operations in western Oregon around the turn of the century, to "grease" plank roads used for skidding logs (Dilworth, 1977, personal communication). The floodplain area where the seep is located was logged in the 1920's and 1930's. Also, according to long-time residents in the area, crude oil was barged up the Klaskanine River and used in running a derrick near the town of Olney (3 miles east) to load logs from the river onto railroad cars (Mrs. Watson, 1977, personal communication). In connection with this operation, two oil storage tanks were once located along the levee adjacent to an old railroad grade a few miles east and west of the oil seep (Figure 44). The crude oil could have been dumped in the area of the oil seep during operation of the railroad or when operations closed down and the storage tanks were removed (Mrs. Watson, 1977, personal communication to Niem).

The nearest sources of crude oil which could have been brought into the area are in California and possibly Washington. However, the chemistry of these oils is different from the chemistry of the Olney oil (see above and Appendix XII) suggesting that the Olney oil is of natural local origin. The Ocean City, Washington oil, which has the closest chemical affinities to the Olney oil (Appendix XII), was drilled in the 1950's and was not commercially exploited.

In addition, paraffins are rapidly degraded by bacterial action and would not have remained "fresh" in an oil dumped at the surface, especially if dumped 50 or 60 years ago. The high paraffin content and unusual chemistry of the Olney oil are, I believe, the strongest evidence favoring an origin by natural seepage from the subsurface. However, because of the activities of man in the area, caution must be exercised in evaluating the orign of the seep.

The origin of the Olney oil seep can be reasonably interpreted in terms of the subsurface geology in the southwestern part of the study area, although this geology does not indicate great promise in terms of source rocks and reservoir rocks. Near-surface bedrock in the vicinity of the Olney seep consists of gently north-dipping late

Oligocene upper Oswald West mudstones (Plate I; Figure 44). The fine-grained lithologies in this stratigraphic interval have little potential as reservoir rocks but would serve as suitable cap rocks. The fine-grained arkosic sandstones in the middle part of the Oswald West mudstones ($Tows_1$ and $Tows_2$, see Lithology section of the Oswald West mudstones and Plate I) may be potential reservoir units in the subsurface. These strata probably lie several hundred feet or more beneath the Olney oil seep. These sandstones are, however, relatively thin (less than 60 feet), laterally discontinuous (Plate I), and have low point-counted porosities (less than 7%) due to diagenetic matrix formation. Reservoir sandstones stratigraphically below the Oswald West mudstones may also exist in the subsurface, perhaps as lateral equivalents of the late Eocene Cowlitz Formation of the northeast flank of the Coast Range (Van Atta, 1971), or the Eocene Unit A of Wolfe and McKee (1968, 1972) in southwestern Washington. However, the Standard Hoaglund #1 well, spudded in the middle part of the Oswald West mudstones five miles to the west of the oil seep (Plate I), failed to penetrate any significantly thick sandstones and at 5,000 feet hit economic basement (Tillamook (?) basalts) (Tolson, 1976).

Oswald West strata in the vicinity of the Olney oil seep dip northward (Plate I). Up-dip migration of petroleum in subsurface reservoirs would, I believe, be terminated at a major fault paralleling the lower Klaskanine River, just south of the Olney oil seep (Plate I). This fault is inferred to be present based on the juxtaposition of north-dipping early to middle Miocene upper Silver Point mudstones south of the river and late Oligocene upper Oswald strata north of the river. Silver Point strata on the south side of the river are on the downthrown block. This displacement may have resulted in impermeable Silver Point mudstones being faulted against Oswald West or older reservoir sandstones in the subsurface, creating an up-dip structural trap for petroleum. The Olney oil seep may have originated by migration of petroleum from subsurface reservoirs to the surface along this fault. Alternatively, subsurface sandstones (Big Creek or in the middle Oswald West) in a small anticlinal structure on the downfaulted south side of the Klaskanine River (Plate I) could also be potential reservoirs for the petroleum postulated to be seeping up along the Klaskanine River fault. The authenticity of the Olney oil seep can be verified only through deep drilling. Reichhold Energy Corporation is now leasing land around the oil seep and plans to drill sometime in the near future (Mrs. Watson, 1977, personal communication).

The source rock potential of the Astoria and Oswald West mudstones is low based on pyrolysis fluorescence testing of mudstone samples from surface exposures. The live hydrocarbon contents of the mudstones analyzed were all less than one percent (non-source;

Appendix X). However, extensive weathering of surface exposures has probably substantially lowered live hydrocarbon abundances. Snavely and others (1977) have pointed out, on the basis of chemical analyses of samples from surface exposures, that Tertiary mudstones of the Oregon Coast Range are immature source rocks (only light hydrocarbons such as methane are present). If the Olney oil seep is natural, it is significant in terms of pointing out the existence of mature hydrocarbons in subsurface source rocks.

The petroleum potential of the region is probably greatest in offshore areas where thicknesses of sediment fill are largest and where depths of burial may have been sufficient ot generate hydrocarbons. Porosities, and presumably permeabilities, are highest in the study area in the very friable, clean, medium-grained sandstones of the Pipeline member (see Petrology section). If submarine fan equivalents of the sandstones of the Pipeline member (submarine canyon deposits in the study area) are present in offshore areas to the west, they would probably be capped by a thick impermeable sequence of late Miocene to Pliocene mudstones and siltstones (Kulm and Fowler, 1974a) and as such are potential petroleum reservoir targets. The Angora Peak sandstone member of the Astoria Formation is also a potential petroleum reservoir target south of the study area in the Oregon offshore (Neel, 1976; Cressy, 1974; Smith, 1975). Shell Oil Company drilled two wells approximately 15 miles offshore in the 1960's which penetrated only mudstones and one thin clean feldspathic sandstone in the Miocene section (Cooper, 1978). Shell Oil may have drilled too far offshore to encounter any thick sandstone bodies.

Thorough summaries of petroleum exploration and drilling in northwestern Oregon, southwestern Washington, and adjacent offshore area are presented by Braislin (1971), Neel (1976), Penoyer (1977), Tolson (1976), and Snavely and others (1977).

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APPENDIX I

Reference Section A-B

Glauconitic Sandstones in the Uppermost Tucker Creek Sandstones

Initial point (A): NW 1/4, SE 1/4, NE 1/4, sec. 11, T. 7 N., R. 10 W. Section starts at north end of short roadcut into hillside off an east-west section of logging road 21 L&C.

Terminal point (B): same roadcut as initial point but at south end of cut. This entire section probably lies stratigraphically less than 100 feet below the base of the Silver Point member of the Astoria Formation.

Unit	Description	Thickness (feet) unit	total
6	silty mudstone, same as unit 2, lenses of glauconitic sandstone in unit, basal contact gradational over 1 foot.	20	43
5	glauconitic sandstone, color same as unit 3, well-indurated, ledge-former, medium-grained at base becoming coarse-grained in middle part and fine-grained and muddy at the top, glauconite concentration is about 50% in middle part and decreases to top and bottom, quartz and glauconite dominant framework grains, moderately to poorly sorted, locally calcite-cemented, detached pillows of glauconitic sandstone in underlying mudstone, basal contact is irregular but fairly sharp, modal analysis in Appendix VI ($x82_3$).	5	23
4	silty mudstone, same as unit 2.	2	18
3	glauconitic sandstone, grayish olive green (5 GY 5/2) weathering to moderate yellowish brown (10 YR 5/4), moderately well-indurated, ledge-former, medium-grained at base and very fine-grained at the top, glauconite and quartz dominant constituents, 60% glauconite at base decreasing to 30% at top, moderately well-sorted at base with mud content increasing upward, structureless, basal contact sharp but undulatory.	4	16
2	silty mudstone, yellowish gray (5 Y 8/1), poorly indurated, scattered glauconite grains, well-burrowed (Scalarituba/Helminthoidia), structureless, rare fragmented molluscan fossils, rare fragmented molluscan fossils, basal contact gradational over 1 foot.	5	12
1	glauconitic sandstone and siltstone, dark yellowish brown (10 YR 4/2), well-indurated, ledge-former, medium-grained and highly glauconitic at base, dark green basal mudstone ripup clasts present, fines upward to a siltstone as glauconite concentration decreases to 0%, rare pelecypods, scaphopods, and carbonized wood fragments present (xf82, Appendix 4, bivalve <u>Spisula albaria</u> collected), no internal stratification, blocky to spheroidal fracturing, iron-stained, 2 feet of silty mudstone exposed below base, basal contact irregular and gradational over 6 inches.	7	7

APPENDIX II

Reference Section C-D

Part of the Lower Silver Point Mudstones

Initial Point (C): NE 1/4, SE 1/4, NE 1/4, sec. 16, T. 7 N., R. 9 W. Section starts 10 feet west of junction of logging spurs 26 and 26-C in roadcut exposure. The initial point lies stratigraphically about 500 feet above the base of the Silver Point mudstones.

Terminal Point (D): about 100 feet north of the junction of spurs 26 and 26-B, NW 1/4, SW 1/4, NE 1/4, sec. 16, T. 7 N., R. 9 W.

Unit	Description	Thickness unit	(feet) total
14	interbedded sandstone and muddy siltstone; sandstone, light greenish gray (5 G 8/1), friable to well-indurated, 10- to 12-inch thick beds at the base of the unit decreasing to less than 2 inches thick at the top of the unit, individual beds have sharp basal contacts and gradational upper contacts, micro-cross-lamination and/or parallel laminations present similar to b and c intervals of Bouma sequence, laminations formed by locally high concentrations of mica and carbonized wood and plant fragments, beds commonly graded from fine-grained at base to very fine-grained at top, some pull-apart sandstone boudins present at top of unit (soft sediment deformation). muddy siltstones, light greenish gray (5 GY 8/1), locally micaceous and carbonaceous, rarely laminated, beds 1/2 to 3 inches thick at base of unit increasing to 3 to 6 inches thick at the top, very fine-grained sandstone lamina present (1-4 mm) locally. abundance of sandstone interbeds decreases upward in unit, mudstone predominant in upper half.	45	204
13	cover, probably mudstone	30	159
12	mudstone with subordinate sandstone interbeds; mudstone, thin-bedded, dark gray (N3) weathering to yellowish gray (5 Y 7/2), scattered mica and carbonaceous debris along bedding planes, thin wispy silt lamina present. sandstone, light bluish gray (5 B 7/1), very fine-grained, 1- to 3-inch thick beds, normally graded, b and c intervals of Bouma sequence present, bottom contacts sharp and upper contacts gradational. basal contact of unit gradational over 1 foot.		
11	sandstone, basal 1 foot is same as unit 9, upper 1 1/2 feet is same as unit 7, basal contact sharp and irregular.	2 1/2	119
10	mudstone, dark gray (N3) weathering to yellowish gray (5 Y 7/2), otherwise same as unit 6, basal contact gradational over several inches.	5	116 1/2

Unit	Description	Thickness unit	(feet) total
9	sandstone, light bluish gray (5 B 7/1), very thinly bedded (less than 1 inch), graded from fine-grained at the base to very fine-grained at the top, carbonaceous laminae present with large (10 mm long) carbonized wood fragments, friable, basal contact sharp.	3	111 1/2
8	mudstone, same as unit 1, basal contact sharp but irregular.	1	108 1/2
7	sandstone, light bluish gray (5 B 7/1) weathering to light greenish gray (5 G 8/1), very fine-grained, well-defined highly micaceous and carbonaceous lamina (grayish black, N2), carbonized wood fragments present, basal contact sharp.	1/2	107 1/2
6	mudstone, similar to unit 1 except faint laminations present formed by scattered micas and carbonaceous debris on bedding planes, wispy silt and very fine-grained sandstone laminae also present, poorly indruated, basal contact covered.	20	107
5	covered	30	87
4	mudstone with very fine-grained sandstone interbeds; mudstone beds 4 to 6 inches thick, lithology same as unit 1; sandstone beds less than 1 inch thick, lithology same as unit 3 sandstones, mudstone-sandstone contacts sharp but undulatory, basal contact covered.	7	57
3	sandstone with subordinate mudstone interbeds; sandstone, color same as unit 2, very fine-grained, well-laminated (1 to 5 mm), micaceous and carbonaceous lamina, friable. mudstone, same as unit 1. basal contact of unit gradational over 1 foot.	25	50
2	sandstone, light bluish gray (5 B 7/1) weathering to grayish orange (10 YR 7/4), medium-grained, friable, micaceous, thinly bedded, fairly clean, iron-staining along bedding planes, basal contact sharp.	5	25
1	muddy siltstone, greenish gray (5 GY 6/1) weathering to yellowish orange (10 YR 5/6), micaceous, blocky fracture, no stratification, rare scattered carbonaceous matter, poorly indurated, basal contact covered.	20	20

APPENDIX III

Reference Section E-F

Part of the Pipeline member, gradational interval between Tps_2 and Tpm

Initial point (E): SE 1/4, SE 1/4, sec. 31, T. 8 N., R. 8 W. Section starts where logging spur C angles sharply to the north, several hundred feet east of logging road 53.

Terminal Point(F): several hundred feet north of initial point along logging spur C, at the point where spur C forks.

Unit	Description	Thickness unit	(feet) total
21	sandstone, color - same as unit 2, medium-grained, structureless, friable, micaceous, arkosic, Fe-oxide stained, entire thickness is probably composed of many individual sedimentation units, mudstone ripup blocks in middle part of unit, 1-2 feet long, same lithology as unit 1, no imbrication; top contact covered.	70	259 1/2
20	cover, probably mudstone	30	189 1/2
19	sandstone, fresh- bluish white (5 B 9/1), weathered - dark yellowish orange (10 YR 6/6), medium-grained at base, coarse-grained at top, poorly sorted, structureless, friable, arkosic, micaceous; basal contact sharp and wavy.	10	159 1/2
18	mudstone, silty and sandy, color- same as unit 5, crude fissility, medium-grained sand locally concentrated along bedding planes, rare scattered carbonized plant matter, conchoidal fracture, Fe-oxide stain; basal contact sharp and planar.	1 1/2	249 1/2
17	sandstone, color - same as unit 2, medium- to fine-grained, well-laminated (5 mm), highly carbonaceous and micaceous laminae, some leaf fragments, poorly sorted, subangular grains, arkosic, Type II sandstone (see text).	2	148
16	cover, probably mudstone	33	146
15	silty mudstone, greenish gray (5 GY 6/1), structureless, blocky fracture, Fe-oxide stain, chippy talus, interbedded pods (3-6 inches) of medium-grained sandstone; basal contact sharp.	5	113
14	sandstone, color - same as unit 1, coarse-grained, no internal stratification, slight upward fining, poorly sorted, friable, arkosic, micaceous, fairly clean; basal contact sharp and planar.	3	108
13	mudstone, same as unit 1; basal contact gradational with underlying sandstone.	1 1/2	105
12	sandstone, same as unit 6.	4	103 1/2
11	cover, probably mudstone	30	99 1/2

Unit	Description	Thickness unit	(feet) total
10	sandstone with interbedded mudstone, sandstone beds about 6 inches thick, graded from coarse at base to medium at top. faint cross-laminations overlain by parallel laminations present in one bed, poorly indurated, poorly sorted, fairly clean, color - light brown (5 YR 5/6), Fe-oxide stain; mudstone beds less than 1 inch thick, lens-shaped, contain scattered sand grains, color - dark yellowish orange (10 YR 6/6), structureless.	6	69 1/2
9	cover, probably sandstone	2	63 1/2
8	sandstone, color - same as unit 2, coarse-grained, poorly sorted, muddy, structureless, micaceous, angular grains, arkosic.	6	61 1/2
7	cover, probably mudstone	35	55 1/2
6	sandstone, color - same as unit 2, coarse-grained at base, medium-grained at top. no internal stratification, abundant mica, esp. at top of unit, poorly sorted, subangular grains, friable, arkosic, Fe-oxide stained; basal contact sharp but irregular, soft-sediment deformation.	4	20 1/2
5	silty mudstone and siltstone, fresh - light olive gray (5 Y 6/1), weathered - dark yellowish orange (10 YR 6/6), faint micaceous laminations, fracturing parallel to bedding ?, poorly indurated, chippy talus; basal contact sharp and wavy.	9	16 1/2
4	sandstone, color - same as unit 2, fine-grained, well-laminated (5 mm), laminae formed by highly micaceous and carbonaceous layers (moderate brown 5 YR 3/4), no grading, poorly sorted, angular grains, matrix-rich, iron-oxide stain; basal contact sharp and wavy.	1 1/2	7 1/2
3	silty mudstone, highly fractured, geothite filling fractures, faint thin laminations formed by concentrations of mica and carbonized plant matter, chippy talus, otherwise same as unit 1; basal contact sharp and planar.	2 1/2	6
2	sandstone, fresh- light bluish gray (5 B 7/1), weathered - yellowish gray (5 Y 8/1), medium-grained at base, coarse-grained at top, no internal stratification, well-indurated, no calcite cement, poorly sorted, arkosic, Fe-oxide stain, angular to subangular grains; basal contact sharp and planar.	1 1/2	3 1/2
1	silty mudstone, moderate yellowish brown (10 YR 5/4), structureless, blocky fracture, scattered mica and comminuted carbonized plant debris, chippy talus (1/2-2 inches), Fe-oxide stained, slope-former; 2-inch thick sandstone dike in mudstone, medium-grained, color - same as unit 2, sharp contacts, moderately indurated, sinuous; basal contact not exposed. Bedding attitude: N45W, 1ONE.	2	2

All sandstones in section are Type I sandstones unless otherwise noted (see text, Lithology section of the Pipeline member).

APPENDIX IV. CHECKLIST OF FOSSILS FROM THE OSWALD WEST MUDSTONES.

	Samples																
Fossils	53	67	77	78	87	91	94	109	122	132	154c	168	173	190	191	229	242
BIVALVIA																	
Katherinella sp. ?	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nemocardium sp.	-	x	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-
Nuculana sp.	-	x	-	-	-	-	-	-	x	x	-	-	-	-	-	-	-
Thracia cf. T. schencki Tegland	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acila sp.	-	-	-	-	-	-	-	x	-	-	x	-	-	-	-	-	-
Macoma cf. M. twinensis Clark	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-
Hiatella sp. ?	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-
Macrocallista cathcartensis (Weaver)	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-
Nuculana cf. N. washingtonensis (Weaver)	-	-	-	-	-	-	-	x	x	-	-	-	-	-	-	-	-
Nemocardium cf. N. lorezanum (Arnold)	-	-	-	-	-	-	-	x	x	-	-	-	-	-	-	-	-
Spisula sp.	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-
Conchocele sp.	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
Lucinoma cf. L. acutilineata (Conrad)	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
Cyclocardia ?	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-
Katherinella or Pitar	-	-	-	-	-	-	-	-	x	x	-	-	-	-	-	-	-
Solamen sp.	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-
Thracia cf. T. condoni Dall	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-
Macoma or Tellina	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-
Solamen cf. S. snavelyi Addicott	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x
Securella sp.	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lucinoma sp.	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Macoma albaria	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-
Yoldia sp.	-	-	-	-	-	-	x	-	-	-	-	-	-	-	x	-	-
Securella ?	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Portlandia cf. P. reagani (Dall)	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-
Tellina aff. T. idae Dall	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-
Cyclocardia aff. C. hannai (Tegland)	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-
Tellinid	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-
Lima sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-

APPENDIX IV. (Continued) CHECKLIST OF FOSSILS FROM THE OSWALD WEST MUDSTONES

Fossils	Samples											
	67	78	109	122	132	154c	168	190	191	256	31-7	70-8
GASTROPODA												
Priscofusus cf. P. chehalisensis Weaver	-	-	-	-	-	-	-	-	x	-	-	-
Naticid	x	x	-	-	-	-	-	x	x	-	-	-
Perse sp.	x	-	-	-	x	-	-	-	-	-	-	-
Perse cf. P. lincolnensis (Van Winkle)	-	-	x	-	-	-	-	-	-	-	-	-
Neverita washingtonensis (Weaver)	-	-	-	-	x	-	-	-	-	-	-	-
Turritella cf. T. blakleyensis Weaver	-	-	-	-	-	x	-	-	-	-	-	-
Turritella n. sp. aff. T. hamiltonensis Clark & T. variata Conrad	-	-	-	-	-	x	-	-	-	-	-	-
Turricula n. sp. ?	-	-	-	-	-	x	-	-	-	-	-	-
Perse cf. P. pittsburgensis Durham	-	-	-	-	-	-	x	x	-	-	-	-
SCAPHOPODA												
Dentalium sp.	x	-	-	-	-	-	-	-	x	-	-	-
Dentalium cf. D. porterensis Weaver	-	-	-	-	-	x	-	-	-	-	-	-
ARTHROPODA												
Callianassa sp.	-	-	-	x	-	-	-	-	-	-	-	-
FORAMINIFERA												
Globigerina sp.						-	-	-	-	x	-	x
Bulimna cf. B. ovata						-	-	-	-	?	-	-
Bulimnella subfusiformis						-	-	-	-	?	-	-
Virgulina sp.						-	-	-	-	x	-	-
Gyroidina sp.						-	-	-	-	x	-	-
Cassidulina crassipuntata						?	-	-	-	-	x	-
Dentalina sp.						x	-	-	-	-	-	-
Nonion incisum						?	-	-	-	-	-	-
Gyroidina orbicularis planata (Cushman)			(no forams)			-	-	-	-	-	x	-
Cibicides cf. C. elmaensis var. A Rau						-	-	-	-	-	x	x
Elphidium ? cf. E. californicum Cook						-	-	-	-	-	x	-
Sphaeroidina variablis Reuss						-	-	-	-	-	-	x

APPENDIX IV. (Continued) CHECKLIST OF FOSSILS FROM THE OSWALD WEST MUDSTONES

Fossils		Samples 154c	168	190	191	256	31-7	70-8
FORAMINIFERA								
Uvigerina garzaensis Cushman & Siegfus	(no forams)	-	-	-	-	-	-	x
Nonion incisum kernensis		-	-	-	-	-	-	x
Anomalina californiensis Cushman & Hobson		-	-	-	-	-	-	x
Pseudoglanduline inflata		-	-	-	-	-	-	x
Cassidulinoides sp.		-	-	-	-	-	-	x

APPENDIX IV. (Continued) FOSSIL CHECKLIST OF THE BIG CREEK SANDSTONES

Fossils	Samples 239	243	250	272	271	273	288	452	451
BIVALVIA									
Anadara cf. A. devincta (Conrad)	x	-	-	-	x	-	-	-	-
Macoma Albaria (Conrad)	x	-	-	-	-	-	-	-	-
Panopea abrupta (Conrad)	x	-	-	-	-	-	-	-	-
Spisula albaria (Conrad)	x	-	-	-	-	x	-	x	x
Thracia trapezoides (Conrad)	-	x	-	-	-	-	x	-	-
Vertipecten fucanus (Dall)	-	x	-	-	-	-	-	-	-
Macoma cf. M. albaria (Conrad)	-	-	x	-	-	-	-	-	-
Spisula ?	-	-	x	-	-	-	-	-	-
Thyasira sp.	-	-	x	-	-	-	-	-	-
Katherinella augustifrons (Conrad)	-	-	-	x	-	-	-	-	-
Lucinoma acutilineata (Conrad)	-	-	-	x	-	-	-	-	-
Patinopecten propaltus ?	-	-	-	x	-	x	-	-	-
Patinopecten oregonensis cancellosus Moore	-	-	-	x	-	-	-	-	-
Litorhadia astoriana (Henderson)?	-	-	-	-	x	-	-	-	-
Anadara sp.	-	-	-	-	-	x	-	x	-
Nuculana cf. N. calinski (Moore)	-	-	-	-	-	-	x	-	-
Nuculana sp.	-	-	-	-	-	-	-	x	-
Panopea cf. P. abrupta (Conrad)	-	-	-	-	-	-	-	x	-
Patinopecten propaltus	-	-	-	-	-	-	-	x	-
Tellina emacerata Conrad	-	-	-	-	-	-	-	x	x
Acila sp. ?	-	-	-	-	-	-	-	-	x
Clinocardium n. sp. aff. C. nuttali	-	-	-	-	-	-	-	-	x
Yoldia cf. Y. cooperi Gabb	-	-	-	-	-	-	-	-	x
GASTROPODA									
Crytonatica oregonensis Conrad	-	-	-	-	-	-	-	x	-
Ophiodermella olympicensis Addicott	-	-	-	-	-	-	-	x	-
Crepidula ?	-	-	x	-	-	-	-	-	-
Turritella oregonensis Conrad	-	-	-	-	-	-	x	-	-
Bruclarkia oregonensis (Conrad)	-	-	-	-	-	-	-	-	x

APPENDIX IV. (Continued) FOSSIL CHECKLISTS

	Tucker Creek				Pipeline			Silver Point $Tspu_1$	
Fossils	154a	154b	18	82	320	74-5	353	423	424
BIVALVIA									
Spisula sp.	x	-	-	-	-	-	-	-	-
Katherinella ?	-	x	-	-	-	-	-	-	-
Litorhadia astoriana Henderson	-	-	x	-	-	-	-	-	-
Nemocardium sp.	-	-	x	-	-	-	-	-	-
Nuculana calinski	-	-	x	-	-	-	-	-	-
Nuculana sp.	-	-	x	-	-	-	-	-	x
Spisula albaria (Conrad)	-	-	x	x	-	-	-	-	-
Delectopecten peckhami (Gabb)	-	-	-	-	x	-	x	x	-
Macoma carlottensis Whiteaves	-	-	-	-	x	-	-	-	-
Cyclocardia sp.	-	-	-	-	-	-	-	x	-
Yoldia cf. Y. newcombei Anderson & Martin	-	-	-	-	-	-	-	x	-
Acila sp.	-	-	-	-	-	x	-	-	-
Conchocele sp.	-	-	-	-	-	x	-	-	-
Tellina congesta Conrad	-	-	-	-	-	x	-	-	-
GASTROPODA									
Turritella n. sp. ?	x	-	-	-		-	-	-	-
Priscofusus medialis (Conrad)	-	x	-	-		-	-	-	-
Aceteon sp. ?	-	-	x	-		-	-	-	-
Turrid	-	-	x	-		-	-	-	-
Priscofusus sp.	-	-	x	-		-	-	-	
SCAPHOPODA									
Dentalium sp.	-	-	x	-		-	-	-	

APPENDIX IV. (Continued) FOSSIL CHECKLIST

Fossils	Pipeline 277	318	314	356	358	365	406	430	334	Silver Point 180	344	345	350
FORAMINIFERA													
Globigerina sp.	x	?	x	-	-	x	?	x	-	x	-	-	?
Bulimna alligata	?	-	-	-	-	-	-	x	-	-	-	-	-
Bulimna cf. B. ovata	?	-	?	-	-	-	-	-	-	-	x	x	?
Virgulina sp.	?	-	-	-	-	-	-	-	-	-	-	-	?
Siphogenerina fragments	-	x	x	x	x	-	x	-	x	-	x	x	x
Arenaceous forms	-	x	x	-	-	x	-	-	-	x	-	-	-
Valvulineria araucana	-	?	-	-	-	-	-	x	-	-	x	x	?
Dentalina sp.	-	-	-	-	-	-	x	x	-	x	-	-	-
Uvigerinella obesa impolita	-	-	-	-	-	-	-	x	-	-	-	-	-
Nodogenerina cf. N. advena	-	-	-	-	-	-	-	-	-	-	-	-	-
Cassidulina crassipunctata	-	-	-	-	-	-	-	x	-	-	-	-	-
Epistominella sp.	-	-	-	-	-	-	-	x	-	-	-	-	-
Bolivina marginata	-	-	-	-	-	-	-	x	-	?	-	-	-
Plectofrondiculina cf. P. miocenica	-	-	-	-	-	-	-	x	-	-	-	-	-
Siphogenerina kleinpelli	-	-	-	-	-	-	-	x	-	-	-		-
Quinqueloculina sp.	-	-	-	-	-	-	-	-	-	-	-	x	-
Buliminella subfusiformis	-	-	-	-	-	-	-	-	-	-	-	-	x

All fossil localities listed in Appendix XX and on Plate I.

APPENDIX IV. (Continued) FOSSIL CHECK LISTS

Fossils	Oswald West		Tucker Creek		Lower Silver Point	
	84	191	154a	154c	207	454
TRACE FOSSILS						
Scalarituba/Helminthoidia	x	-	-	-	-	-
Toredo borings	-	x	-	x	-	-
Trichichnus	-	-	x	-	-	-
Unnamed, possibly non-marine	-	-	-	-	x	-
Helminthoidia	-	-	-	-	-	x

Molluscan fossils identified by Warren O. Addicott (1977, written communication).

Foraminifera identified by Weldon W. Rau (1977, written communication).

Trace fossils identified by C. Kent Chamberlain (1977, written communication).

APPENDIX IV. (Continued). U. S. GEOLOGICAL SURVEY CENOZOIC LOCATION NUMBERS FOR MOLLUSCAN FOSSIL COLLECTIONS (collections with U. S. G. S. Branch of Paleontology and Stratigraphy, Menlo Park, California).

Sample: 367 (field sample no.) - M6405 (U. S. G. S. Cenozoic Location no.)

Oswald West mudstones

Middle part: 53 - M6881, 67 - M6960, 77 - M6882, 84 - none (trace fossil), 87 - M6885, 91 - M6886 & M6992, 94 - M6887, 109 - M6964, 122 - M6965, 132 - M6966, 168 - M6889, 173 - M6891, 190 - M6892, 191 - M6893, 31-7 - none (foram).

Upper part: 68 - M6883, 154c - M6888, 229 - M6894, 242 - M6968, 256 - none (foram), 70-8 - none (foram).

Big Creek sandstones

239 - M6896, 243 - M6895, 250 - M6897, 271 - M6898, 272 - M6899 & M6969, 273 - M6900, 288 - M6901, 451 - M6972, 452 - M6973.

Tucker Creek sandstones

154a - M6993, 154b - M6440, 18 - M6880 & M6959, 82 - M6884.

Pipeline member

320 - M6902 & M6970, 353 - M6903, 74-5 - M6390.

Silver Point member ($Tspu_1$)

423 - M6904, 424 - M6905.

APPENDIX V

Heavy Mineralogy of Oswald West and Astoria Formation Sandstones

	Oswald West		Tucker Creek	Big Creek	Silver Point	Pipeline		
	49	190	154c	264	412	327	333	429
Amphiboles								
Hornblende								
Green	41	24	19	17	13	28	34	31
Blue-green	4	10	15	13	2	4	18	20
Brown	-	1	tr	-	-	1	3	11
Lamprobolite	-	-	-	-	-	-	-	tr
Tremolite	-	3	2	tr	2	10	2	-
Pyroxenes								
Hypersthene	5	-	2	2	2	2	20	11
Enstatite	4	4	tr	3	2	2	-	4
Augite	5	7	5	7	10	3	tr	tr
Epidote								
Clear	1	1	1	6	tr	1	-	2
Green	15	14	11	13	7	3	1	5
Zoisite	-	-	-	1	-	-	1	-
Clinozoisite	2	1	-	1	tr	-	tr	tr
Garnet								
Clear	3	6	6	8	5	11	8	3
Pink	-	-	tr	-	-	-	1	-
Green	-	1	-	-	-	-	-	-
Yellow-brown	-	-	2	-	-	-	2	-
Red-brown	-	1	-	-	-	3	-	-
Apatite	2	9	tr	1	8	-	tr	tr
Andalusite	-	-	tr	2	-	-	tr	-
Anthophyllite	-	1	-	-	-	3	-	-
Idocrase	-	-	-	-	-	-	-	1
Monazite	4	4	2	3	tr	2	3	2
Rutile	1	1	2	tr	4	-	1	2
Sphene	4	8	21	8	2	11	2	1
Staurolite	1	3	tr	4	4	2	1	2
Tourmaline								
Schorlite	4	2	5	4	21	5	-	1
Elbaite	-	-	-	-	1	-	-	-
Zircon	4	2	4	2	14	2	2	1
Cassiterite	-	-	-	tr	tr	-	-	-

Above percentages based on total of non-opaque, non-micaceous minerals. Percentages below based on total of all minerals counted.

	49	190	154c	264	412	327	333	429
Biotite								
Red-brown	2	12	5	8	10	22	2	-
Green	tr	7	2	8	9	21	tr	1
Opaques	60	18	60	54	81	89	19	26

See Plate I and Appendix XI for sample locations.

APPENDIX VI. MODAL ANALYSES OF SANDSTONES FROM THE OSWALD WEST MUDSTONES AND ASTORIA FORMATION

	Oswald West mudstones			Tucker Creek sandstones				Big Creek sandstones		Silver Point mdst	
Sample No.	190	36-7	26	57	154c	224	82	263	286	222	412c
Quartz											
Monocrystalline	18	12	21	14	16	21	3	23	28	17	12
Polycrystalline	3	3	1	4	3	1	1	2	3	5	6
Quartzite	tr	1	-	2	tr	-	tr	tr	-	2	1
Chert	-	-	1	3	-	-	-	-	-	1	-
Feldspar											
Plagioclase	5	4	2	5	2	4	tr	4	7	5	2
Orthoclase	18	5	7	12	9	12	7	9	6	22	8
Sanidine	-	-	tr	1	2	-	-	-	tr	-	-
Rock Fragments											
VRF	3	8	4	10	7	2	-	6	2	3	4
MRF	2	tr	1	tr	1	-	-	2	tr	3	3
IRF	-	-	-	tr	1	-	-	tr	-	2	-
SRF	1	1	2	2	1	-	-	-	-	3	1
Mica											
Muscovite	2	tr	2	1	1	2	tr	1	3	3	1
Biotite & Chlorite	5	2	1	2	2	3	-	10	5	4	6
Opaques	4	4	10	1	3	5	tr	8	2	2	4
Mafics	2	1	1	-	1	-	-	-	2	-	-
Glauconite	tr	28	-	-	1	1	53	-	-	-	-
Others	3	1	3	3	12*	1	-	4**	4	3	3
Cement											
$CaCO_3$	-	-	-	-	-	15	14	-	-	-	-
Hematite	-	-	2	1	-	-	-	-	-	-	-
Porosity	5	6	7	8	9	7	2	9	3	5	10
Matrix	29	33	34	30	28	25	15	22	34	20	39
Grain size	vf	f	vf	m	f	vf	m	f	f	f	vf

Tr = less than 1%

See Appendix XI for sample locations

Samples in approximate stratigraphic order

*10% carbonaceous matter

**2% carbonaceous matter

vf - very fine f - fine m - medium

APPENDIX VI (Continued)

Sample No.	Pipeline member						
	280	315	400	360	408	333	332
Quartz							
Monocrystalline	21	23	29	21	28	27	16
Polycrystalline	4	4	9	4	4	2	4
Quartzite	1	3	1	2	2	1	1
Chert	-	tr	1	tr	1	tr	-
Feldspar							
Plagioclase	4	6	5	7	4	6	10
Orthoclase	10	11	12	15	12	15	10
Sanidine	-	1	1	1	2	1	3
Rock Fragments							
VRF	2	16	2	10	7	11	12
MRF	3	3	1	5	7	2	1
IRF	tr	2	2	4	tr	tr	tr
SRF	1	3	-	tr	1	2	1
Mica							
Muscovite	1	tr	2	1	2	4	1
Biotite & Chlorite	2	1	tr	2	4	2	2
Opaques	3	1	1	3	tr	1	17
Mafics	-	-	-	-	tr	tr	tr
Glauconite	-	-	-	-	tr	tr	-
Others	tr	1	1	tr	tr	tr	3
Cement							
Hematite	-	-	13	-	2	4	-
Zeolite	tr	5	-	4	1	-	2
Porosity	12	10	12	3	13	11	5
Matrix	34	9	8	17	9	9	1
Grain size	m	m	m	m	m	m	f

APPENDIX VII. SANDSTONE SIZE ANALYSIS DATA - ASTORIA FORMATION AND OSWALD WEST MUDSTONES (See Plate I and Appendix XI for sample locations)

Samples	Sand %	Silt + Clay %	Coarsest 1% phi	Median phi	Mean phi	Sorting phi	Skewness phi	Kurtosis phi
Oswald West mudstones								
Middle part								
190 (Tows$_1$)	84.8	15.2	2.00	3.10	3.25	0.88	0.52	2.02
26 (Tows$_2$)	74.3	25.7	1.86	3.08	3.54	1.27	0.60	1.32
49 "	65.0	35.0	1.91	3.69	3.95	1.30	0.34	1.12
117	72.3	27.7	2.24	3.50	3.70	0.92	0.38	1.30
170	80.9	19.1	1.87	2.79	3.33	1.05	0.62	1.66
Tucker Creek member								
154c	78.9	21.1	1.29	2.81	3.16	1.35	0.47	1.34
57c	87.2	12.8	0.14	1.75	2.17	1.41	0.57	1.32
Big Creek member								
270	90.3	9.7	0.84	2.68	2.73	0.97	0.23	1.75
264	88.8	11.2	1.19	2.70	2.79	0.79	0.31	1.33
240	78.4	21.6	2.00	3.56	3.64	0.78	0.25	1.68
299	84.7	15.3	1.31	3.28	3.32	0.86	0.18	1.96
Silver Point member								
Lower Part	85.9	14.1	1.76	2.87	3.07	0.93	0.51	2.01
207	73.8	26.2	1.92	3.23	3.61	1.19	0.53	1.35
412c								
Pipeline member								
Type I sandstone								
399$_T$	91.3	8.7	-0.05	1.69	1.91	1.40	0.38	1.61
399$_B$	92.2	7.8	0.00	1.60	1.73	1.22	0.35	1.61
333$_{3T}$	94.0	6.0	0.29	1.73	1.90	1.04	0.36	1.24
333$_{3B}$	89.9	10.1	0.25	1.73	2.00	1.24	0.43	1.34
333$_{2T}$	91.0	9.0	0.25	1.75	1.94	1.21	0.41	1.48

APPENDIX VII. (Continued)

Samples	Sand %	Silt + Clay %	Coarsest 1% phi	Median phi	Mean phi	Sorting phi	Skewness phi	Kurtosis phi
Pipeline member (Continued)								
333_{2B}	90.8	9.2	0.20	1.75	1.97	1.22	0.43	1.49
333_{1T}	93.7	6.3	0.41	1.68	1.79	0.94	0.31	1.34
333_{1B}	92.4	7.6	0.22	1.73	1.88	1.14	0.36	1.54
389_{T}	82.2	17.8	0.71	2.21	2.69	1.59	0.57	1.49
389_{B}	96.7	3.3	0.63	1.66	1.89	0.78	0.47	1.08
449a	93.6	6.4	1.10	2.06	2.18	0.71	0.48	1.89
429	94.9	5.1	0.54	1.76	1.84	0.82	0.32	1.67
400	92.4	7.6	0.62	1.82	2.00	1.02	0.42	1.44
315	89.7	10.3	0.41	1.72	2.06	1.28	0.51	1.47
373a	90.2	9.8	0.42	1.76	2.03	1.27	0.49	1.65
280	87.8	12.2	0.50	1.90	2.21	1.37	0.49	1.46
Type II sandstone								
373b	82.6	17.4	1.10	2.69	3.02	1.24	0.49	1.64
Type III sandstone								
332	92.6	7.4	0.53	2.20	2.28	0.94	0.26	1.57
449b	87.9	12.1	0.97	2.62	2.81	1.21	0.24	2.06
327	83.7	16.3	1.05	2.86	3.10	1.11	0.38	1.93

Statistical parameters are those of Folk and Ward (1957)

Pipeline member: Samples with same number are from same outcrop. Numeral subscripts indicate position of bed in outcrop, i.e. #1 is lowest, #3 is highest, Subscript B - bottom of individual bed. Subscript T - top of individual bed. Small case letter subscript - differentiates sandstone types.

APPENDIX VIII

CLAY MINERALOGY OF SANDSTONE AND MUDSTONE SAMPLES

Analysis Procedure (after M. Harward, 1976)

A. Segregation of clay size material (< 2 u) in rock sample.

1. Disaggregate sample by boiling in distilled water or by gentle grinding with rubber pestle.
2. Wet sieve the sample using a 4Ø size sieve. Save the < 4Ø size fraction and add water, if necessary, to disperse the silt and clay. If flocculation is a problem, add Calgon to mixture in a ratio of 5.5 grams/liter. Agitation in rotary stirrer may be necessary to insure complete suspension.
3. Centrifuge the clay-silt suspension for 5 minutes at 750 R. P. M. This will leave the <2u clay fraction in suspension. Pour off the suspension and save. Re-suspend silt residue.
4. Repeat step (3) four times using the silt residue left after each centrifugation.
5. Place accumulated clay suspension in centrifuge tube and centrifuge at 6,000 R. P. M. for 10 minutes. Discard the supernatant and save clay residue.

B. Potassium and magnesium saturation, and X-ray slide preparation.

1. Place 2/3 of clay residue (from step 9) in a plastic centrifuge tube and the remainder in another tube.
2. Mg-saturation: Add a small portion of 1N $MgCl_2$ solution to the tube containing 2/3 of the clay residue. Mix thoroughly by shaking. Centrifuge at 6,000 R. P. M. for 10 minutes and discard supernatant. Repeat twice and remove excess Mg by washing clay 2-3 times with distilled water.
3. K-saturation: Wash the clay in the tube containing 1/3 of the clay residue 2-3 times with 1N KCl solution according to procedure in step (2). Remove excess K by 2-3 washings with distilled water.
4. Prepare two slides of Mg-saturated clay and one slide of K-saturated clay. This is done by smearing a thin even coating of the clay paste on a petrographic slide. Place the two Mg-saturated slides in a 54% R. H. dessicator. Place the K-saturated slide in an oven set at 105^{o}C.

C. X-ray analysis of clay samples.

1. Mg-saturated samples

   a. Run X-ray analysis on one of the slides with humidity control on the gonioneter set at 54% R. H. (2θ range - 2^{o} to 25^{o}). Return slide to 54% R. H. dessicator.
   b. Place one of the slides in the Glycerol dessicator so that it lies flat. Draw a vacuum. Place dessicator in oven and heat at 105^{o}C for 2-3 hours. Cool 12 hours before opening. Run X-ray analysis with humidity control set at 54% R. H.
   c. Place the other Mg-saturated slide in the Ethylene Glycol dessicator so that it lies flat. Draw a vacuum and heat in oven at 65^{o}C for 2-3 hours. Cool for 12 hours. Run X-ray analysis with humidity control set at 54% R. H.

2. K-saturated slides.

   a. Run X-ray analysis of the K-saturated slide (dried at 105^{o}C) with the humidity control set at 0% R. H.
   b. Place the slide in the 54% R. H. dessicator and allow to equilibrate for 12 hours. Run X-ray analysis with humidity control set at 54% R. H.

c. Heat K-saturated slide at 300°C for 3 hours and analyze in dry air (0% R. H.).
d. Heat slide at 550°C for 3 hours and analyze in dry air.

D. With seven diffractograms for each clay sample, determine the variations in the basal 0001 d-spacings with each treatment. Compare these variations with those listed in the following table for each major clay mineral type. (also see Brown, 1972, and Carroll, 1970).

APPENDIX VIII. (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	Montmorillonite	Beidellite	Vermiculite	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	"	"	"	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

Clay mineral	Pipeline 333 (ss)	Big Creek 264 (ss)	Silver Point 207 (mdst)	Oswald West 7 (mdst)	Oswald West 199 (mdst)
Montmorillonite (hydroxy-interlayered)	x	x	x	-	x
Chlorite intergrade	-	-	?	x	-
Chlorite	x	x	?	-	x
Beidellite	-	?	-	-	-
Mica	x	x	x	-	x
Kaolinite	-	-	x	-	?
Amorphous material	-	-	-	x	-
Clinoptilolite or heulandite	x	-	-	-	-

APPENDIX IX

Chemical Analyses of Basalt Samples

Sample	8-9-1	278	201
SiO_2	55.5	55.5	53.0
Al_2O_3	13.2	13.6	13.8
FeO	13.2	11.8	12.1
MgO	3.8	3.5	4.6
CaO	6.7	6.6	8.2
Na_2O	3.6	3.5	3.3
K_2O	1.55	1.70	1.05
TiO_2	1.90	2.05	1.95

All samples are Depoe Bay chemical-petrologic type basalt (Snavely and others, 1973). Sample locations listed in Appendix XI.

APPENDIX IX (Continued)

Modal Analyses of Depoe Bay Basalt Samples

Sample	278	8-9-1
Plagioclase	31%	48%
Clinopyroxene	24	28
Iron oxides	12	16
Tachylyte glass	31	-
Quartz	-	7
Alteration Product		
Calcite	2	tr

See Plate I and Appendix XI for sample locations

APPENDIX X. HYDROCARBON CONTENT OF SANDSTONE AND MUDSTONE SAMPLES

Procedure

Pyrolysis-fluorescence analysis 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 Source Rock Laboratory, was followed with minor changes. Each sample was prepared by crushing the rock sample to small pieces slightly larger than 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. After cooling, chloroethane (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, 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 (from Penoyer, 1977, p. 225).

APPENDIX X. (Continued)

HYDROCARBON CONTENT OF SANDSTONE AND MUDSTONE SAMPLES

(Locations shown in Plate I and listed in Appendix XI).

Unit, Lithology, and Sample Number	Wt. % Total Hydrocarbons	Source Rock Quality
Pipeline member		
403 - mudstone	<1.0	marginal source
403 - mudstone	<0.5	non-source
327 - sandstone	<0.5	non-source
Silver Point member		
344 - mudstone	<0.5	non-source
345 - mudstone	<0.5	non-source
350 - mudstone	<0.5	non-source
201 - mudstone	<1.0	marginal source
207 - mudstone	<0.5	non-source
Oswald West mudstones		
65 - mudstone	<0.5	non-source
Tucker Creek sandstones		
154 - sandstone	<1.0	marginal source

APPENDIX XI

SAMPLE LOCATIONS

Sample number	Location
	T. 7 N., R. 10 W.
7	mdst, roadcut, spur 31-F, NW 1/4, SW 1/4, sec. 14
18	ss, road cut, spur 31-M, SE 1/4, SW 1/4, sec. 11
26	ss, roadcut, log rd. 31, SW 1/4, NW 1/4, sec. 11
49	ss, roadcut, log rd. 31, SE 1/4, NW 1/4, sec. 11
53	slst, roadcut, log rd. 31, NW 1/4, NE 1/4, sec. 11
57c	ss, roadcut, spur 26, SE 1/4, SE 1/4, sec. 14
65	mudst, roadcut, Fletcher X-over, SE 1/4, NE 1/4, sec. 14
67	ss, roadcut Fletcher X-over, SE 1/4, NE 1/4, sec. 14
77	mudst, roadcut, spur 12-B, SE 1/4, NW 1/4, sec. 13
78	slst, roadcut, spur 12-J, NE 1/4, SE 1/4, sec. 11
82	mdst, roadcut, spur 21 L&C, SE 1/4, NE 1/4, sec. 11
84	mdst, roadcut, spur 21 L&C, NW 1/4, NE 1/4, sec. 11
87	ss, roadcut, spur 11-21, SE 1/4, SW 1/4, sec. 2
91	ss, roadcut, spur 11L-4, NE 1/4, SW 1/4, sec. 3
94	ss, roadcut, spur 11L-4, SE 1/4, NW 1/4, sec. 3
109	slst, roadcut, spur 11L-6, SW 1/4, NE 1/4, sec. 3
117	ss, roadcut, log rd. 11-21, SW 1/4, SW 1/4, sec. 2
122	slst, roadcut, spur 11-Q, NW 1/4, NW 1/4, sec. 2
31-7	mdst, roadcut, Lewis & Clark Rd., SW 1/4, SW 1/4, sec. 1
36-7	slst, roadcut, spur 13, NW 1/4, NW 1/4, sec. 13
	T. 8 N., R. 10 W.
132	ss, roadcut, log rd. 11-21, SW 1/4, SW 1/4, sec. 35
	T. 7 N., R. 9 W.
154a, b	ss, roadcut, spur 14L, NE 1/4, NE 1/4, sec. 17
154c	mdst, same as above
168	slst, roadcut, spur 31, NW 1/4, NW 1/4, sec. 6
170	slst, roadcut, spur 32, SE 1/4, NE 1/4, sec. 6
173	mdst, roadcut, Tucker Creek N., SW 1/4, NW 1/4, sec. 5
190	ss, roadcut, spur 25, SW 1/4, SE 1/4, sec. 5
191	slst, roadcut, spur 25, NE 1/4, SW 1/4, sec. 5

APPENDIX XI. SAMPLES LOCATIONS (Continued)

Sample number	Location
	T. 7 N., R. 9 W.
199	mdst, roadcut, spur 11, SE 1/4, NE 1/4, sec. 8
201	mdst, bslt, roadcut, spur H, SE 1/4, SW 1/4, sec. 16
207	mdst, roadcut, spur 26, NW 1/4, NW 1/4, sec. 15
222	slst, west side N-S ridge, NE 1/4, SW 1/4, sec. 16
229	mdst, roadcut, spur off Palmer Rd., NW 1/4, NW 1/4, sec. 12
239	ss, roadcut, spur 14, NE 1/4, SW 1/4, sec. 1
240	ss, roadcut, spur 14, NE 1/4, SW 1/4, sec. 1
242	mdst, roadcut, spur 11, SW 1/4, SW 1/4, sec. 1
243	ss, roadcut, spur off Palmer Rd., NW 1/4, SW 1/4, sec. 1
256	mdst, roadcut, Palmer road, NE 1/4, NW 1/4, sec. 12
412	ss, roadcut, spur B, NW 1/4, NW 1/4, sec. 5
429	ss, roadcut, Walluski Loop Rd., NE 1/4, SE 1/4, sec. 34
430	mdst, roadcut, Stoner Rd., NE 1/4, NE 1/4, sec. 33
454	mdst, roadcut, spur 12, SE 1/4, SW 1/4, sec. 23
8-9-1	mdst, bslt, roadcut, Highway 202, NE 1/4, NE 1/4, sec. 13
	T. 7 N., R. 8 W.
250	slst, roadcut, log rd. 28, SW 1/4, SW 1/4, sec. 6
263	ss, roadcut, Palmer Rd., SE 1/4, SW 1/4, sec. 6
264	ss, roadcut, Palmer Rd., NW 1/4, NE 1/4, sec. 7
270	ss, roadcut, Fisher Rd., NW 1/4, NW 1/4, sec. 8
271	ss, roadcut, Fisher Rd., NW 1/4, NW 1/4, sec. 8
272	slst, roadcut, spur 28, NW 1/4, NW 1/4, sec. 8
273	slst, roadcut, log, rd, 28, SW 1/4, SW 1/4, sec. 6
277	mdst, roadcut, spur B-4, SW 1/4, NW 1/4, sec. 6
278	bslt, roadcut, NW 1/4, SE 1/4, sec. 6
280	ss, roadcut, spur 28-B, SE 1/4, NW 1/4, sec. 6
286	ss, roadcut, Twilight M. L., NW 1/4, NE 1/4, sec. 8
288	slst, roadcut, spur Q, SE 1/4, SE 1/4, sec. 5
299	ss, roadcut, spur 28, SE 1/4, SE 1/4, sec. 6
70-8	mdst, stream cut, SW bank of Klaskanine R., NE 1/4, SE 1/4, sec. 18

APPENDIX XI. SAMPLES LOCATIONS (Continued)

Sample number	Location
	T. 8 N., R. 8 W.
314	mdst, roadcut, Twilight M. L., SW 1/4, SW 1/4, sec. 32
315	same
318	mdst, roadcut, Twilight M. L., SE 1/4, SW 1/4, sec. 32
320	mdst, roadcut, spur 44, NE 1/4, SE 1/4, sec. 32
327	mdst, roadcut, spur 44, NE 1/4, SE 1/4, sec. 32
332	ss, roadcut, spur 32, NE 1/4, NE 1/4, sec. 32
333	ss, roadcut, spur 32, NE 1/4, NE 1/4, sec. 32
334	ss, roadcut, spur 32, NW 1/4, NE 1/4, sec. 32
344	mdst, roadcut, spur 25, NW 1/4, NW 1/4, sec. 20
345	mdst, roadcut, West Twilight, SW 1/4, NE 1/4, sec. 20
350	mdst, roadcut, spur 25, NE 1/4, SW 1/4, sec. 29
353	mdst, roadcut, spur 53, SE 1/4, NE 1/4, sec. 31
356	mdst, roadcut, spur 53, NW 1/4, SE 1/4, sec. 31
358	mdst, roadcut, spur C, SE 1/4, NE 1/4, sec. 31
360	ss, roadcut, spur C, SE 1/4, SE 1/4, sec. 31
423	mdst, roadcut, spur 13, NE 1/4, SE 1/4, sec. 20
424	mdst, roadcut, spur 19, SW 1/4, SE 1/4, sec. 20
	T. 8 N., R. 9 W.
365	ss, roadcut, Wicks Rd., NW 1/4, NW 1/4, sec. 26
373	ss, roadcut, Pkpeline Rd., SW 1/4, SW 1/4, sec. 25
389	ss, roadcut, Nelson Rd., SW 1/4, NW 1/4, sec. 36
399	ss, roadcut, John Day Rd., SW 1/4, NW 1/4, sec. 24
400	ss, roadcut, spur 16, NW 1/4, NW 1/4, sec. 22
403	mdst, roadcut, spur 16, NE 1/4, NW 1/4, sec. 22
406	mdst, roadcut, spur 16, NE 1/4, SW 1/4, sec. 22
408	ss, roadcut, spur 16, SW 1/4, SE 1/4, sec. 22
449	ss, roadcut, Young's River Rd., SW 1/4 SW 1/4, sec. 29

APPENDIX XII. GEOCHEMICAL ANALYSIS AND COMPARISON OF SEEP OILS IN CALIFORNIA, NORTHWEST OREGON, AND SOUTHWEST WASHINGTON

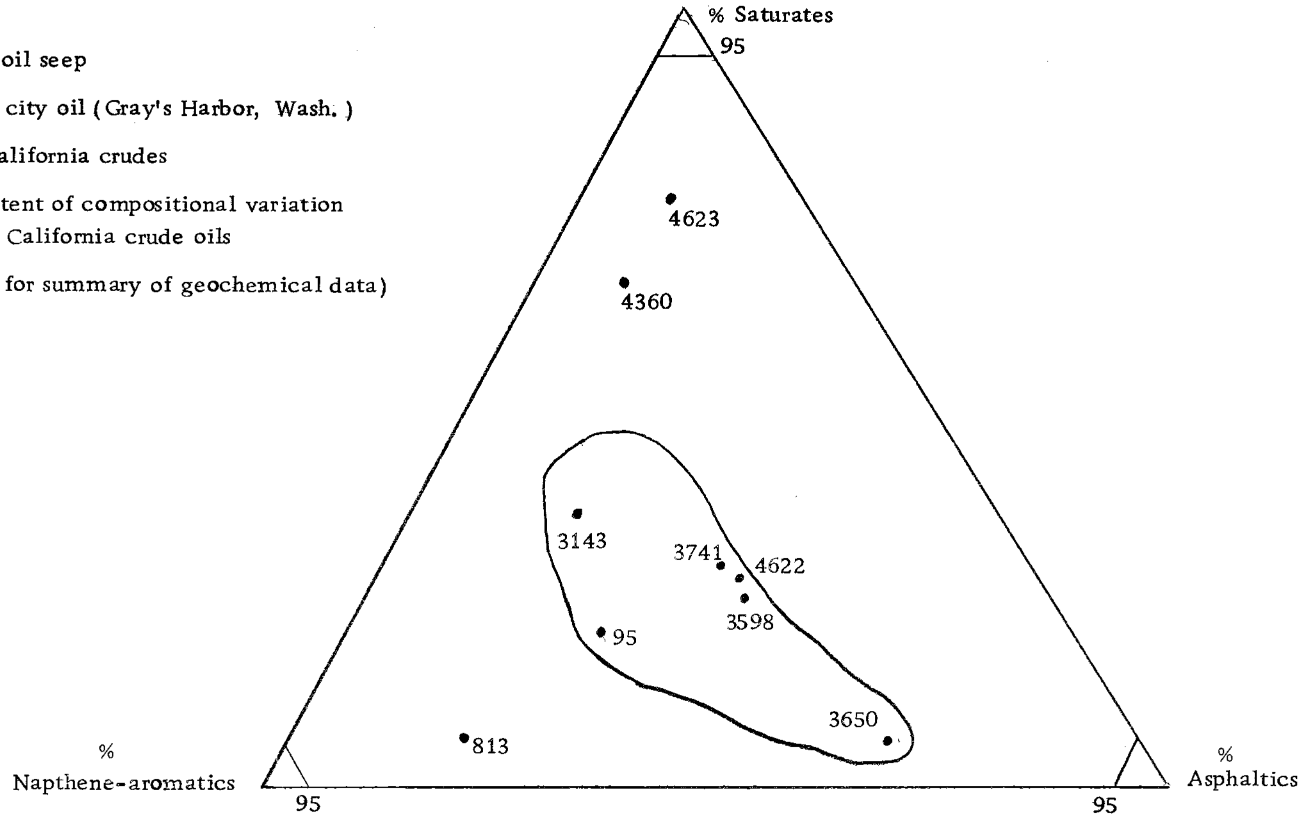
4623 - Olney oil seep

4360 - Ocean city oil (Gray's Harbor, Wash.)

all others - California crudes

———— extent of compositional variation of California crude oils

(see next page for summary of geochemical data)



(data courtesy of A. J. Miller and M. C. Parsons of Mobil Oil Company)

APPENDIX XII. (Continued) SUMMARY OF GEOCHEMICAL DATA ON WEST COAST SEEPS AND CRUDE OILS
(data courtesy of A. J. Miller and M. C. Parsons of Mobil Oil Company)

FRL No.	Locality	Age	% Hydrocarbons Saturated	% Hydrocarbons Naph. - Aromatics	% Asphaltics
4622	Oil Creek, Petrolia Northern California	?	26	35	39
4623	Logging site near Olney, Oregon	?	74	16	10
95	South Belridge Field	Pilocene	21	52	27
813	West Cat Canyon	U. Miocene	8	73	19
3143	Livermore Wildcat Alameda Co., Calif.	Miocene (?)	34	48	18
3598	Tar Creek Area	Oligocene	25	35	40
3650	Oxnard Field	Miocene	6	27	66
3741	1969 Union Oil Spill Offshore Sta. Barbara	Miocene (?)	28	36	36
4360	Gray's Harbor Wildcat Washington State	Miocene	67	24	9