PROSPECTS FOR NATURAL GAS PRODUCTION

AND

UNDERGROUND STORAGE OF PIPE-LINE GAS

IN THE

UPPER NEHALEM RIVER BASIN

COLUMBIA-CLATSOP COUNTIES,

OREGON

1976

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
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OIL AND GAS INVESTIGATIONS 5

PROSPECTS FOR NATURAL GAS PRODUCTION AND UNDERGOUND STORAGE OF PIPE-LINE GAS IN THE UPPER NEHALEM RIVER BASIN COLUMBIA-CLATSOP COUNTIES, OREGON

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Abstract

Tectonic history synthesized from a study of the geology of the upper Nehalem basin shows that conditions were conducive to migration and entrapment of hydrocarbons. Therefore, test drilling in Columbia County on prospective structures has the dual objectives of exploring for production as well as locating a storage site.

Increased demand for natural gas by industry and domestic users in Oregon over the past 20 years has led the gas industry management to look into possibilities for establishing large storage facilities. One of the most efficient and safe methods available for gas storage is to place it in natural underground reservoirs and withdraw it as needed when seasonal demand is heavy. Success of the Jackson Prairie underground storage project near Chehalis, Washington encouraged the present study for potential sites in Oregon.

Northwestern Oregon was chosen as a likely prospective area because it is relatively close to the Portland metropolitan area and geologic conditions there are quite similar to those found at Jackson Prairie. Nearly 10,000 feet of Tertiary marine rocks underlie Columbia County in the northwest corner of the State. Potential reservoir rocks are known to exist in the geologic section of the area, and a storage site appears to be available where there is enough capping shale and siltstone to safely confine the stored gas.

Mapping done in this study outlined several large fold structures having potential for underground storage of natural gas. Subsurface data obtained from two deep past oil exploration holes show there are prospective storage zones 3,000 to 4,000 feet below the surface on one large fold near the town of Mist. Reichhold Energy Corporation and Northwest Natural Gas Company drilled a 6,000-foot test hole south of the Mist structure in 1975. To date, information obtained in this drilling has not been released.

Petrographic descriptions of sandstone samples from Columbia and eastern Clatsop Counties are contained in Part II of this report along with tables of porosity-permeability tests. Details of the Jackson Prairie underground storage structure in Washington are discussed in Appendix A. Details of the storage project are accompanied by a cross-section through the field. Appendixes B through D list information obtained from drilling in the upper Nehalem basin. Appendixes E through H give data on porosity and permeability of samples collected from the upper Nehalem basin.

PART I

GEOLOGY, PROSPECTIVE FOLD STRUCTURES, AND RESERVOIR CHARACTERISTICS IN THE UPPER NEHALEM RIVER BASIN, OREGON

V. C. Newton, Jr.*

Introduction

Purpose and scope

The present study was undertaken by the Department in order to evaluate potential for commercial production of natural gas in the upper Nehalem River drainage basin, northwest Oregon. A secondary objective of the investigation was to examine geologic data to see if underground storage of pipeline gas is a possibility in this region. The two objectives are consistent because the same geologic conditions are necessary for both. Most of the present natural gas storage fields in the United States are located in depleted oil or gas reservoirs.

The upper Nehalem basin was selected as a likely prospect since it contains one of the most complete sections of middle Tertiary marine rocks onshore in the State. The area also has been given considerable attention by the oil industry over the past 30 years, and a fair amount of subsurface data has been made available by the drilling of four deep test holes in the basin.

The use of natural gas in Oregon and Washington has grown considerably since construction of the Northwest Pipeline system in 1957. Currently, the pipeline capacity is not large enough to meet peak loads during winter cold spells, so that a system of interruptible service must be used in which domestic users are given a preference. In the event exploration drillings in the upper Nehalem basin fail to discover natural gas, there remains the possibility for an underground storage reservoir. Local underground storage could be used to "smooth out" peak loads, eliminating serious dislocations of industry.

The investigation was designed to remap in detail the rock exposures in the upper Nehalem basin. Previous mapping has been of a reconnaissance nature, except for those studies which cover selected locations. Mapping of geologic structure was essential to ascertain the production and storage potential of the region. Collection of samples and cores was undertaken in order to determine rock characteristics for correlating stratigraphic units and to test sandstones for reservoir characteristics (Figure 1 A and B). Petrographic analyses were made on selected sandstone cores. Assemblage of these data along with more detail in geologic mapping enabled the author to make an assessment of the potential for natural gas production and for underground storage of pipeline gas.

Interpretation of structures and rock types was enhanced by use of aerial photos and the interpretation of space photos. New paleontological information with contributions of dated locations has been added to the study by Mobil Oil Company. Attempts by the author to obtain additional micropaleontological information were thwarted by deep weathering of outcrops or by selection of barren samples.

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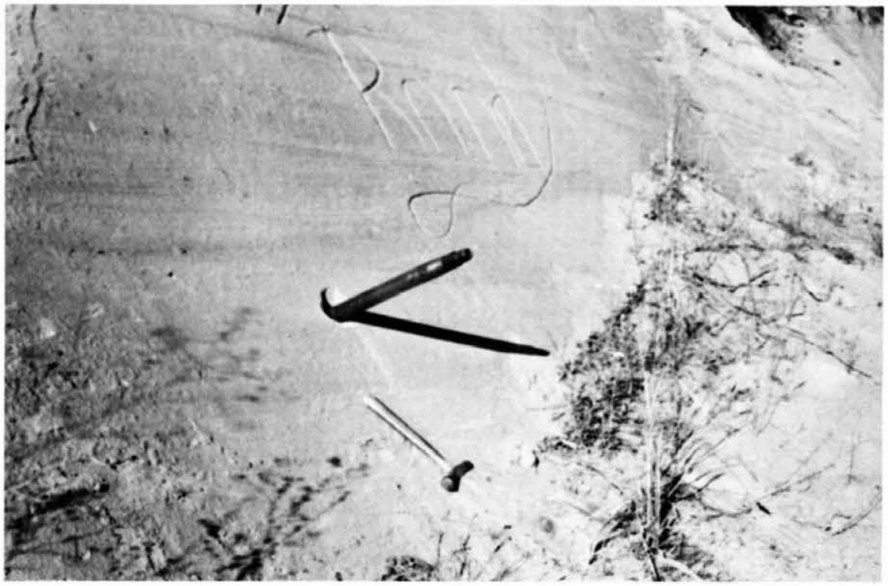


Figure 1A. Punch-type core barrel driven into an outcrop of Pittsburg Bluff sandstone.

Figure 1B. Core hole in medium-grained, friable, arkosic sandstone taken with a 1-7/8-inch by 18-inch thin-wall core barrel.

Acknowledgments

The author greatly appreciates the assistance given by many individuals and corporations in preparation of this report. The investigation was partly funded by Northwest Natural Gas Company and by Reichhold Energy Corporation with grants of $3,600 each. The assistance from Richard E. Thoms, Portland State University; Weldon W. Rau, Washington Geology and Earth Resources Division; Mobil Oil Company; and Texaco, Inc. in obtaining paleontological information was very helpful to the study. Special thanks are extended to Fred H. Wurden, geological consultant, and Donald M. Ford, Washington Division of Geology and Earth Resources, for furnishing data on the Jackson Prairie Storage Project (Appendix A). The author is also grateful for all the well data supplied by Texaco, Inc. Without this information the study would have lacked considerable geologic detail.

Harry J. Meyer, Northwest Natural Gas Company, accompanied the writer during field investigations on several occasions, contributed geological interpretations from studies of aerial photographs, and made useful suggestions regarding this report. Wesley G. Bruer, Consulting Geologist for Reichhold Energy Corp. contributed many helpful suggestions and assisted in making a final review of the manuscript.

The author also wishes to thank Robert J. Deacon for reviewing the manuscript and for offering helpful suggestions.

Appreciation is also expressed to my wife, Ruth, who assisted me on many of the field traverses.

Finally, a great deal of credit must be given to the Department's staff members for editing and typing the text and for preparing the maps and illustrations for publication.

Previous work in the area

The earliest report concerning geology of the Oregon Coast Range was given by J. D. Dana, who accompanied the U. S. Exploring Expedition in 1838-1842 under the command of Charles Wilkes. Thomas Condon made a continuous study of the Coast Range Province from the time he became Oregon's first State Geologist in 1874. J. S. Diller described the geology of northwest Oregon in 1896. These early investigators were followed by Dall (1909), Arnold and Hannibal (1913), Washburne (1914), Clark and Arnold (1918), Hertlein and Crickmay (1925), Schenck (1927), Weaver (1937 and 1943), Durham (1944), Warren, Norbisrath, and Grivetti (1945), Warren and Norbisrath (1946), Wilkinson and others (1946), Lowry and Baldwin (1952), Deacon (1953), Van Atta (1971), and McDougall (1975). Paleontological work has been as intensive in this part of Oregon as at any other location in the State.

Investigations made by Warren and Norbisrath (1946), Deacon (1953), and Van Atta (1971) have been used extensively in making this present analysis of geologic conditions in the upper Nehalem basin.

Geography

The area covered in this study (see Figure 2) is located in the northwest corner of Oregon, situated mainly in Columbia County, but also includes the eastern one-sixth of Clatsop County. The geologic map accompanying the report comprises the Cathlamet, Clatskanie, Birkenfeld, and Vernonia topographic quadrangles, which were used as the base for geologic mapping. The area is traversed by U. S. Highway 26, which crosses the southern part of the study area, and by U. S. Highway 30, which follows the Columbia River at the north boundary. Oregon Highway 47 is a north-south arterial; and Oregon Highway 202 runs generally east-west through the Vernonia and Birkenfeld quadrangles.

Clatsop and Columbia Counties have provided luxuriant timber stands for the lumber industry over the past 75 years. Douglas fir and cedar are the main commercial species utilized. Cutting has progressed to the second and third generation trees, with only sparsely scattered clumps of older trees left.

Vernonia, the largest city in the study area, is located near its center. Population was listed as 1,362 in 1972. This city has been a logging headquarters since the turn of the century. Clatskanie is the second largest city in the area, with a population of 1,275, and has a more varied industrial base than Vernonia, since it is located near the navigable Columbia River.

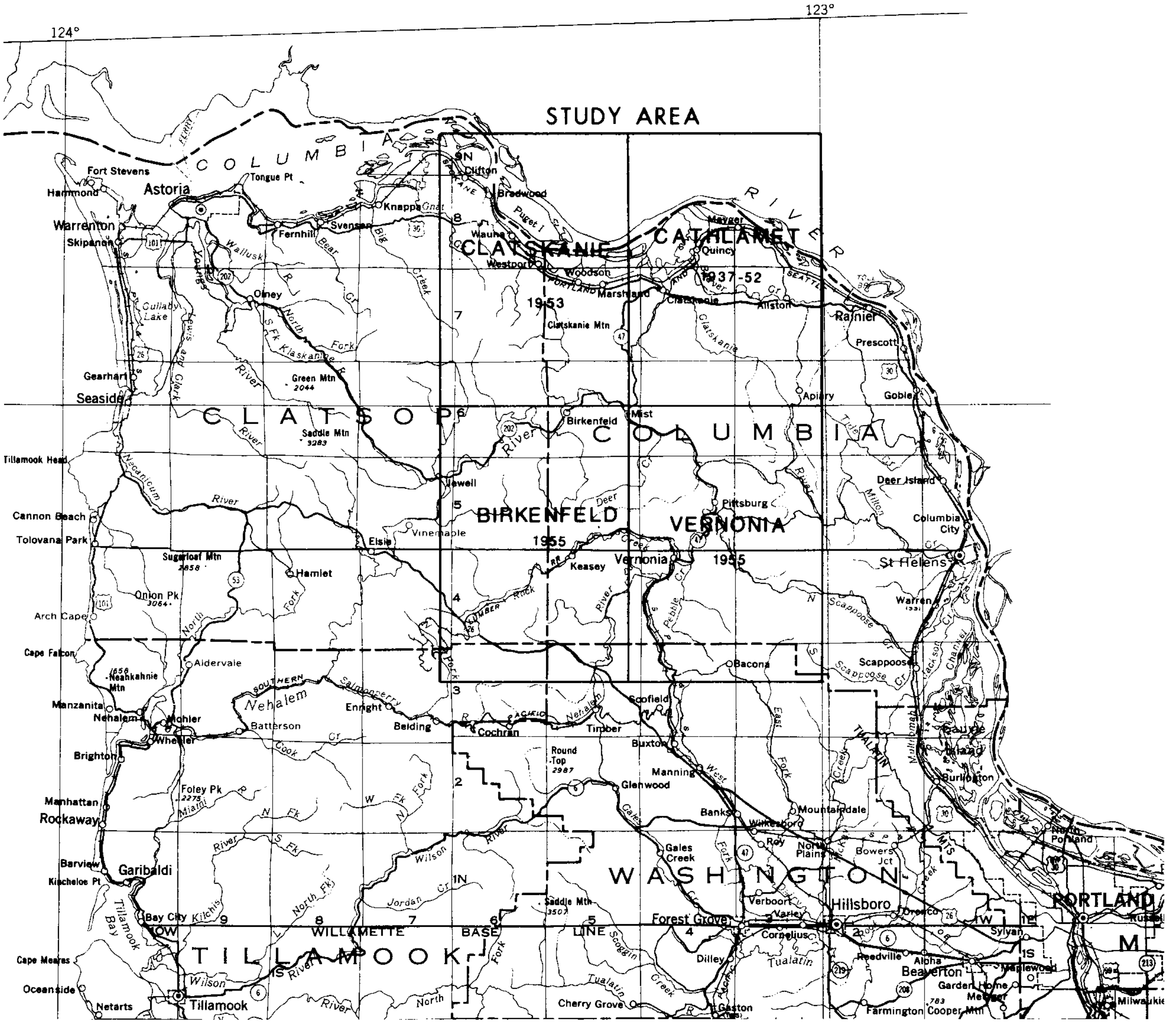


Figure 2. Index map of northwestern Oregon showing location of study area and topographic map coverage.

Topographic relief in the upper Nehalem basin varies from rugged to low hills bordering rather narrow flat lowlands. Nicolai Mountain is the highest peak in the map area, reaching a height of 3,020 feet. Many peaks reach an elevation of 2,000 feet, and average base level elevation of the main streams is 600 feet. The greatest relief is seen just south of Nicolai Mountain, where Big Creek has cut deeply into sedimentary units 2,000 feet below the peak. Relief is rugged along the east side of the study area and in the southwest portion.

The Nehalem River and Rock Creek form the main drainage ways, with numerous fairly large creeks feeding them. A mild climate and high rainfall are characteristic of the region and result in a heavy growth of vegetation. Annual precipitation in the study area is between 60 and 70 inches and mean temperature is 52°F.

Exposures of bedrock are limited mainly to logging roadcuts and to some parts of the stream beds and banks. Where roadcuts have been exposed for several years, the rock is often too weathered to obtain good samples, and the attitude of bedding is very likely to be affected by slope-creep and slumping. In general, weathering of outcrops has destroyed identifiable microfossils.

Geomorphology

The Nehalem River rises east of the Coast Range, flows in an arcuate pattern subparallel to the Columbia River, and empties into the Pacific Ocean 40 miles south of the mouth of the Columbia. The upper part of the Nehalem drainage area, known as the upper Nehalem basin, is bounded on the west by the Eocene lavas and sedimentary rocks of the Coast Range anticline and on the north and east by Miocene basaltic lava flows.

Structurally, the basin is part of the lower Columbia River downwarp composed of Tertiary marine sedimentary rocks capped by Miocene lavas. The Nehalem River has eroded its arcuate course around the northward plunging Coast Range anticline and through the Miocene lavas, exposing Tertiary marine sedimentary rocks over a broad area. Here the river has formed a flood plain, and tributary streams have incised deeply with lowering of base level in the main valley. A flattened surface at altitudes ranging between 900 and 1,200 feet suggest that the Nehalem River cut a former base level 400 feet above the present (Warren and Norbisrath, 1946).

Erosion during Pliocene and Holocene time has undercut the capping Miocene lavas, producing a steep topography around the northern and eastern margins of the Tertiary sedimentary basin. Warping of the lavas has caused the streams to produce a reverse topography on a grand scale by removing basalt from the higher areas and leaving the low areas in relief. The uplands on the east side of the study area rise to elevations of 1,300 to 1,800 feet, while the Tillamook Highlands at the southwest corner of the area reach to over 3,000 feet.

Drainage patterns reflect the rock type and structure in a typical manner. A dendritic drainage pattern has developed over Eocene and Miocene basaltic lavas. The drainage texture is finer in these areas than in those underlain by sedimentary formations. A trellis drainage pattern has developed on the sedimentary rocks parallel to the axial trends of folds and along fault and jointing structures. Several striking lineations, apparent on aerial photographs, agree with structures mapped in the field; most notable alignments are seen where basaltic dikes cut the sedimentary rocks. Prominent sandstone cliffs in the Pittsburg Bluff Formation account for linear features seen south of Mist and along Pebble Creek in the eastern area.

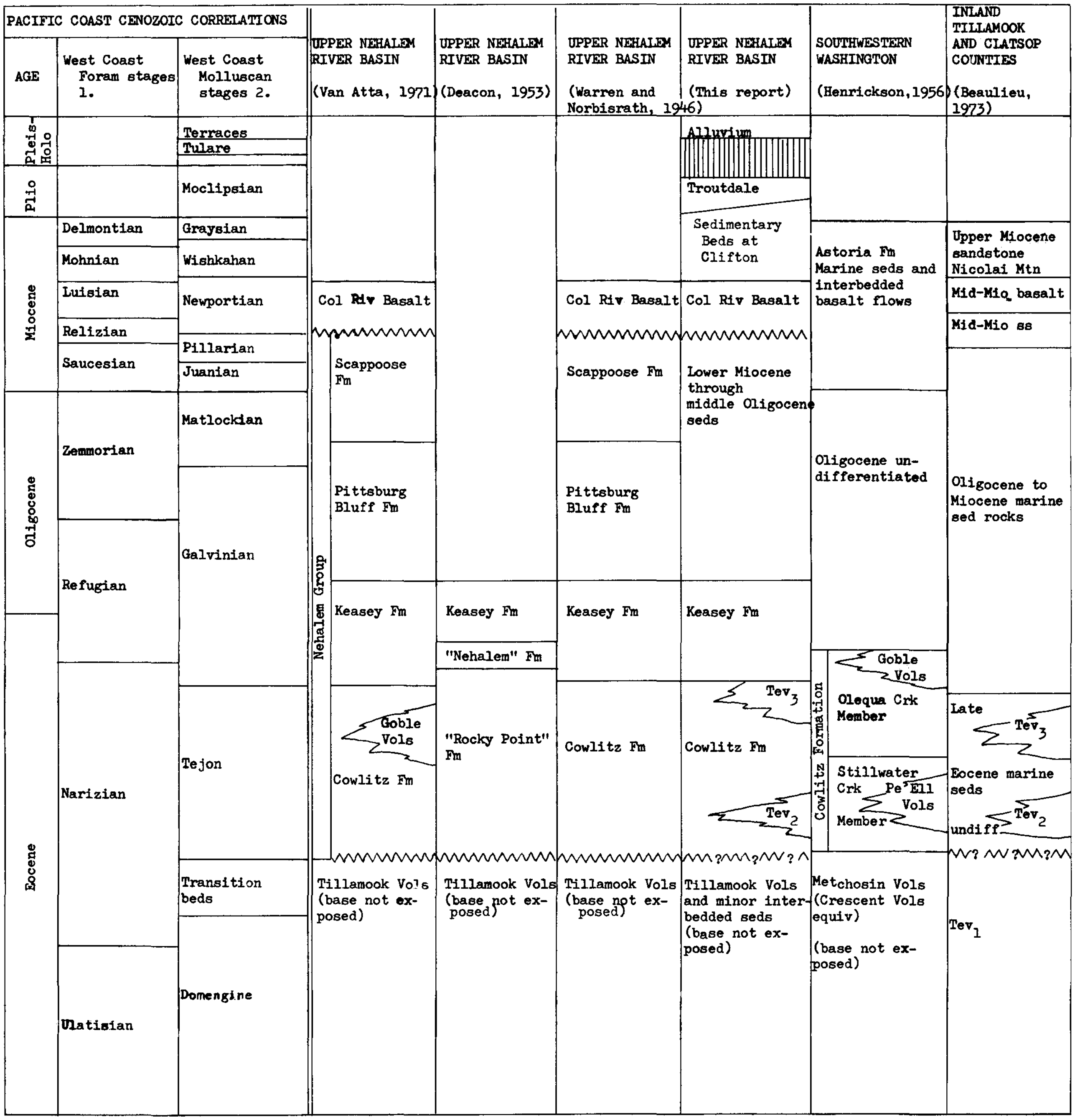
Stratigraphy

Three main rock types occur in the upper Nehalem basin: a lower sequence of basaltic submarine flows, an intermediate sedimentary section consisting of units ranging in age from upper Eocene through lower Miocene, and a capping series of Miocene basalt flows (see Figure 3). Data obtained from two deep Texaco exploration holes drilled in Columbia County indicate that Tertiary sedimentary units extend to a depth of at least 10,000 feet. Below a depth of 5,000 feet, volcanic rocks are interbedded with sediments and become the main rock type at greater depth.

Figure 4 shows a generalized geologic column for the area. Sedimentary units are typically fine grained and argillaceous, with some beds of medium-grained, fairly clean sandstone. Mapping done for this investigation describes a section of Tertiary rocks measuring approximately 20,000 feet in thickness, including submarine basaltic flows of the Tillamook Volcanics (see cross section on geologic map).

Figures 5 and 6 graphically illustrate the formations penetrated by the two Texaco wells. Much more volcanic rock was found in the hole near the town of Clatskanie, suggesting that an upper Eocene volcanic center (Goble Volcanics) lies on the east side of the upper Nehalem basin.

Attempts were made in the present field mapping to correlate lithologic characteristics and rock types in order to establish separate formations. However, it was found that basaltic flows and mudrock facies were the only rock types that could be mapped as separate units by their physical characteristics and stratigraphic relationships. Sandstones, shales, and concretionary limestone beds were found to be discontinuous and therefore could not be used for lateral correlations. The main and thickest mudrock exposures occur within what earlier studies have called the Keasey Formation. Scappoose Formation (?) mudrocks crop out in two or three locations directly under the Columbia River Basalt along the east side of the study area.

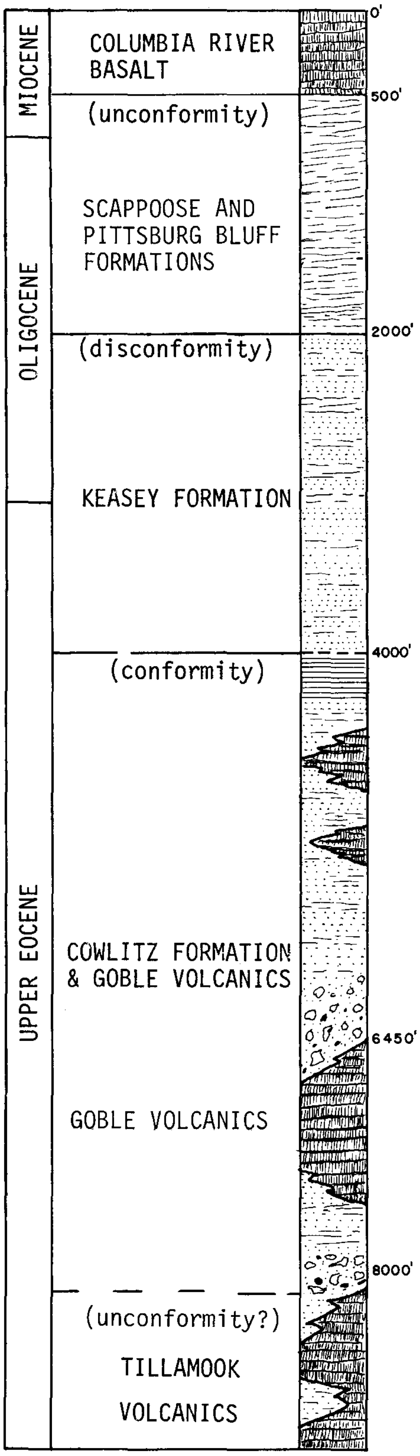


1. Modified from W.W. Rau, 1966

2. Modified from W.O. Addicott, 1976, and J. Armentrout, 1973

Figure 3. Correlation chart for the upper Nehalem basin in northwestern Oregon and for southwestern Washington (after Warren and Norbisrath, 1946; Beaulieu, 1971; and this report).

UPPER NEHALEM RIVER BASIN



Basalt: *dark gray-black, fine-grained, columnar flows, some interbedded pyroclastics.*

Siltstone, argillaceous tuffaceous sandstone, some clean sandstone, some mudstone: *gray, weathers to yellowish color, fossiliferous, often spotted with pumiceous material, some medium-grained arkosic sandstone, carbonaceous material, some pebble bands, cross bedding, micaceous, some thin limestone beds, few thin coal seams.*

Tuffaceous sandstone, mudstone, and shale: *micaceous, argillaceous, fossiliferous, interbeds of light-colored tuff, dark greenish-gray, weathers to buff color, concretionary limestone beds, some limestone layers.*

Mudstone and siltstone: *micromicaceous, dark greenish-gray, weathers to buff color, some thinly bedded, concretionary limestone, fossiliferous, some glauconite layers.*

Shale: *dark gray, micaceous, fossiliferous, some fine-grained shaley sandstone, tuffaceous sandstone, and water-laid tuff. Interbedded basaltic flows and flow breccia. Goble equivalent.*
Sandstone: *gray, massive, fine to medium-grained, micaceous, some carbonaceous material, cross bedding.*

Volcanics: *basalt flows and breccias, calcite and zeolite veining, pillow structure.*

Claystone and siltstone: *dark gray, well stratified, fossiliferous, containing white, intercalated Goble basalt flows.*
Conglomerate: *rust stained, hard, pebble, cobble, and boulder basaltic, some fossils.*

Volcanics: *greenish-gray, pillow structure, zeolite and calcite veining; flow breccia and interbedded claystone, siltstone, and argillaceous sandstone, tuff.*
(Bottom not exposed in area)

Figure 4. Generalized geologic section in the upper Nehalem basin.

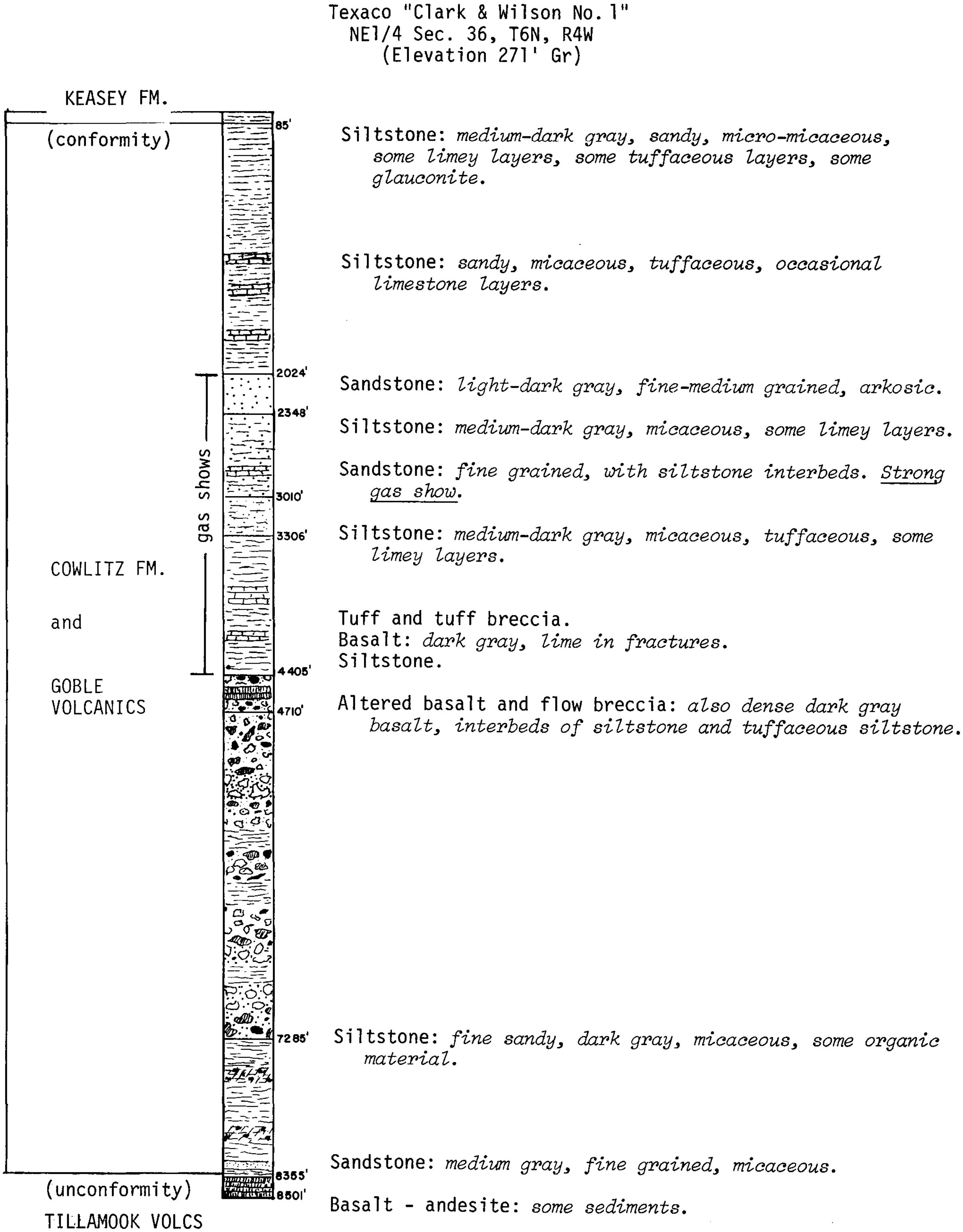
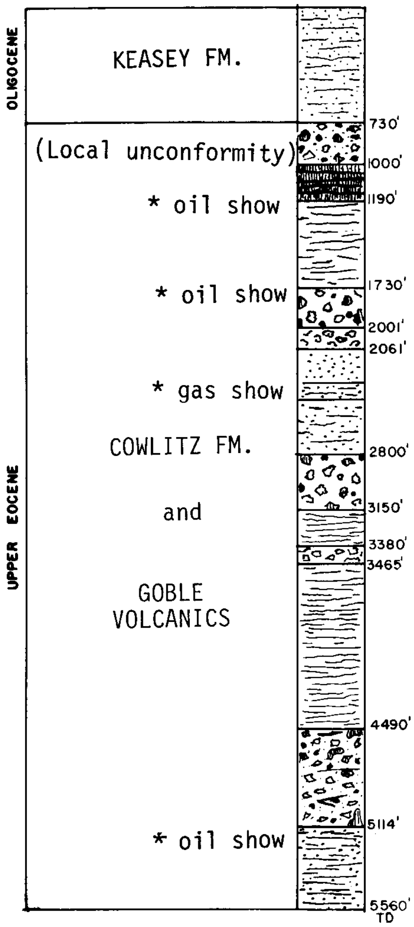


Figure 5. Composite log of the Texaco "Clark & Wilson No. 1" well.

Texaco "Clatskanie No. 1"
NE1/4 Sec. 19, T6N, R4W
(Elevation 271' Gr)



Sandstone and siltstone: *Light gray, fine, silty, arkosic, micaceous, with some white ash, fossiliferous, carbonaceous.*

Volcanic breccia: *dark gray, fragments of basalt.*

Basalt: *black, with augite, oily odor.* *

Siltstone and claystone: *medium-dark gray, argillaceous, carbonaceous, micac, some pumice, tuffaceous claystone. Good flash, free oil in mud.* *

Volcanic breccia: *fragments of amygdaloidal basalt.*

Conglomerate: *basalt pebbles.*

Sandstone: *dark gray, hard, tuffaceous, some calcite veins. Good gas flash.* *

Sandy limestone.

Sandstone and siltstone: *dark gray, tuffaceous, lignite, calcite veins.*

Volcanic breccia: *green, basalt fragments, calcite veins.*

Siltstone: *gray, argillaceous, fossiliferous, and brown carbonaceous siltstone, some calcite veins.*

Volcanic breccia.

Siltstone: *dark brown, black, hard, argillaceous, very micaceous, carbonaceous material, some calcite veins.*

Volcanic breccia: *green, waxy, with tuff and siltstone.*

Siltstone and sandstone: *Light gray, hard, limey micaceous. Light yellow ether cut.* * *Thin flow of volcanic breccia.*

Sandstone and siltstone: *Lost tools in hole, abandoned.*

Figure 6. Composite log of the Texaco "Clatskanie No. 1" well.

Investigations of sedimentary structure and of the fauna contained in the sedimentary units of the upper Nehalem basin indicate that the marine depositional environment varied from open marine, deep-water conditions to shallow-water shelf conditions. Sandstones are argillaceous arkoses and feldspathic wackes. Mudstones and siltstones are the dominant rock types, with a less amount of shale. Concretionary limestone beds are most common in the Keasey and Pittsburg Bluff Formations (Pittsburg Bluff and Scappoose Formations are mapped as one unit in this study).

Mica is ubiquitous in the sedimentary rocks of the area, with muscovite more plentiful than biotite. Biotite occurs in certain strata in the upper Nehalem basin. The flakes are often deformed and bleached. Both the biotite and larger muscovite flakes are believed to be derived from igneous parent rock. The very fine muscovite seen in many of the fine-grained rocks is probably detrital material.

Tillamook Volcanics (Tev 2)

Warren, Norbisrath, and Grivetti (1945) assigned the name Tillamook Volcanics to the thick section of Eocene basalt and flow breccias forming the core of the northern Coast Range in Oregon and containing interbedded marine shales and siltstones along with a minor amount of silty sandstone. Warren, Norbisrath, and Grivetti believed that the volcanics were lower upper Eocene age and older.

Beaulieu (1973) divided the Eocene volcanics of inland Tillamook and Clatsop Counties into 3 units. His lowermost unit, Tev 1, which may be equivalent to the Siletz River Volcanics to the south, consists of pillow basalt, zeolite-cemented lapilli tuff, and tuff breccia with some interbeds of baked sedimentary rocks and is judged to be middle Eocene (Ulatisian) on the basis of fauna found in the sedimentary interbeds. At stratigraphic intervals between the three volcanic units are marine sedimentary rocks of middle to late Eocene age which Beaulieu groups together as undifferentiated Tesu.

Volcanic unit Tev 1 is not exposed in the area of this investigation; however, unit Tev 2 and Tev 3 extend into the southwestern part and are mapped as Tillamook Volcanics and Goble Volcanics respectively.

South of the map area, the Tev 2 unit is represented by at least 2,000 feet of subaerial basaltic flows (Beaulieu, 1973). The unit is believed to overlie the older Eocene volcanics (Tev 1) and sedimentary rocks (Tesu, in part) with angular unconformity, which agrees with the regional uplift and erosion in the early part of upper Eocene time, as proposed by Snavely and Wagner (1963).

In the area of this investigation, Tillamook Volcanics (Tev 2) consist of dense grayish black basalt and altered submarine flows which are in fault contact with lower Cowlitz sediments.

Cowlitz Formation (Tec)

Upper Eocene sediments in the upper Nehalem basin are mapped as Cowlitz Formation for this report to agree with the same designation by most earlier workers; however, correlations of these sediments in the upper Nehalem basin with those in southwestern Washington were based on faunal evidence and not mapped continuity of beds. Geological mapping by Roberts (1958), Beikman and others (1961), and Livingston (1966) extends the Cowlitz correlation to within a few miles of the Columbia River, just north of the present study. Beds at Mount Solo, across the Columbia River from Allston, Oregon, are called Cowlitz Formation by Livingston (1966). This exposure is 10 miles north of the Texaco "Clatskanie No. 1" test hole, where upper Eocene sediments were encountered at a depth of 1,190 feet. The next closest exposure of Eocene sedimentary rock is near Keasey, 22 miles southwest from Mount Solo.

Rocks called Cowlitz Formation in this report are typical of the general lithologic character of units mapped as Cowlitz in southwestern Washington. Cowlitz beds there, including both the lower and upper portions, are described as near-shore marine and brackish water deposits containing massive micaceous, arkosic sandstone, sub-bituminous coal strata, and interbedded basaltic flow rocks.

South of the map area, the Spencer Formation and Helmick beds also correlate with the Cowlitz. Helmick beds overlie middle Eocene Yamhill sediments in the Salem quadrangle. Schlicker and Deacon (1967) traced the upper Eocene Spencer sandstone northward along the western edge of the Willamette Valley to the north half of the Forest Grove quadrangle. There the Spencer sandstone was faulted on the north against upper to middle Eocene volcanics (sec. 5, T. 1 S., R. 4 W.) and thus it could not be traced continuously to exposures of upper Eocene sediments near Timber Junction along Sunset Highway, 18 miles to the north.

The conglomerate at the base of argillaceous sandstone along Rock Creek near Keasey was described by Warren and Norbisrath (1946) as a basal member of the Cowlitz unconformably overlying Tillamook Volcanics. Mapping for the present investigation indicates that the conglomerate more likely represents a local unconformity related to a high area of Cowlitz age volcanics.

Cowlitz sediments appear to be littoral to sublittoral deposits. Siltstones are finely laminated, displaying cut and fill structures and low-angle cross-laminations, and contain finely comminuted plant debris (Van Atta, 1971). The section constructed from mapping in the Clear Creek drainage south of Rocky Point indicates that the lower portion of the Cowlitz consists of 2,600 feet of bedded dark- to medium-gray argillaceous, micaceous siltstone; subordinate strata of fine silty micaceous, arkosic sandstone; and dark-gray, thinly stratified micro-micaceous shale. Cowlitz sediments contain very little volcanic glass, in contrast to Oligocene sediments.

The upper sandstone strata of the Cowlitz Formation has been preserved on the downfaulted side of the Rocky Point fault near Keasey, and these beds are conformably overlain by lower Keasey strata. According to Deacon (1953), the Cowlitz (proposed Rocky Point Formation by Deacon) at this location consists of 1,000 feet of basal conglomerate and overlying argillaceous sandstone and siltstone containing large concretions. Adding this section to the Clear Creek section gives a total of at least 3,600 feet of Cowlitz sediments in the southwest area.

Goble Volcanics (Tev 3)

Goble Volcanics are interbedded with upper and lower Cowlitz sediments and represent at least two main periods of volcanism during the late Eocene. In the map area, Goble Volcanics consist of dark gray-black submarine and subaerial basalt flows, mudflow breccias, some pyroclastics, and basaltic dikes and sills. Locally, the basalts are chloritized and cut by calcite and zeolite-filled fractures. Rocks of this type are exposed in the Saddle Mountain quadrangle to the west and extend into the map area where they form Green Mountain in T. 5 N., R. 6 W. (Figure 7). Warren and Norbisrath (1946) included the Green Mountain flows in the Tillamook Volcanics and interpreted an uncomformable relationship between these volcanic flows and the overlying Cowlitz Formation. However, on the south side of the Green Mountain volcanic mass, Goble Volcanics are overlain by and interbedded with an estimated 1,000 feet of lower Cowlitz sediments.

Goble Volcanics exposed along the Columbia River near Rainier, Oregon are interbedded with upper Cowlitz sediments and are therefore younger than the volcanic rocks forming Green Mountain.

Keasey Formation (Tok)

The lower Keasey Formation consists of approximately 350 feet of stratified, dark-gray marine siltstone and shale with thin interbeds of glauconitic sandstone along Rock Creek near Keasey (proposed Nehalem Formation by Deacon, 1953). These strata represent the type section of Keasey shale described by Schenck (1927). The Keasey Formation was divided into three lithologic members by Warren and Norbisrath (1946) (Figure 8). These three members can be described as: (1) a lower dark-gray glauconitic, tuffaceous mudstone which interfingers with a volcanic sandstone, (2) a middle massive, tuffaceous siltstone, and (3) a sequence of concretionary tuffaceous siltstone and mudstone beds (McDougall, 1975). The Keasey Formation is believed to conformably overlie the Cowlitz Formation.

Warren and Norbisrath (1946) extended the Keasey westward along Rock Creek to include light-gray tuffaceous mudstone and siltstone containing silty concretionary limestone layers 1 to 2 feet thick. A fairly thick sequence of black organic shale, which developed in the Keasey on the northwest flank of the Tillamook highlands, is exposed west of Birkenfeld and near the town of Jewell. Total thickness of the Keasey is probably in excess of 2,000 feet (Warren and Norbisrath, 1946). A lithofacies map covering the study region shows that exposures of Keasey rocks are predominantly mudstones (see geologic map). Keasey sediments were deposited at bathyal to sub-bathyal depths according to paleontological studies of microfauna from the type section (McDougall, 1975). The occurrence of glauconite in some of the sediments also suggests they were laid down under open-marine or outer-shelf environment (Otvos, 1966).

Between Green Mountain and Birkenfeld, the lithology changes to siltstone and fine-grained, silty, micaceous sandstone, in contrast to the predominantly mud-rock facies elsewhere. Warren and Norbisrath (1946) found abundant plant remains in this section, but no diagnostic fossils, and concluded that these

Figure 7. Spheroidal weathering in upper Eocene basalt (Tev 3) along Buster Creek road, northwest of Green Mountain.

Figure 8. Bluff of Keasey mudstone and siltstone along the west bank of the Nehalem River south of Mist.

sediments were deposited rapidly in a brackish water environment, precluding a favorable habitat for mullusca. The author attempted to collect microfauna from this section of rocks, but all the samples were barren of fossils. There is a question as to whether these rocks belong to the Keasey ot Pittsburg Bluff Formation.

Primary structures in the Keasey include cross-laminations, ripple laminations, bioturbidation features, load casts, and occasional flame structures (Van Atta, 1971). The Keasey Formation is highly fossiliferous, yielding museum quality specimens.

Gries Ranch beds are included within the Keasey Formation in this study. Warren and Norbisrath (1946) described conglomerates and massive sandstone in Conyers Creek as overlying the Keasey. Wilkinson and others (1946) considered Gries Ranch beds in the St. Helens quadrangle equivalent to lower Keasey. Conglomerate and sandstone exposures, formerly designated as Gries Ranch beds, are believed to be local units within the Keasey Formation.

Middle Oligocene to lower Miocene sandstone and siltstone, undifferentiated (Tom)

Middle Oligocene to lower Miocene marine sedimentary rocks of the Pittsburg Bluff and Scappoose Formations occur along the eastern and northern margins of the map area. Their combined thickness is estimated to be 800 feet along the eastern portion and possibly as much as 1,500 feet to the north in the central downwarp. Although a disconformable relationship is generally thought to exist between the two units, no distinguishing characteristics could be found during this mapping effort, and the two units were therefore mapped as undifferentiated (Tom).

Warren and Norbisrath, 1946, found Pittsburg Bluff resting with slight discordance on the Keasey Formation near Vernonia. The lower Pittsburg Bluff sediments resemble the Keasey, but they generally contain more siltstone (Figure 9). The lower sandstones form prominent bluffs along Pebble Creek and northward to Mist along the east bank of the Nehalem River. Like the Keasey, this portion of the Pittsburg Bluff contains concretionary limestone beds. The upper portion of the Pittsburg Bluff beds consist of massive fine-to-medium grained arkosic sandstones and interbedded siltstone. Occasional layers of white volcanic ash, now altered to clay, are present. Zeolite in the sediments probably resulted from diagenesis of rhyolitic volcanic glass. Much of the silica found in these rocks was likely released during formation of zeolite from volcanic glass (Van Atta, 1971).

Locally the sandstones are cross-bedded, display subparallel, wavy iron-stained laminae, and contain carbonized wood fragments and occasional thin coal seams. A bed 2 to 3 feet thick has been mined from two tunnels along Coal Creek in the SE$\frac{1}{4}$ sec. 23, T. 4 N., R. 4 W., and a sub-bituminous coal bed 3 to 5 feet thick is exposed in cuts along the Columbia Forest Road in NW$\frac{1}{4}$ sec. 15, T. 4 N., R. 3 W. Facies changes are common in the Pittsburg Bluff Formation. Structures and lithology suggest that these beds were deposited partly under shallow marine conditions and partly as delta sediments. Torrential cross bedding can be seen in Pittsburg Bluff sediments, with cut and fill structures as well as occasional conglomerate lenses (see Figure 10). The Pittsburg Bluff is as richly fossiliferous as the Keasey. The upper Pittsburg Bluff Formation is more tuffaceous than the overlying rocks assigned to the Scappoose Formation and contains occasional layers of white volcanic ash, now altered to clay. However, there are some clean (matrix-free) arkosic sandstone beds in this section.

Scappoose beds are believed to have a disconformable relationship to the underlying Pittsburg Bluff Formation, but in this mapping effort no distinguishing characteristics could be found between the two formations in the field, so the units were not mapped separately. Van Atta (1971) described the Scappoose Formation as being cleaner, more quartzose, and having less volcanic ash than Pittsburg Bluff strata. He concluded that the two formations could be mapped separately in his area upon lithologic differences.

Miocene sediments, undifferentiated (Tm)

Miocene sediments consisting of yellowish, fine- to medium-grained, micaceous sandstone with a lesser amount of sandy mudstone underlie and are interbedded with Columbia River Basalt on the east and south slopes of Nicolai Mountain and along U. S. Highway 30, approximately 7 miles west of the town of Wauna (Figure 11). Wells and Peck (1961) mapped the sedimentary rocks south of Nicolai Mountain and in the upper Big Creek drainage as middle Miocene Astoria Formation. Beaulieu (1973) mapped sedimentary rocks south of Nicolai Mountain as Oligocene to Miocene age in his "Toms" unit.

Figure 9. Roadcut in weathered argillaceous sediments of lower Miocene to upper Oligocene age along the Mist-Clatskanie highway.

Figure 10. Conglomerate lens in the Pittsburg Bluff Formation on Coal Creek road.

Figure 11. Miocene sandstone in cut along Shingle Mill road just north of Nicolai Mountain.

In this investigation, Miocene sandstone overlying the Columbia River Basalt west of Bradley State Park on U. S. Highway 30, and referred to as "Clifton Beds" by Lowry and Baldwin (1952), and the sediments interbedded and directly underlying Miocene flows at Nicolai Mountain are assigned to Miocene sediments undifferentiated unit Tm (see geologic map). No marine fossils have been found in the "Clifton Beds," and they are believed to be fresh-water deposits. Some of the sedimentary rocks beneath the Columbia River Basalt and mapped as unit Tm may be equivalent to strata mapped as Scappoose Formation by Warren and Norbisrath (1946) or as unit Tom in this report.

Conglomerate beds of uncertain relationship occur beneath the Columbia River Basalt at several locations in eastern Columbia County as follows: 1 mile northeast of Oregon Highway 47 in a logging roadcut in the south half of sec. 36, T. 7 N., R. 4 W., (Wilkinson and others, 1946) where the Texaco "Clatskanie No. 1" was drilled; and along Bacona Road north of Buxton.

Columbia River Basalt (Tcr)

The Columbia River Basalt consists of grayish-black, dense, aphanitic basaltic flows (Figure 12 and 13) with lesser amounts of flow breccias, pyroclastics, and intrusive rocks. Total thickness of the basalt is estimated to be 1,000 feet in the central basin. As determined by Wilkinson and others (1946), a significant unconformity between the Tertiary marine sedimentary formations and the overlying Columbia River Basalt indicates uplift and deep erosion prior to the extrusion of the lavas. Columbia River Basalt uncomformably overlies rocks ranging in age from late Eocene to early Miocene in northwestern Oregon. The basalt flows are interbedded with marine Astoria Formation in the lower Columbia Valley. Total thickness of the basalt is estimated to be 1,000 feet in the central basin.

Figure 12. Weathered Columbia River Basalt exposed along Oak Ranch highway near Camp Wilkerson.

Figure 13. Siltstone inclusion exposed in quarry rock (Columbia River Basalt) was probably plucked from underlying sediments as lava flowed across the area.

Troutdale terrace gravels (Tt)

Troutdale terrace gravels unconformably overlie Miocene units. Only limited remnants of Troutdale terraces were mapped in the upper Nehalem basin. These deposits consist of gravels and sands containing quartzite, basalt, and granitic cobbles. Troutdale gravels are exposed in a pit along Oregon Hwy. 47 just west of Clatskanie. A second exposure of the Troutdale gravels was mapped by Wells and Peck (1961) northwest of Rainier, Oregon, overlying Columbia River Basalt.

Quaternary alluvium (Qal)

The thickest deposits of young alluvium are found along the flood plain of the Columbia River. Elsewhere the stream valleys feeding the Columbia River, the Nehalem River, and its tributaries have thin alluvial deposits. The valleys are relatively young geomorphically and their floors are still being carved out of the lava flows and marine sedimentary rocks.

Structure

Structural mapping in the upper Nehalem basin was difficult owing to limited exposures and to abundant slumps and slides. The short time available for field mapping in this project leaves much more work for later studies.

The upper Nehalem basin is part of the lower Columbia River downwarp, which formed prior to extrusion of Miocene lavas. Uplift and arching of the northern Coast Range formed a northward plunging anticline which projects as a salient into this downwarp. Contacts of sedimentary units bend around the Coast Range cross-warp in the upper Nehalem valley.

Large northwest-southeast trending subparallel folds cross the area. Smaller secondary east-west structures were identified but are not shown on the map accompanying this report. The major folds appear to be fairly broad, simple features with little associated faulting. Dips on fold limbs range from 10° to 20°, and in most cases enough field attitudes were obtained to determine direction of fold plunges. Vertical closure on the folds is on the order of 1,000 to 1,500 feet. A significant break in the axial trace of the large fold near Mist has been interpreted as a fault. Toward the southwest, the basement rock (Tillamook Volcanics, Tev 2) rises until it outcrops at the very southwest corner of the region mapped. Northwest-trending warps are believed to flatten out progressively northwestward over the basement structure. The syncline shown in the southwest part of the map on the west flank of the Tillamook Highland dies out near the top of the arch.

Faults mapped thus far are oriented northwest-southeast, east-west, and normal to the major fold axes. The several large, steeply dipping, northwest-trending faults mapped west of Timber Junction and north of Sunset Highway are probably reverse, with possibly some strike slip movement, since folding suggests compressional stresses. Faults with reverse movements are described by Deacon (1953). Opposite the large fault near Keasey, on the northeast side, the downfaulted block preserves upper Cowlitz sands and shales. A large east-west fault near Clatskanie, mapped by Wells and Peck (1961), is shown on the geologic map. The type of displacement along this fault is not known. Other faults were mapped in the current investigation, but most of them were relatively small features or their lengths could not be determined because of limited exposure.

Basalt dikes make conspicuous lineations in the topography and were first recognized as lineaments on aerial photographs. They have since been confirmed by field mapping. The intrusives are mostly dark-gray and black, fine-grained mafic rocks with some coarser grained gabbroic types.

Many lineations are defined on aerial photographs of the area; but field evidence has not substantiated all of them as being structural features. R. D. Lawrence, Oregon State University, produced a lineation map of northwest Oregon (Figure 14) made from interpretations of satellite photographs. Several large feature are inferred, but they also have not been confirmed as geologic structures. A significant, large, east-west structure is shown trending across the entire northwest corner of the State. More field checking of this lineation should be done. Some of the lineations correspond to known fold structures or faults; others outline formation contacts or resistant ridges.

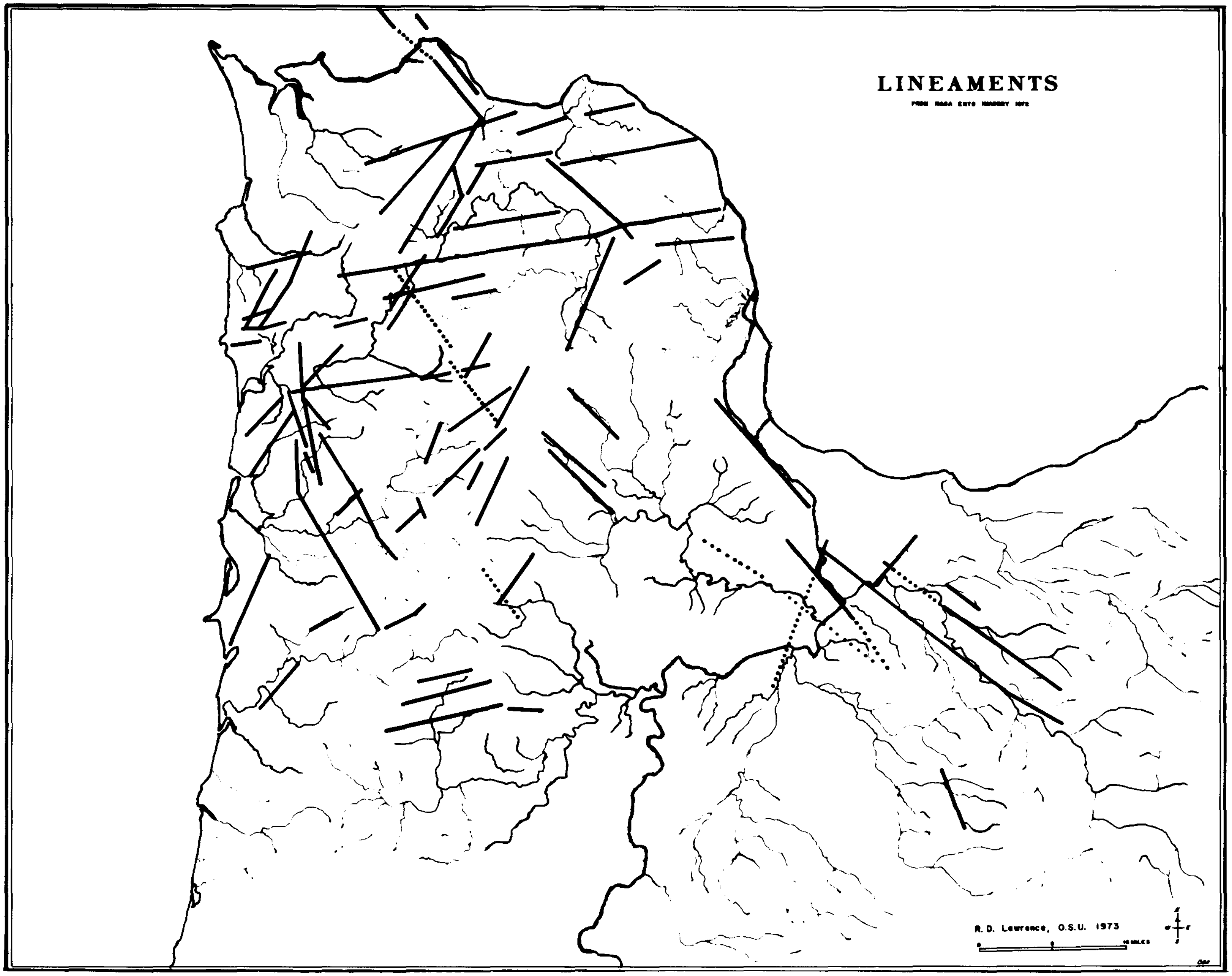


Figure 14. Satellite lineation map of northwest Oregon.

Geologic History

Evolution of the Tertiary basin in northwestern Oregon can be read from fossil evidence, lithology, and from mineral constituents of the rocks. Reconstructions of geologic history in northwest Oregon were made by Wilkinson and others (1946), Warren and Norbisrath (1946), Deacon (1953), Snavely and Wagner (1963), and Van Atta (1971). The comprehensive dissertation by Van Atta has contributed a great deal to understanding past geologic events affecting the area, particularly for provenance of detrital material and subsequent diagenesis of certain mineral components.

A record of pre-Tertiary history is totally lacking for northwestern Oregon, as no exposures can be seen in this region and no drill holes reached pre-Tertiary rocks. Outcrops of Paleozoic and Mesozoic marine rocks in Oregon are limited to the northeastern, central, and southwestern parts of the State. Some of the current ideas on geologic history involving the western edge of the North American continent suppose that volcanic islands in the east Pacific Ocean were rafted by crustal spreading in Eocene time to the margin of the continent and that the intervening material was subducted beneath the North American plate in Oligocene time. It this is an accurate model, Tertiary rocks in western Oregon and Washington lie directly on oceanic crust, and none of the older sedimentary units will be found in the substrata of this region (Beaulieu, 1972). A second hypothesis does not involve crustal drifting but presumes that extrusion of tremendous amounts of volcanic material in Eocene time resulted in subsidence of the adjoining continental shelf and slope. In this case, Tertiary rocks would be underlain by older sedimentary (?) units. Resolution of this enigma depends on aquisition of more geologic evidence.

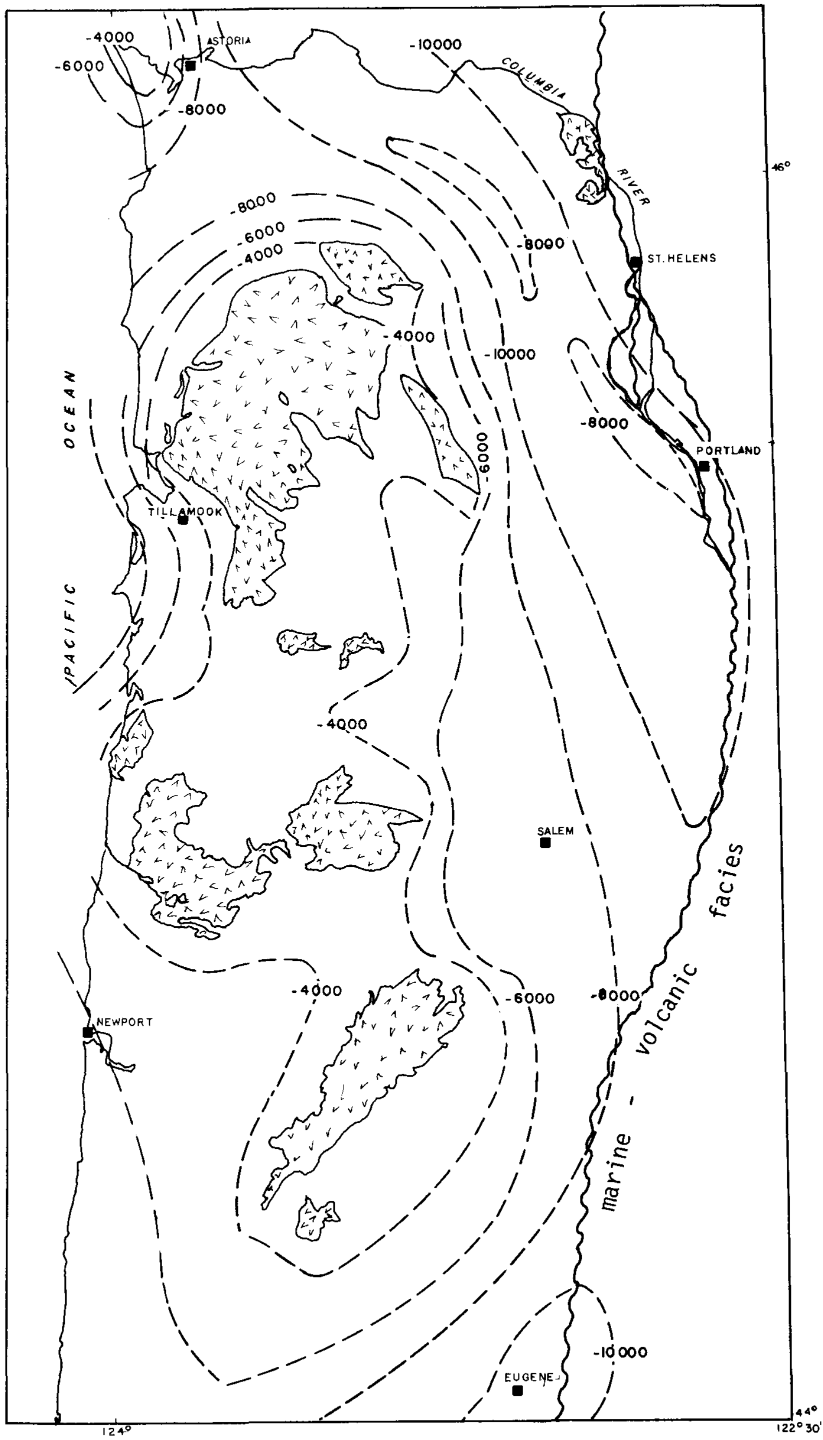
Exposures of marine sedimentary rocks in western Oregon and Washington outline the site of an inland Tertiary sea which covered the region between 40 and 20 million years ago. Thickness of marine sediments is believed to be in excess of 10,000 feet at places in western Oregon (see Figure 15).

The known geologic history of northwestern Oregon begins with voluminous extrusions of submarine basaltic lavas, breccia, and pyroclastics of Eocene age which built a low archipelago of volcanic islands in northwestern Oregon and western Washington. As the basin subsided these basaltic lavas attained an estimated thickness of 10,000 feet or more at their volcanic centers.

In the area of this study, marine siltstone and sandstone became interbedded with the submarine lava and breccias, forming the Tillamook Volcanics. As volcanism waned in Eocene time, marine sediments received less volcanic debris and more plutonic and metamorphic materials from highlands to the south and northeast (Van Atta, 1971). Near the close of middle Eocene time, the volcanic islands were probably reduced in elevation to near sea level. In late Eocene time basalt and breccia (Goble Volcanics) issued from local vents and from centers northeast of the study area. These flows became interbedded with Cowlitz sediments. No major volcanic eruptions occurred during Oligocene time in the upper Nehalem Basin, but pyroclastics and metamorphic debris entered the basin from an eastern source. Cross-bedded structures, fragments of carbonized wood, and leaf fossils suggest that much of the Cowlitz Formation was deposited in a shallow shelf environment.

The overlying Keasey Formation is believed to have been deposited at bathyal to sub-bathyal depth (McDougall, 1975); however, some of its finer-grained sediments could have resulted from the lowering of relief and the reduction of erosive activity. Early studies of the region indicate that breaks occurred between deposition of the rock formations in the upper Nehalem basin; but later studies, including the present study, concur that the sediments in this region were more or less continuously laid down as the region was downwarped, with intermittent volcanic activity causing localized changes in deposition. The Keasey Formation and Pittsburg Bluff Formation contain a fair amount of rhyolitic and andesitic material, probably from volcanic centers along the northeast edge of the Nehalem basin (Van Atta, 1971).

The massiveness of the middle Pittsburg Bluff sandstones shows increased subsidence and acceleration in the rate of sediment deposition in middle Oligocene time. Cessation of subsidence but continued sedimentation caused a shallowing of water in late Pittsburg Bluff time. Lithologies and sedimentary structures indicate that the depositional environment gradually shifted from shallow shelf to delta type by late Pittsburg Bluff and Scappoose time. Scappoose sediments are believed to have been deposited as marsh and delta-front sands and silts. Van Atta (1971) states, "Volcanic activity during Oligocene time east of the upper Nehalem River basin is shown by the persistence of andesitic and basaltic glass and rock fragments in the sediments. Scappoose sediments contain more arkosic debris than older units, similar to the Cowlitz, pointing to a main source in the Rocky Mountains to the northeast."



volcanic highs

Figure 15. Isopach map of Tertiary marine sediments younger than middle Eocene age.

Warping of rocks in the northern Coast Range is believed to have begun in Eocene time, resulting in a regional unconformity between the Tillamook Volcanics and underlying units. Minor deformation of rocks of this region near the close of Oligocene time caused westward recession of the Tertiary sea during which some folding occurred and local unconformities developed. A major break in sedimentation occurred in northwest Oregon prior to the outpouring of Miocene lavas. During this interval, the region was uplifted above sea level and deeply eroded. By middle Miocene time most of the Coast Range province had emerged from the sea.

The earliest period of folding in northwestern Oregon produced northeast-trending folds. In late Eocene time, northwest-trending folds began to develop and were compressed into their present relief during late Miocene time. A third period of major Tertiary tectonism, occurring near the close of Pliocene time, produced large north-south structures. The Coast Range anticline formed at this time, and the ancestral Cascade Range volcanoes began erupting from a north-south chain of vents (Hendricksen, 1956).

Pleistocene sedimentation was confined to the present shelf region and to continental basins. Continental glaciation did not extend into Oregon; however, significant amounts of glacial outwash were carried into the Columbia River system.

Prospects

In considering the Upper Nehalem basin as a good prospect for finding natural gas or for underground storage of pipeline gas, explorationists should review the geologic and hydrologic elements needed to form and trap hydrocarbons. Data collected from producing areas throughout the world show that several essential conditions must exist. Generation of petroleum requires a thick section of marine, or in some unusual instances lacustrine, sedimentary deposits laid down in shelf and nearshore environments. Abundant organic remains must be intermixed with the rock debris to serve as parent material for oil and gas. Layers of coarse sediments are necessary to serve as reservoir space and passageways for migration of hydrocarbons. Capping layers of less permeable shale or siltstone are needed to prevent upward escape of reservoir fluids. The last essential element needed for entrapment of oil and gas is the geologic structure which forms the enclosure for formation fluids.

Folding and faulting must occur after sediments and associated organic debris have been deeply buried in order to allow diagenesis of organic material and to control migration and entrapment of hydrocarbons.

All these conditions appear to be present in the study area. At least 9,000 feet of upper Eocene marine sedimentary section exists beneath the surface in the upper Nehalem basin. Porous and permeable sands overlain by impervious shale and siltstone can be found in the Cowlitz and Keasey Formations. Good sands and interbedded shale occur in the upper Oligocene and lower Miocene sections; however, erosion of these units has probably destroyed closures. Folding is believed to have been greatest during middle Miocene time, which is later than the deposition of most of the sedimentary units. Dark shale and siltstone, layers of carbonaceous material, and abundant fossil remains are evidence that large quantities of organic material were deposited with the rock debris.

In the past, a great deal of concern has been expressed about the destructive effect of heat on hydrocarbon deposits by nearby volcanic intrusions. Experience in other areas shows that igneous intrusions have little destructive effect beyond a few feet of contact with adjacent rocks, and in many cases the fused contact zone is no more than a few inches wide. Oil and gas are produced in many areas where volcanic rocks have intruded the sedimentary formations.

Volcanic rocks in general make poor source materials for reservoir sediments. The shales, siltstones, and argillaceous sands derived from volcanic rocks tend to be finer grained than other types of sediments and do not give up contained fluids as readily.

The Mist anticline holds good prospect for underground storage because it is underlain at sufficient depth by porous sandstone beds capped by impermeable layers of shale and siltstone. Reservoir sands can be seen in the Texaco "Clark & Wilson" well log (Figure 5).

Stratigraphic conditions near Mist are very similar to those found at the Jackson Prairie underground storage site in western Washington. Natural gas is stored in micaceous arkosic sandstone of the Skookumchuck Formation (Snavely and others, 1958),which is equivalent to the Cowlitz Formation (see Appendix A). Storage capacity of 23 billion cubic feet has been developed there in a geologic structure covering a surface area of 3,000 acres.

Another 30 billion cubic feet of storage may be possible in the lower Skookumchuck Formation (Cowlitz Formation). Development of sands is probably greater at the Jackson Prairie site than near Mist, but storage capacity equivalent to the upper storage zones at Jackson Prairie should be available at the Mist site.

Four major folds were interpreted from field data collected in this project. Selection of the most promising anticline is based upon the following logic: The axial trace of the Coast Range anticline appears to trend from a point 2 miles southeast of Green Mountain northward to approximately 2 miles northwest of Mist. The anticline plunges northeastward along this axis. Updip to the south, the upper Cowlitz sandstone, a potential reservoir rock, is exposed at the surface near "Keasey Station." Folds in the southwestern portion of the study area have, therefore, less potential sedimentary sections above the Eocene volcanics than do structures to the northeast. This suggests that the Mist and Clatskanie structures should be the best prospects of the four structures mapped.

Texaco, Inc. apparently reached this conclusion, as the firm decided to drill test holes on both of these folds. Results of Texaco drilling revealed that volcanic rocks increased to the northeast, reflecting a thickening of Goble Volcanics in that direction. According to this evidence, the Mist structure appears to be a better potential prospect.

Work done in the present study suggests that it is possible to move upstructure northwest of the Texaco "Clark & Wilson" (see geologic map). The interpretation given here is that the "Clark & Wilson" tested the highest point on the structure between Mist and the southeast end of the fold. If a fault with apparent strike-slip movement offsets the anticline just south of Mist, potential reservoir sands north of Mist have not been tested.

Formation tests in the Texaco "Clark & Wilson" were inconclusive in the interval 2,017 to 2,076 feet and apparently sands at 3,064 to 3,094 feet are saturated with connate marine water. However, the water was fairly fresh, which may indicate invasion by drilling fluid and permeability damage to the sand during drilling. Formation tests in the lower sedimentary section between 7,880 and 8,000 feet showed conclusively that the sands were saturated with connate marine water.

Good shows of gas were obtained from cores in the "Clark & Wilson" down to 3,241 feet, moderate shows to a depth of 3,084 feet, and mild gas shows down to 3,302 feet. Interpretation of electric logs by the author indicates that sands in the Texaco "Clatskanie" appear to be water saturated below 1,950 feet. Some gas shows and traces of oil were obtained in the Cowlitz sediments between 1,394 and 5,156 feet in the Clatskanie well. This well was drilled near the top of an anticline passing near Clatskanie and extending northwestward into Washington (Livingston, 1966). No formations tests were run on the Clatskanie well, which was abandoned prematurely because the drill pipe was twisted off while drilling at 5,650 feet.

Sands within the Tillamook Volcanics, encountered in the "Clark & Wilson" well, proved to have fair permeability by yielding saltwater flows on formation tests. Hydrocarbons may be found in this interval by moving updip on the Coast Range high. These sands were found to be saturated with saltwater near Mist and therefore are porous and permeable. The Vernonia anticline (?) and Rocky Point fold offer updip locations for Lower Cowlitz and Tillamook sands. The anticline shown passing through Vernonia was not well defined in the present study, so that additional field work and geophysical data are needed to better define this structure.

Future exploration for oil and gas looks attractive west of the upper Nehalem basin along the central portion of the lower Columbia downwarp in both Oregon and Washington. Fold structures and a thicker Tertiary sedimentary section occur in that region. The question to be resolved there is whether or not reservoir sands can be found at depth.

Geophysical studies are needed along with additional geologic mapping to locate possible drill sites. Of these, seismic and gravity surveys appear to offer the most definitive data in areas of low to moderate relief.

Recommended Future Studies

Additional studies are recommended to determine if petroleum source rocks exist in the marine sedimentary formations of northwestern Oregon. These investigations would also have the secondary objective of locating underground storage reservoirs.

Extracted gas concentration and total organic content of marine sedimentary samples can be useful data in determining the level of thermal diagenesis of organic matter in the rocks. By graphically plotting extractable gas concentration versus organic content, the hydrocarbons present can be classified as epigenetic or syngenetic. Petroleum source potential can be evaluated from the abundance and chemical composition of the total released gas. Source-rock tests currently available can determine the potential for generation of commercial quantities of hydrocarbons.

More paleontologic data are needed to fully understand the geology of the upper Nehalem basin. It was found in this investigation that weathering is too deep to rely on outcrop samples for identifiable specimens. The area south of Birkenfeld in the Deep Creek and Deer Creek drainages could be studied in greater detail than was possible in the current work.

Finally, much more can be done with sedimentary features to clarify stratigraphic and environmental conditions. Some of the thicker sand bodies and limestone lenses could be mapped in detail with the hope of identifying formation boundaries.

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PART II

PETROGRAPHY OF SELECTED SAMPLES FROM THE PITTSBURG BLUFF AND COWLITZ FORMATIONS IN NORTHWESTERN OREGON

Robert O. Van Atta*

Introduction

Select samples from the Pittsburg Bluff Formation (Oligocene) and Cowlitz Formation (Eocene), Vernonia and Birkenfeld quadrangles, Oregon, were analyzed for granulometry and compositional characteristics . This was accomplished by disaggregating rocks, determining grain-size characteristics by standard methods using sieves and pipette analysis, and by microscopic examination of grain mounts. Samples studies, their field locations, and size and compositional classification are given in Table 1.

Petrography

Granulometry

The majority of the rocks studied are muddy sandstones or silty sandstones (Table 1). The sand-silt-clay size ratio of each sample is given in Table 2 and plotted on Figure 1. Size parameters of each sample, determined by graphic measures suggested by Folk (1974), include the mean size, which is a measure of the over-all average size; sorting, which is a measure of the range in grain-size; and skewness, which measures the excess of coarse or fine grains in the rock. Scales of the sorting and skewness classification used for purposes of this report are given in Table 3, together with the grouping of samples studied.

These rocks range from poorly sorted to very poorly sorted, with 78 percent of the samples classifying in the latter category. All of the rocks are strongly fine skewed, meaning that there is an abundance of fines over the amount of coarse material. This latter measure is, of course, sensitive to the degree of weathering and production of clay material in the rocks. Since some degree of weathering is evident in most samples, the rock can probably be characterized as fine-skewed.

A comparison of the over-all mean size to sorting and to skewness, shown in Figure 3, suggests that these are inversely related. That is, finer rocks are more poorly sorted and are less strongly coarse skewed.

Composition

Classified according to Folk (1974), (see Figure 2), these rocks range from arkose to lithic arenite, with the majority either feldspathic arenite or feldspathic litharenite. Composition was determined by identifying components in grain mounts, using the petrographic microscope (Table 4). Grain mounts were then stained, using a modification of the techniques of Bailey and Stevens (1960). In this manner very accurate determinations can be made with respect to quartz, types of feldspar, and rock fragments and volcanic glass. The relative percentages of all components are recalculated into three categories - quartz (silica), feldspar, and rock fragments (plus glass) - ignoring minor accessory minerals, for purposes of classification.

The compositions of the sand and coarse silt fractions of these rocks suggest that they are formed of sediments derived from plutonic igneous rocks, metamorphic rocks, and volcanic rocks in that relative order of contribution. Plutonic and metamorphic rocks would be characteristic of known mountainous regions lying to the east and northeast; the volcanics could have been derived from the south, east and/or north. Some rocks, such as VN 1, 8, and 16, have a very high proportion of volcanic material. Samples 1 and

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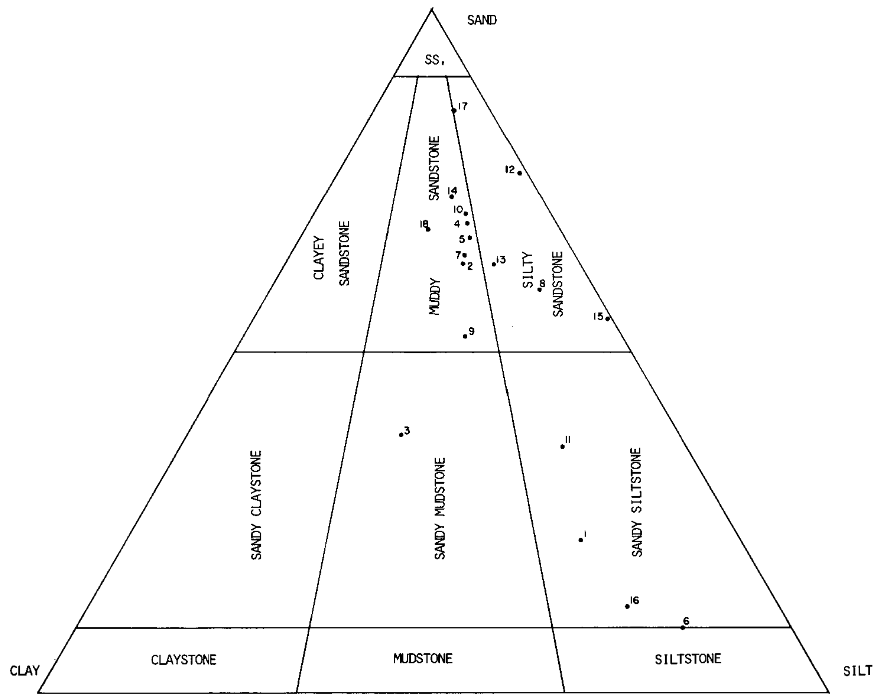

Figure 1. Size classification of terrigenous sediments, Pittsburg Bluff Formation, Oregon (after Folk, 1974).

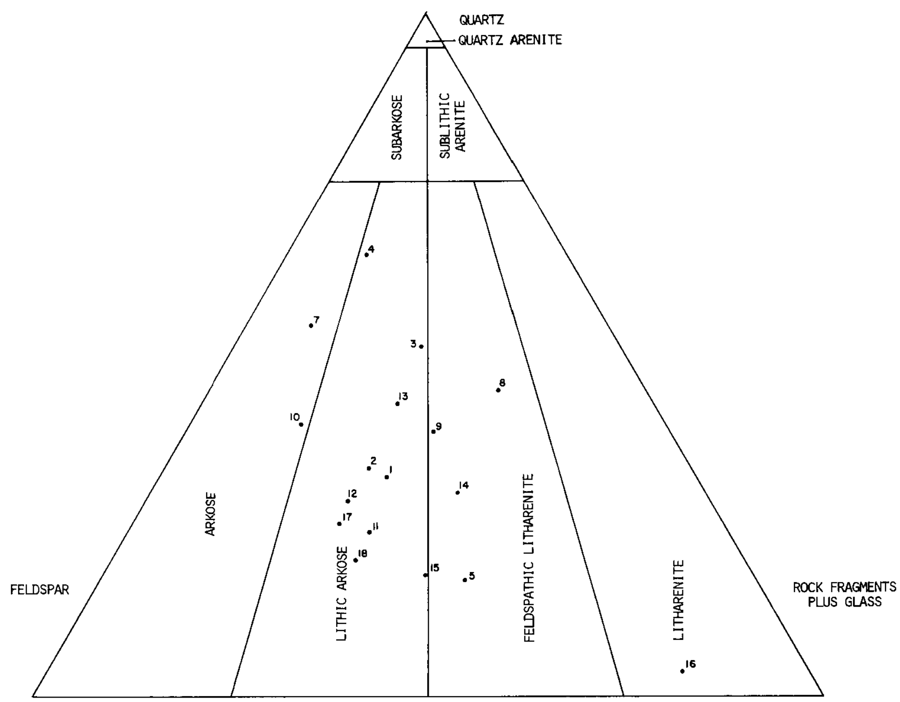

Figure 2. Classification of sandstone (after Folk, 1974).

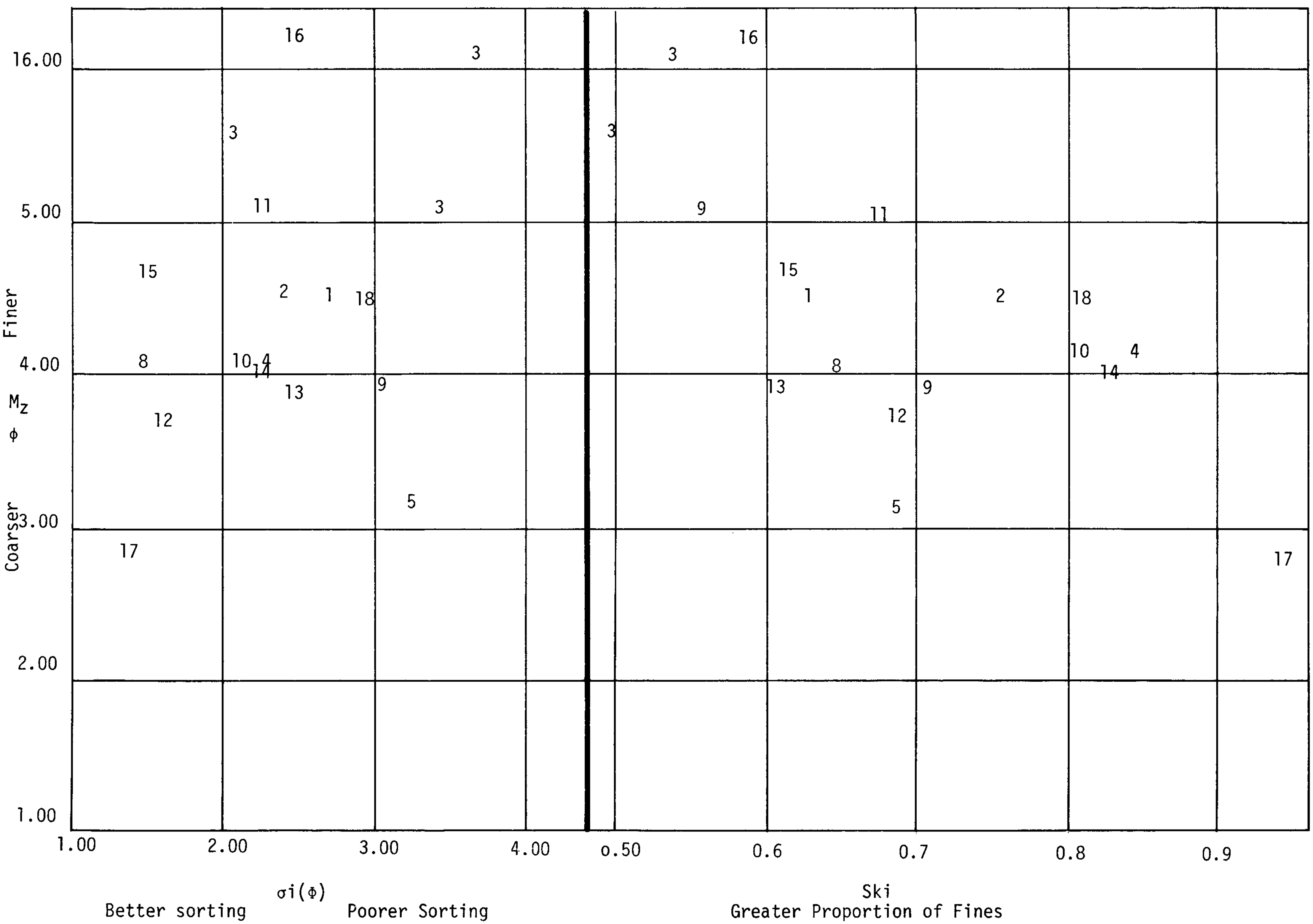

Figure 3. Comparison of sorting index and skewness with mean size.

TABLE 1. Descriptions of samples studied

Lab. No.	Location	Rock Classification
VN 1	Oak Ranch SW sec. 5, T. 5 N., R. 3 W.	Sandy siltstone: Immature, tuffaceous, micaceous lithic arkose
VN 2	Coates Road E1/4 sec. 21, T. 5 N., R. 4 W.	Muddy, very fine sandstone: Immature, micaceous lithic arkose
VN 3	Coates Road NW sec. 29, T. 5 N., R. 4 W.	Micaceous, lithic arkosic mudstone
VN 4	Kenusky Road NE sec. 6, T. 4 N., R. 3 W.	Muddy, very fine sandstone: Immature, micaceous, carbonaceous, lithic arkose
VN 5	Clatskanie SW sec. 13, T. 7 N., R. 5 W.	Muddy, fine sandstone: Immature, feldspathic litharenite, very friable
VN 6	Oak Ranch NW sec. 6, T. 5 N., R. 3 W.	Sandy siltstone: Immature, micaceous feldspathic litharenite(?)
VN 7	Camp 8 Road SW sec. 29, T. 5 N., R. 3 W.	Muddy, fine sandstone: Immature, micaceous arkose
VN 8	Type Pittsburg Bluff NE sec. 23, T. 5 N., R. 4 W.	Silty, very fine sandstone: Immature, fossiliferous, feldspathic litharenite
VN 9	Clatskanie SE sec. 26, T. 7 N., R. 5 W.	Muddy, very fine sandstone: Immature, micaceous, feldspathic litharenite
VN 10	Pebble Creek 22 Center sec. 22, T. 4 N., R. 4 W.	Muddy, very fine sandstone: Immature, micaceous arkose
VN 11	Pebble Creek 3 NW sec. 10, T. 4 N., R. 4 W.	Sandy siltstone: Immature, micaceous, lithic arkose
VN 12	Eastside Road SE sec. 5, T. 4 N., R. 5 W.	Silty, very fine sandstone: Submature, micaceous lithic arkose
VN 13	Buster Camp NW sec. 23, T. 5 N., R. 6 W.	Silty, very fine sandstone: Immature, lithic arkose, fair induration
VN 14	Pebble Creek 19 SE sec. 16, T. 4 N., R. 4 W.	Muddy, very fine sandstone: Immature, micaceous, feldspathic litharenite
VN 15	Coal Creek E1/4 sec. 30, T. 4 N., R. 3 W.	Silty, very fine sandstone: Submature, micaceous, fossiliferous, lithic arkose, very friable
VN 16	Dairy Creek NW sec. 7, T. 3 N., R. 3 W.	Sandy siltstone: Immature, tuffaceous litharenite
VN 17	West of Bacona NW sec. 35, T. 4 N., R. 4 W.	Muddy to silty-fine sandstone: Submature, micaceous, lithic arkose, very friable
VN 18	Mansfield Lookout SE sec. 13, T. 4 N., R. 4 W.	Muddy, very fine sandstone: Immature, micaceous, lithic arenite

Table 2. Graphic size parameters, Pittsburg Bluff and Cowlitz Formations*

Sample Number	Graphic Size Values					Size Parameters			Sand-Silt-Clay Ratio		
	ϕ_5	ϕ_{16}	ϕ_{50}	ϕ_{84}	ϕ_{95}	M_z (ϕ)	σ_i (ϕ)	SK_i	% Sand	% Silt	% Clay
VN 1	3.00	3.70	4.70	9.00	12.50	4.57	2.76	0.63	22	58	20
VN 2	2.55	3.08	3.60	7.10	11.90	4.59	2.42	0.76	62	23	15
VN 3	2.25	2.70	4.68	11.00	13.00	6.13	3.70	0.54	39	28	33
VN 4	2.55	2.78	3.10	6.70	11.10	4.19	2.28	0.85	69	20	11
VN 5	0.15	0.55	1.65	7.30	10.30	3.17	3.23	0.69	66	22	12
VN 6	2.95	4.36	5.10	7.34	11.62	5.60	2.06	0.50	10	77	13
VN 7	1.10	1.68	2.58	7.50	11.70	3.92	3.06	0.71	64	22	14
VN 8	3.06	3.36	3.78	5.06	10.40	4.07	1.54	0.65	59	33	8
VN 9	1.46	2.20	3.80	9.20	12.50	5.07	3.42	0.56	52	28	20
VN 10	2.85	2.95	3.38	6.22	11.75	4.18	2.17	0.81	70	19	11
VN 11	3.20	3.52	4.28	7.40	11.90	5.07	2.29	0.68	37	48	15
VN 12	2.04	2.48	2.96	5.70	7.68	3.71	1.66	0.69	77	22	1
VN 13	1.85	2.12	3.18	6.48	11.20	3.93	2.51	0.61	62	27	11
VN 14	2.60	2.72	3.08	6.18	11.10	3.99	2.15	0.83	72	17	11
VN 15	2.90	3.34	3.90	6.80	7.50	4.68	1.56	0.62	55	44	1
VN 16	3.38	4.40	5.30	9.00	12.40	6.23	2.52	0.59	13	68	19
VN 17	1.85	2.02	2.45	3.92	8.00	2.80	1.41	0.95	85	10	5
VN 18	2.04	2.38	2.96	8.22	12.20	4.52	3.00	0.81	68	15	17

*After Folk, 1974

TABLE 3

Comparison of size parameters of Pittsburg Bluff and Cowlitz Formations sediments using Folk's measures (1974)

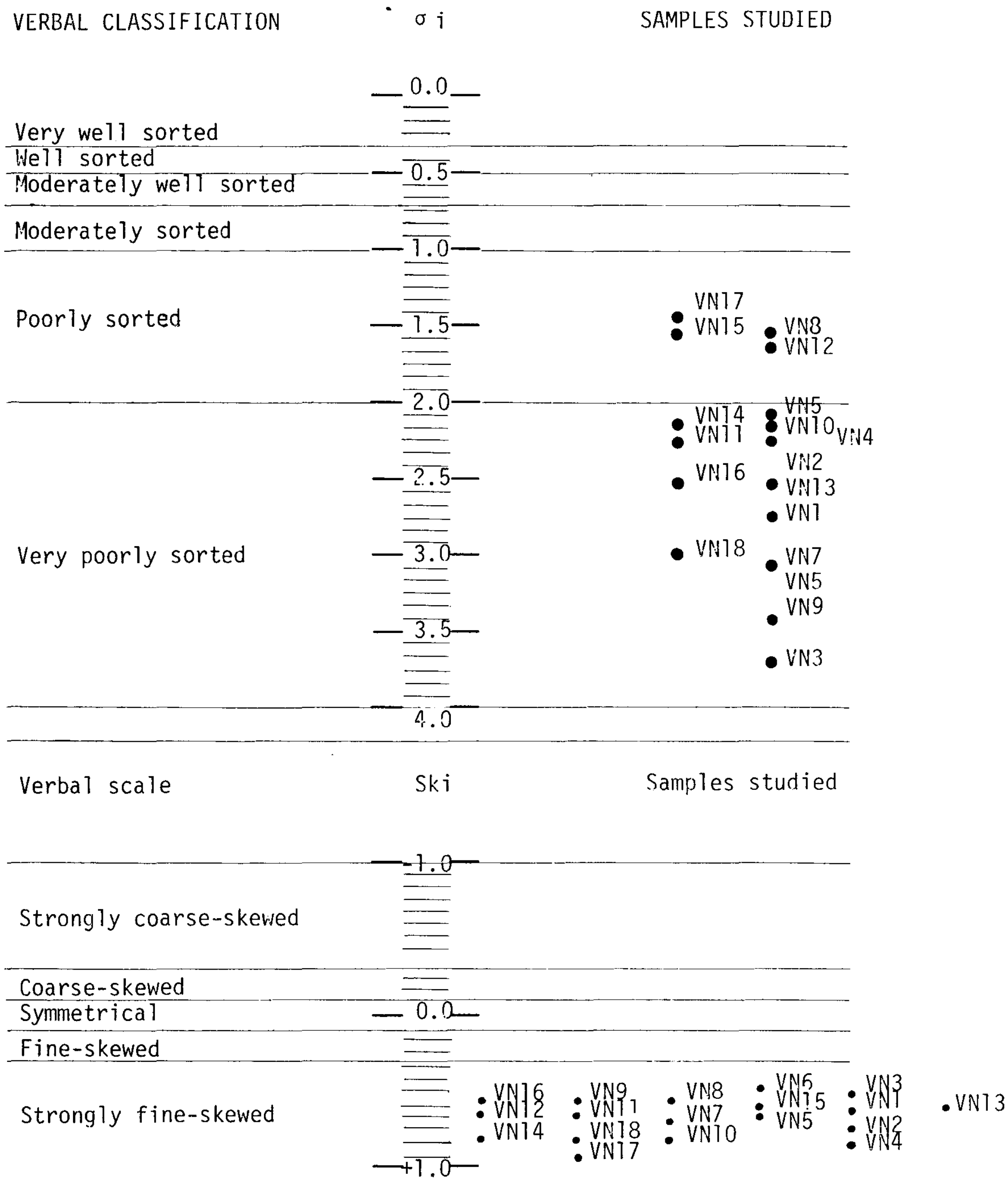

Table 4. Percentage composition from stained grain mounts

Sample Number	Quartz "Silica"	Feldspar K-spar	Feldspar P-spar	Feldspar Total	Labile Components Glass	Labile Components R. F.	Labile Components Total	Other	Recalculated to 100% Q	Recalculated to 100% F	Recalculated to 100% R. F.
VN 1	30	5	31	36	16	11	27	7	32	39	29
VN 2	29	7	28	35	5	18	23	13	33	40	27
VN 3	47	9	15	24	6	15	21	9	51	26	23
VN 4	59	10	14	24	1	8	9	8	64	26	10
VN 5	17	11	23	34	3	41	44	5	18	36	46
VN 6	-	-	-	-	-	-	-	-	-	-	-
VN 7	51	15	21	36	3	5	8	6	54	38	8
VN 8	41	3	15	18	24	10	34	7	44	19	37
VN 9	32	12	12	24	3	22	25	18	39	30	31
VN 10	36	24	17	41	7	6	13	11	40	46	14
VN 11	22	20	21	41	1	27	28	9	24	45	31
VN 12	27	21	21	42	T*	25	25	7	29	45	26
VN 13	42	14	17	31	T*	24	24	3	43	32	25
VN 14	26	9	18	27	0	34	34	12	30	31	39
VN 15	15	16	19	35	2	33	35	15	18	41	41
VN 16	4	5	10	15	48	26	74	8	4	16	80
VN 17	23	32	12	44	1	24	25	7	25	48	27
VN 18	17	24	18	42	1	26	27	13	20	49	31

*T=Trace (0.5%)

16 are among the four finest-grained rocks, also. There probably is a correlation between the amount of fine-grained material and the amount of volcanic material in rocks of this region. Other rocks studied in the southern part of the upper Nehalem basin (Van Atta, 1971) suggest this same relationship.

Since composition of detrital components is only slightly related to size characteristics and has little to do with depositional environment, mineralogy of these rocks was not studied in any depth for purposes of this report.

Discussion

The granulometry of these sedimentary rocks suggest that a fairly large suspension load of sediment was available to most of the environments of deposition, as revealed by their strongly fine-skewed character. Using the methods of Visher (1969), comparison of size distributions plotted on probability paper (a special type of graph paper designed to reveal separate populations of grain sizes within a sediment sample) shows that it is possible to detect two or three saltation populations within each sample. This indicates the variability of strength of currents which were distributing the sediments. A few samples - VN 3, VN 5, VN 7, VN 12, VN 15, and VN 17 - have well-sorted traction populations, the coarsest part of the sediment, which may make up as much as 30 to 40 percent of the total. This would suggest quite strong currents which were capable of moving this material, with an admixture of fines from the suspended sediment. There apparently was not much reworking of the sediment once it was deposited, a condition which could obtain either because of greater depth of water or because of very rapid rates of sedimentation.

Samples VN 12 and VN 13 were from the sandstone member of the Cowlitz Formation. They are typical of this member of the Cowlitz Formation in having a very small proportion of clay-sized matrix material (1 and 11 percent respectively) and a well-sorted coarse fraction, indicating that strong current action moved this material in the traction load during sediment transport.

The composition of samples VN 12 and VN 13 is also typical of the sandstone member of the Cowlitz Formation. Both samples contain only a trace of volcanic glass and no volcanic rock fragments. The samples taken for this study from the Pittsburg Bluff Formation contain at least 1 percent volcanic glass, and a majority of the rock fragments of most samples are volcanic. All the rock fragments in the Cowlitz Formation samples are phyllite, stretched and sutured quartzite, and chert.

The most significant difference between the sandstones of the Cowlitz Formation and those of the Pittsburg Bluff Formation is that nearly all the Cowlitz sands contain a lower percentage of clay matrix and are generally better sorted and less fine-skewed.

Conclusions

Analysis of these samples indicates that with suitable sampling procedures textural trends in lithofacies should be discernable. For example, the over-all size characteristics of the Pittsburg Bluff Formation in the Vernonia-Pittsburg region, as compared with those of the Sunset Highway (U. S. 26) region, reveal that there is a definite coarsening of sediment toward the north. The facies distribution of the matrix-free Cowlitz sands should be relatively simple to work out. Such trend analysis could lead to fairly accurate descriptions of depositional environments and possible identification of stratigraphic traps for water or hydrocarbons. The sandstone member of the Cowlitz Formation contains a lower percentage of fine matrix, which makes it a more likely reservoir rock.

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A P P E N D I X

APPENDIX A

JACKSON PRAIRIE GAS STORAGE PROJECT, CHEHALIS, WASHINGTON

by Fred H. Wurden* and Donald M. Ford**

The Jackson Prairie underground gas storage project was initiated in the early 1960's by Washington Natural Gas Company, the Washington Water Power Company, and Northwest Pipeline Corporation. The 3,000-acre storage field is located nine miles southeast from the city of Chehalis in western Lewis County (Figure 1). The geologic structure was discovered by Pleasant Valley Oil and Gas Company and J. W. Tanner while drilling for oil and gas production in 1958. The structure was found to be nonproductive, so the company abandoned its "Guenther No. 1" test hole at 8,015 feet. The hole (re-named Storage Unit No. 1) was re-entered in November 1963 by the present operators to test for gas storage potential (see Table 1).

Increased use of natural gas in the Northwest for domestic and industrial needs resulted in construction of the present extensive pipeline systems. Because pipelines are designed to carry the anticipated average-demand volume, cold weather spells make it necessary to interrupt service to certain industrial customers, since it is not economically feasible to design pipe lines for carrying peak loads that occur only a few weeks of the year. Local gas storage facilities assist in smoothing out the load peaks, particularly underground storage where very large amounts of gas can be held.

Most of the 366 underground storage projects in the United States utilize depleted oil or gas reservoirs; however, the Jackson Prairie project used brackish-marine aquifers contained in the upper Eocene Skookumchuck Formation. Fifty other underground gas storage projects in the United States store gas in brackish and saline aquifers. It was found that the sandstone at Jackson Prairie was saturated with brackish water, so that some of it had to be pumped from the "dome" structure in order to create storage for gas. Water removal wells are located around the perimeter of the project to withdraw water from the lower portion of the structure, thus creating a cap of void space at the crest of the "dome." Operators of the storage project have a permit from the State Department of Ecology to release 50,000 gallons of brackish water a day into the Cowlitz River at favorable flow conditions.

The Jackson Prairie project lies in the south-central part of the Cowlitz basin as shown on the location map Figure 1. The basin is believed to be underlain by brackish marine and non-marine sedimentary rocks to depths in excess of 7,000 feet. Subsurface conditions of the area are generally depicted on the cross section shown in Figure 2 after the interpretation made by Fred Wurden, geological consultant for Washington Natural Gas Company and its partners. Some modifications were made to Figure 2 for purposes of this report. The oldest rocks known to underlie the basin are pillow lavas, volcanic breccia, and interbedded marine sediments of the McIntosh Formation. The McIntosh volcanic series is believed to be roughly equivalent in type and age to the rocks mapped as Tillamook Volcanics in the upper Nehalem River basin. The McIntosh sediments are correlative with the middle Eocene Yamhill Formation. These deposits were laid down under shallow marine conditions in the Cowlitz basin.

According to Snavely and others (1958), the Northcraft Formation conformably overlies the McIntosh Formation. The Northcraft consists chiefly of volcanics and nonmarine rocks and is believed to be equivalent to the lower part of the Goble Volcanics. Late Eocene volcanics in the Chehalis-Centralia area are gabbroic and basaltic sills and dikes intrusive into the Skookumchuck Formation. These volcanics separate the top three storage zones from the lower zones. The age of the volcanics in this area is late Eocene to early Oligocene. Farther south, near Castle Rock and in northwestern Oregon, these basaltic flow rocks issued from vents to the east of the Tertiary marine basin and attain their maximum thickness along the Columbia River. Late Eocene flows at Castle Rock are correlated with the Goble Volcanics.

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** Donald M. Ford, Assistant Supervisor, Washington Division of Geology and Earth Resources

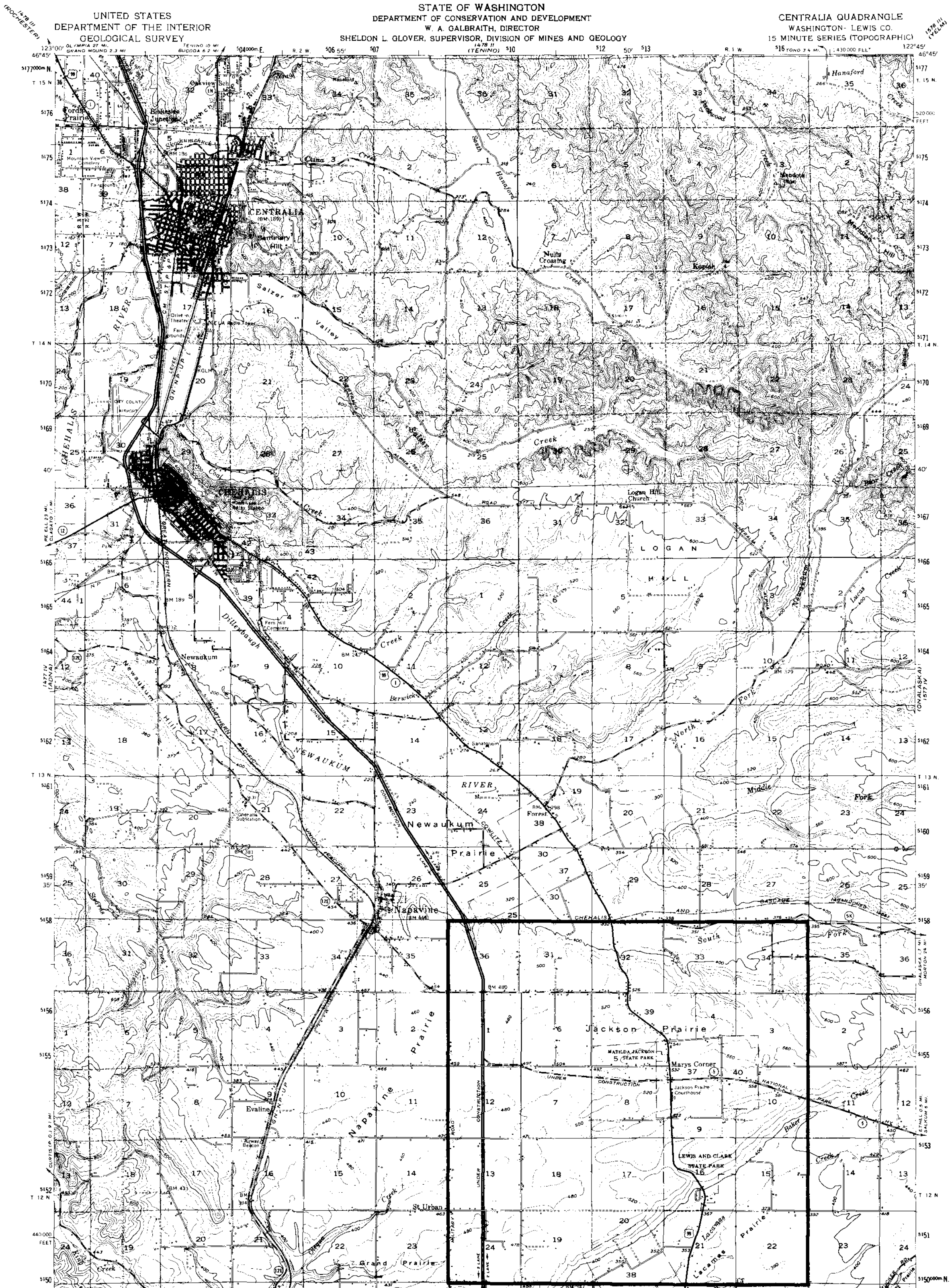

Figure 1. Location of the Jackson Prairie gas storage project, T. 12 N., R. 1 W., Lewis County, Washington.

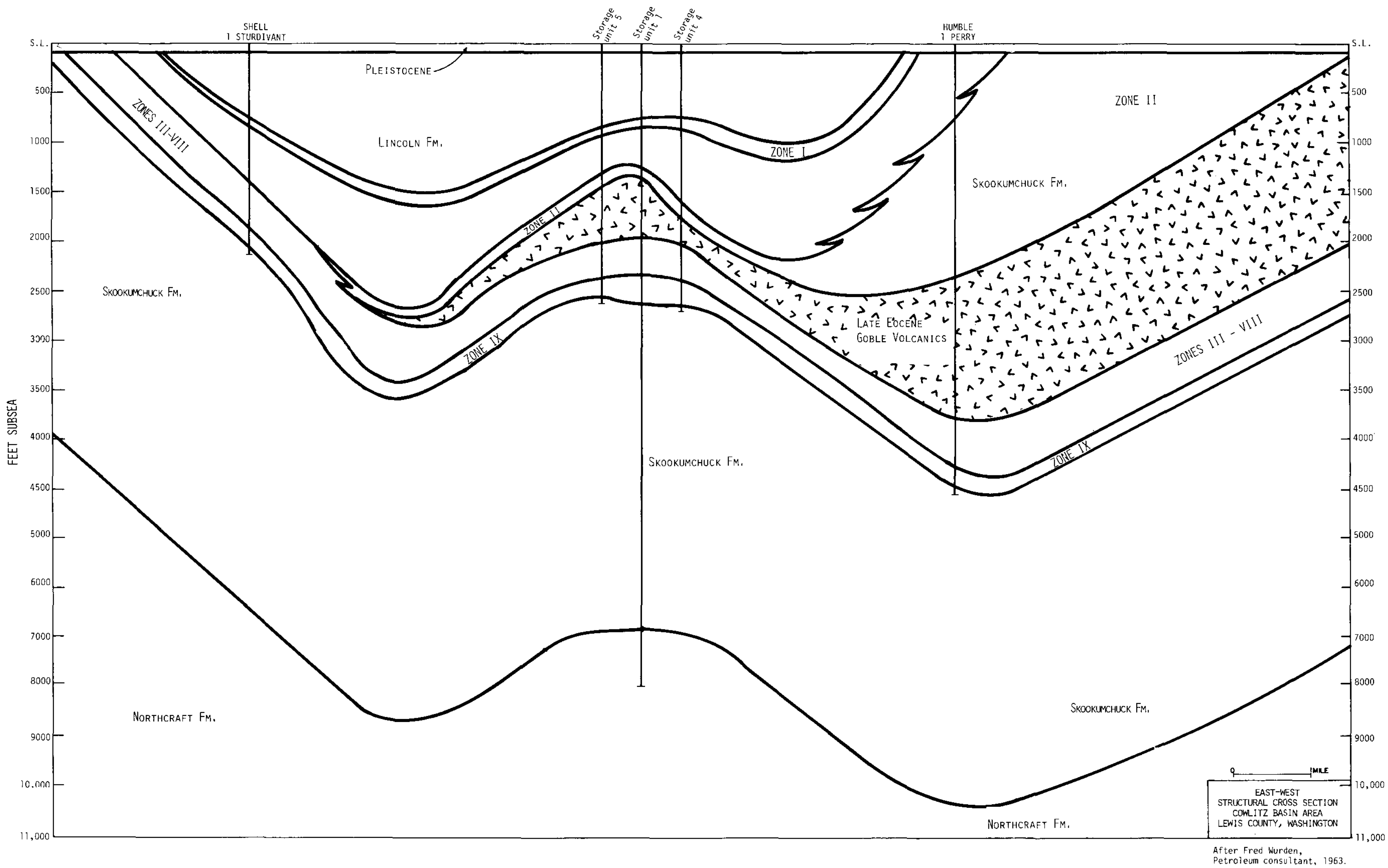

Figure 2. East-west structural cross section, Cowlitz basin area, Lewis County, Washington.

TABLE 1. Pleasant Valley Oil and Gas, Washington Water Power Company, Washington (Natural Gas Company and El Paso Natural Gas Company) Jackson Prairie Storage Unit-Well No. 1

Geological Data

Formation	Depth (feet)	Elevation (feet)	Thickness (feet)
Logan Hill Fm. (Pleistocene)	Surface		480
Lincoln Fm. (Oligocene)	480-1737	- 47	1257
Storage Zone 1	1270-1380	- 743	110
Skookumchuck Fm. (Upper Eocene)	1737-7380	-1210	5643
Storage Zone 2	1737-1878	-1210	141
Goble Volcanics	1878-2508	-1351	130
Storage Zone 3	2508-2540	-1981	32
Storage Zone 4	2607-2628	-2080	21
Storage Zone 5	2643-2660	-2116	17
Storage Zone 6	2664-2740	-2137	76
Storage Zone 7	2780-2865	-2253	85
Storage Zone 8	2892-2904	-2465	12
Storage Zone 9	2918-3182	-2391	264
Northcraft Fm.	7380	-6853	Not penetrated

Porosity-Permeability

Depth (feet)	Perm. (md)	Porosity (%)	Saturation Oil (%)	Saturation Water (%)	% Gas Bulk Vol.
1587	19.0	38	0	95	2.0
1594	0.0	29	0	82	5.0
1600	7.5	31	0	92	3.0
1663	52.0	23	0	93	1.7
1671	61.0	47	0	92	3.6
1678	41.0	23	0	64	1.1
1744	500.0	36	0	93	2.7
1815	NR	38	0	81	7.2
1836	1017.0	37	0	80	7.0
1862	550.0	38	0	79	8.4
2515	1280.0	38	0	84	16.0
2527	121.0	37	0	65	35.0
2534	207.0	35	0	70	30.0
2588	9.4	33	0	86	14.0
6042	2010.0	29	0	91	9.0
6058	413.0	33	0	75	25.0

Lenticular strata of sandstone, siltstone, shale, and interbedded coal seams form the Skookumchuck Formation. The Skookumchuck overlies older rocks with angular unconformity indicating an intervention of uplift and temporary withdrawal of the sea. These beds were laid down in a brackish- to fresh-water lagoonal environment in the area of the storage project. Sandstones in the Skookumchuck closely resemble those of its age equivalent, the Cowlitz Formation. Sandstones are fine to medium grained, micaceous, carbonaceous, basaltic, and arkosic. Sands of the Skookumchuck are the storage reservoirs for the Jackson Prairie project. Porosity of these sandstones ranges from 5.3 to 35.2 percent in the Cowlitz basin. Permeability ranges from 1.4 to 3,506 millidarcies (Snavely and others, 1958). Permeability in Zone II storage reservoir ranges from 1 to 3 darcies and the average weighted porosity is 36 percent (Hoglund, 1976).

The Lincoln Creek Formation conformably overlies the Skookumchuck in the central Cowlitz basin. It consists of shallow marine deposits composed of sand, silt, and shale. The Lincoln Creek Formation is roughly equivalent to the upper Keasey, Pittsburg Bluff, and lower Scappoose Formations of northwestern Oregon. Zone 1 is a fine- to very fine-grained sandstone located in the Lincoln Creek Formation and was one of the zones tested early in the storage investigations. It is not being used for storage.

Sandstone Zones 1 through 9 are separated by shale, siltstone, and coal beds, thereby effecting a seal against vertical migration of the stored gas. Zone 1 is in the Lincoln Creek Formation, Zone 2 is in the uppermost Skookumchuck Formation above late Eocene volcanics. Zone 2 is subdivided into subzones A, B, and C, which are separate sandstone bodies. The storage reservoir presently consists of Zones 2A, 2B, and 2C. They are located approximately 1,800 feet beneath the ground surface, initially saturated with salt water. Zones 3 through 8 lie just beneath late Eocene volcanics in the Skookumchuck Formation. Zone 9 consists of a massive sandstone several hundred feet thick. It is underlain by several thousand feet of Skookumchuck sands, shales, siltstones, and coal beds in the central Cowlitz basin.

A total of 63 wells have been drilled at Jackson Prairie since the storage project began. Storage capacity developed in the upper zones now totals 23 billion cubic feet. Additional exploration and testing indicates another 30 billion cubic feet of storage may be developed in the deeper zones.

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APPENDIX B. DRILLING AND TEST INFORMATION, UPPER NEHALEM BASIN, OREGON

COMPANY	WELL NAME	LOCATION	YEAR DRILLED	TOTAL DEPTH	WELL DATA
Allied Oil Co.	"Buxton Well"	½ mile east of Buxton Washington Co.	1925	1,600'	No information
Lease Holding Syndicate	Dutch Canyon well	NW¼ Sec. 17, T. 3N., R. 2W. Columbia Co.	1925-1927	4,426'	Salt water in black sand at 1,740-1,780'. Gas sand at 1,850-1,872' reportedly blew mud and water 20' above the derrick floor. A few traces of oil were encountered between 2,140' and 2,330'. ANALYSIS OF SAMPLE Methane CH_4 - 7.87%; Nitrogen N_2 - 91.75%; Oxygen O_2 - 0.33%; Carbon Dioxide CO_2 - 0.05%
Prescott, City of	Water well	SW¼ Sec. 25, T. 7N., R. 2W. Columbia Co.	1925	1,008'	Top of Goble basalt at 15', bottom at 972'(?)
Richfield Oil Corp.	Barber 1	SE¼ Sec. 23, T. 1N., R. 1W. Multnomah Co.	1946	7,885'	No oil or gas shows. Bottomed in Tillamook Volcanics.
Sunray Mid-Continent Oil	Kappler 1	NW¼ Sec. 12, T. 2N., R. 2W. Multnomah Co.	1957	1,666'	No oil or gas shows. Goble basalt 775-1,666' T.D. Cowlitz not tested (?)
Texaco, Inc.	Clark & Wilson	NE¼ Sec. 19, T. 6N., R. 4W. Columbia Co.	1946-1947	8,501'	Gas shows: 2,034-2,042', 3,064-3,084', and 3,221-3,241' (no fluorescence noted, however, mud contaminated with oil as a result of fishing operations during drilling from 8,159-8,500'.) FT (2017-2076) Packer failed. FT (2042-2076) Packer failed. FT (2036-2076) Test 45 min. Recovered 85' rise of mud. FT (3064-3094) Test 40 min. Recovered 620' net rise; 100' of mud and 520' of brackish water, 6,000ppm NaCl. FT (3214-3241) Test 45 min. Recovered 1,250' net rise; 270' mud and 980' of brackish water, 5,140ppm NaCl. 5½" casing cemented at 8,100'. WNSO 7835 - squeezed; WNSO 7950 - squeezed; WSO 7833;

DRILLING AND TEST INFORMATION, UPPER NEHALEM BASIN, OREGON, Continued

COMPANY	WELL NAME	LOCATION	YEAR DRILLED	TOTAL DEPTH	WELL DATA
					WSO 7950. DST (7965-8000) Test 7 hours. Well flowed salt water at 70 B/D rate, no trace of oil or gas. Salinity tested 12,200ppm NaCl. IFP 600psi, FFP 3550psi, FSIP 3950psi. DST (7880-7900 and 7920-7937) Test 10 hours, 22 min. Fluid surfaced in 4 hours, 53 min. Well flowed salt water at a 68 B/D rate, slight amount of flammable gas, no oil. Salt water tested 17,500ppm NaCl. IFP 500psi, FFP 3,500psi, FSIP 3,900psi. FORMATION GAS 7880-7900' Methane 12.87%; Nitrogen 80.03%; Oxygen 7.10%. FORMATION GAS 7920'-7937' Methane 21.35%; Nitrogen 78.65%; Oxygen 0.00%.
Texaco, Inc.	Cooper Mt. No. 1	SE¼ Sec. 25, T. 1S., R. 2W. Columbia Co.	1945-1946	9,263'	Non-flammable gas in salt water at 7,862-9,263'. FT (2793-2845) Test 20 min. Recovered 35' rise of mud. FT (3505-3534) Test 30 min. Recovered 312' rise of muddy salt water, 57,400ppm NaCl. 7" casing cement at 7,862'. DST (7862-9263) Test 8½ hours. No water cushion used. Mud surfaced in 2 hours, 25 min. Salt water surfaced in 5 hours. Well flowed frothy salt water at a 29 B/hr rate. Water temp. was 88.5°F. Gas in salt water was nonflammable. Salinity tested 80,400ppm NaCl. FFP 3,700psi.
Texaco, Inc.	Benson-Clatskanie No. 1	NE¼ Sec. 36, T. 7N., R. 4W. Columbia Co.	1945	5,650'	Oily odor in volcanic breccia 730-760', no cut. Gas and oil show 1,394-1,449' and free oil in mud returns. Gas show 2,159-2,170'. Light yellow ether cut after several hours from cores 5,114-5,156'. No information tests run. Reamer stuck in the hole at 5,640'. Hole had to be abandoned.

APPENDIX C. SHALLOW DRILLING BY TEXACO COMPANY IN THE UPPER NEHALEM BASIN, OREGON

Company or Owner	Well Name	Location and Elevation	Map no.	When drilled	Depth (feet)	Remarks
The Texas Co.	Anlicker No. 1	400' S. & 1400' E. of NW. cor. sec. 29, 6N.-2W. Elev. 365'	22	1943	350	Rotary core hole for subsurface data.
The Texas Co.	Anlicker No. 2	600' N. & 2300' W. of SW. cor. sec. 20, 6N.-2W. Elev. 510'	18	1943	310	Rotary core hole for subsurface data.
The Texas Co.	Anlicker No. 3	1650' S. & 2100' E. of NW. cor. sec. 20, 6N.-2W. Elev. 571'	19	1943	500	Rotary core hole for subsurface data.
The Texas Co.	Anlicker No. 4	2000' E. & 850' S. of NW. cor. sec. 29, 6N.-2W. Elev. 425'	23	1943	315	Rotary core hole for subsurface data.
The Texas Co.	Brough No. 1	1650' N. & 2200' E. of SW. cor. sec. 15, 6N.-3W. Elev. ?	17	Early 1940's	505 or +	Rotary core hole for subsurface data.
The Texas Co.	Closner No. 1	1000' N. & 900' W. of SE. cor. sec. 22, 7N.-4W. Elev. 164'	4	1943	370	Rotary core hole for subsurface data.
The Texas Co.	Doren No. 1	2200' S. & 2200' W. of NE. cor. sec. 15, 7N.-4W. Elev. 98'.	3	1943	774	Rotary core hole for subsurface data.
The Texas Co.	Edwards No. 1	2600' N. & 2200' W. of NE. cor. sec. 36, 7N.-4W. Elev. 250'.	11	1943	860	Rotary core hole for subsurface data.
The Texas Co.	Evenson No. 1	1000' S. & 600' E. of NW. cor. sec. 8, 6N.-3W. Elev. 480'.	16	1943	990	Rotary core hole for subsurface data.

APPENDIX C. SHALLOW DRILLING BY TEXACO COMPANY IN THE UPPER NEHALEM BASIN, OREGON (Continued)

Company or Owner	Well Name	Location and Elevation	Map no.	When drilled	Depth (feet)	Remarks
The Texas Co.	Evenson No. 3	2200' N. & 2400' E. of SW. cor. sec. 5, 6N.-3W. Elev. 400'	15	1943	930	Rotary core hole for subsurface data.
The Texas Co.	Gilbert No. 1	1600' N. & 2400' E. of SW. cor. sec. 20, 6 N.-2W. Elev. 552'.	21	1943	700	Rotary core hole for subsurface information.
The Texas Co.	Gregory No. 1	50' S. & 2000' E. of NW. cor. sec. 20, 6N.-2W. Elev. 530'.	20	1943	400	Rotary core hole for subsurface data.
The Texas Co.	Gustafson No. 1	1250' N. & 300' W. of SE. cor. sec. 31, 7N.-3W. Elev. 275'.	12	1943	303	Rotary core hole for subsurface data.
The Texas Co.	Jensen No. 1	300' N. & 2100' E. of SW. cor. sec. 32, 7N.-3W. Elev. 350'.	14	1943	970±	Rotary core hole for subsurface data.
The Texas Co.	Johnson No. 1	2200' N. & 100' W. of SE. cor. sec. 35, 7 N.-4W. Elev. 220'	9	1943	242	Rotary core hole for subsurface data.
The Texas Co.	Mist No. 1	300' S. & 500' E. of NW. cor. sec. 20, 6N.-4W. Elev. ?	33	About 1945 or 1946	95 or +	Rotary core hole for subsurface data.
The Texas Co.	Mist No. 2	2450' N. & 400' E. of SW. cor. sec. 24, 6N.-5W. Elev. ?	26	About 1945 or 1946	550 or +	Rotary core hole for subsurface data.
The Texas Co.	Mist No. 3	100' S. & 2500' W. of E¼ cor. sec. 24, 6N.-5W. Elev. ?	27	About 1945 or 1946	100 or +	Rotary core hole for subsurface data.
The Texas Co.	Mist No. 4	450' S. & 700' E. of NW. cor. sec. 24, 6N.-5W. Elev. ?	28	About 1945 or 1946	332 or +	Rotary core hole for subsurface data.

APPENDIX C. SHALLOW DRILLING BY TEXACO COMPANY IN THE UPPER NEHALEM BASIN, OREGON (Continued)

Company or Owner	Well Name	Location and Elevation	Map no.	When drilled	Depth (feet)	Remarks
The Texas Co.	Mist No. 5	2150' N. & 1550' E. of SW. cor. sec. 20, 6N.-4W. Elev. ?	34	About 1945 or 1946	190 or +	Rotary core hole for subsurface data.
The Texas Co.	Mist No. 6	850' S. & 850' E. of NW. cor. sec. 20, 6N.-4W. Elev. ?	35	About 1945 or 1946	130 or +	Rotary core hole for subsurface data.
The Texas Co.	Mist No. 7	800' N. & 150' E. of SW. cor. sec. 13, 6N.-5W. Elev. ?	24	About 1945 or 1946	85 or +	Rotary core hole for subsurface data.
The Texas Co.	Mist No. 8	2400' N. & 1300' W. of SE. cor. sec. 13, 6 N.-5W. Elev. ?	25	About 1945 or 1946	897 or +	Rotary core hole for subsurface data.
The Texas Co.	Mist No. 9	450' S. & 700' E. of NW. cor. sec. 24, 6N.-5W. Elev. ?	29	About 1945 or 1946	835 or +	Rotary core hole for subsurface data.
The Texas Co.	Mist No. 10	2400' N. & 2500' E. of SW. cor. sec. 18, 6N.-4W. Elev. ?	30	About 1945 or 1946	455 or +	Rotary core hole for subsurface data.
The Texas Co.	Mist No. 11	400' S. & 1700' W. of NE. cor. sec. 18, 6N.-4W. Elev. ?	31	About 1945 or 1946	670	Rotary core hole for subsurface data.
The Texas Co.	Mist No. 12	400' N. & 1750' E. of SW. cor. sec. 17, 6N.-4W. Elev. ?	32	About 1945 or 1946	1025 or +	Rotary core hole for subsurface data.
The Texas Co.	Mist No. 13	2350' S. & 1850' E. of NW. cor. sec. 28, 6N.-4W. Elev. ?	37	About 1945 or 1946	409 or +	Rotary core hole for subsurface data.
The Texas Co.	Mist No. 14	950' S. & 550' E. of NW. cor. sec. 28, 6N.-4W. Elev. ?	38	About 1945 or 1946	375 or +	Rotary core hole for subsurface data.

APPENDIX C. SHALLOW DRILLING BY TEXACO COMPANY IN THE UPPER NEHALEM BASIN, OREGON (Continued)

Company or Owner	Well Name	Location and Elevation	Map no.	When drilled	Depth (feet)	Remarks
The Texas Co.	Nolls No. 1	700' N. & 1900' W. of SE. cor. sec. 10, 7 N.-4W. Elev. 332'.	1	1943	530	Rotary core hole for subsurface data.
The Texas Co.	Olson No. 1	2400' N. & 2200' W. of SE. cor. sec. 27, 7N.-4W. Elev. 115'.	6	1943	320	Rotary core hole for subsurface data.
The Texas Co.	Olson No. 2	2400' N. & 2200' W. of SE. cor. sec. 27, 7N.-4W. Elev. 115'.	7	1943	310	Rotary core hole for subsurface data.
The Texas Co.	Potter No. 1	650' N. & 1860' W. of SE. cor. sec. 8, 4N.-3W. Elev. ?	39	Early or middle 1940's	608 or +	Rotary core hole for subsurface data. Small show gas. Analysis: CO_2, 0.4%; O, 0.2%; H, 0.5%; CO, 0.0%; N, 46.7%; methane, 51.8%; ethane, 0.0%; illuminant, 0.2%. Btu, 530.9; sp. gr., 0.7513.
The Texas Co.	Powell No. 1	2200' N. & 1850' W. of SE. cor. sec. 19, 7N.-4W. Elev. ?	5	Early or middle 1940's	458 or +	Rotary core hole for subsurface data.
The Texas Co.	Rice No. 1	1750' S. & 1400' W. of NE. cor. sec. 27, 7N.-4W. Elev. 149'.	8	1943	440	Rotary core hole for subsurface data.
The Texas Co.	Tachella No. 1	750' N. & 2100' W. of SE. cor. sec. 31, 7N.-3W. Elev. 275'.	13	1943	990	Rotary core hole for subsurface data.
The Texas Co.	Townsend No. 1	2400' N. & 900' E. of SW. cor. sec. 11, 7N.-4W. Elev. 92'.	2	1943	455	Rotary core hole for subsurface data.

APPENDIX D. WATER ANALYSES FROM DEEP WELLS IN UPPER NEHALEM BASIN

COMPANY	WELL	LOCATION	DEPTH	ANALYSIS (ppm)							
				Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl
Lease Holding Syndicate	"Dutch Canyon"	NW ¼ Sec. 17, T. 3N., R. 2W. Columbia County	4,100'	1,610	24	8,340	28	0	16	4.4	15,200
Sunray-Mid-Cont. Oil Co.	Kappler No. 1	NW¼ Sec. 12, T. 2N., R. 2W. Multnomah County	1,600'	-	-	-	-	-	-	-	28,900
Texaco, Inc.	Clark & Wilson No. 1	NE¼ Sec. 19, T. 6N., R. 4W. Columbia County	8,000'	-	-	-	-	-	-	-	17,400
Texaco, Inc.	Cooper Mt. No. 1	SE¼ Sec. 25, T. 1S., R. 2W. Washington County	8,000'	15,900	10.5	4,180	75	0	28.1	25.2	35,490

APPENDIX E. POROSITY-PERMEABILITY OF SANDSTONE CORES TAKEN FROM SELECTED OUTCROPS, UPPER NEHALEM BASIN**

SAMPLE LOCATION	GEOLOGIC FORMATION	PERMEABILITY (MILLADARCIES)	POROSITY (PERCENT)	LAB NO.*	ROCK CLASSIFICATION
Oak Ranch SW Sec. 5, T. 5N., R. 3W.	Upper Oligocene to Miocene	37	28.4	VN-1	Siltstone; sandy, tuffaceous, micaceous, lithic arkose, immature.
Oak Ranch NW Sec. 6, T. 5N., R. 3W.	Upper Oligocene to Miocene	4.5	42.0	VN-6	Siltstone; sandy, micaceous, feldspathic, litharenite (?), immature.
Kenusky Crk. NE Sec. 6, T. 4N., R. 3W.	Upper Oligocene to Miocene	290	33.4	VN-4	Sandstone; very fine gr., argillaceous, micaceous, cabonaceous, lithic arkose, immature.
Clatskanie-Mist SW Sec. 13, T. 7N., R. 5W.	Upper Oligocene to Miocene	43	26.1	VN-5	Sandstone; fine gr., argillaceous, very friable, feldspathic **litharenite**, immature.
Camp 8 Rd. SW Sec. 29, T. 5N., R. 3W.	Upper Oligocene to Miocene	224	31.6	VN-7	Sandstone; fine gr., argillaceous, micaceous arkose, immature.
Clatskanie-Mist SE Sec. 26, T. 7N., R. 5W.	Upper Oligocene to Miocene	3,040	35.3	VN-9	Sandstone; very fine gr., argillaceous, micaceous, feldspathic litharenite, immature.
Coal Crk. E¼ Sec. 30, T. 4N., R. 3W.	Upper Oligocene to Miocene	41	21.5	VN-15	Sandstone; very fine gr., silty, micaceous, fossiliferous, very friable, lithic arkose, submature.
Dairy Crk. NW Sec. 7, T. 3N., R. 3W.	Upper Oligocene to Miocene	-	-	VN-16	Siltstone; sandy, tuffaceous litharenite, immature.
West of Bacona NW Sec. 35, T. 4N., R. 4W.	Upper Oligocene to Miocene	-	-	VN-17	Sandstone; fine gr., silty, argillaceous, micaceous, lithic arkose, very friable.

POROSITY-PERMEABILITY OF SANDSTONE CORES TAKEN FROM SELECTED OUTCROPS, UPPER NEHALEM BASIN**, Continued

SAMPLE LOCATION	GEOLOGIC FORMATION	PERMEABILITY (MILLADARCIES)	POROSITY (PERCENT)	LAB NO.*	ROCK CLASSIFICATION
Mansfield Lookout SE Sec. 13, T. 4N., R. 4W.	Upper Oligocene to Miocene	-	-	VN-18	Sandstone; very fine gr., argillaceous, micaceous lithic arenite.
Pebble Crk. Center Sec. 22, T. 4N., R. 4W.	Upper Oligocene	925	38.4	VN-10	Sandstone; very fine gr., argillaceous, micaceous arkose, immature.
Pebble Crk. NW Sec. 10, T. 4N., R. 4W.	Upper Oligocene	239	33.9	VN-11	Sandstone; very fine gr., micaceous, lithic arkose.
Pebble Crk. SE Sec. 16, T. 4N., R. 4W.	Upper Oligocene	1,065	35.8	VN-14	Sandstone; very fine gr., argillaceous, micaceous, feldspathic litharenite, immature.
Type Pittsburg Bluff NE Sec. 23, T. 5N., R. 4W.	Upper Oligocene	700	37.7	VN-8	Sandstone; very fine gr., silty, fossiliferous, feldspathic litharenite, immature.
Coates Rd. E¼ Sec. 21, T. 5N., R. 4W.	Keasey	-	-	VN-2	Sandstone; very fine, micaceous, lithic arkose, immature.
Coates Rd. NW Sec. 29, T. 5N., R. 4W.	Keasey	-	-	VN-3	Mudstone; lithic, arkosic.
Deep Crk. SW Sec. 17, T. 5N., R. 5W.	Keasey (?)	31	33.7	-	Sandstone; fine gr., clean, micaceous, lithic arkose, very friable.
Clear Crk. NW Sec. 31, T. 4N., R. 5W.	Cowlitz	66	31.5	-	Sandstone; fine gr., silty, micaceous, lithic arkose.
Eastside Rd. SE Sec. 5, T. 4N., R. 5W.	Cowlitz	206	34.0	VN-12	Sandstone; very fine gr., silty, micaceous, lithic arkose, submature.

POROSITY-PERMEABILITY OF SANDSTONE CORES TAKEN FROM SELECTED OUTCROPS, UPPER NEHALEM BASIN**, Continued

SAMPLE LOCATION	GEOLOGIC FORMATION	PERMEABILITY (MILLADARCIES)	POROSITY (PERCENT)	LAB NO.*	ROCK CLASSIFICATION
Clear Crk. NE Sec. 28, T. 4N., R. 5W.	Cowlitz	46	30.9	-	Sandstone; very fine gr., silty, micaceous, lithic arkose.
Rocky Point NW Sec. 23, T. 4N., R. 5W.	Cowlitz	71	32.0	-	Sandstone; fine gr., silty, micaceous, lithic arkose.
Buster Camp NW Sec. 23, T. 5N., R. 6W.	Cowlitz	823	36.2	VN-13	Sandstone; very fine gr., silty, lithic arkose, immature.

*Number assigned by R. O. Van Atta for petrographic determination.
**Analyses by Core Laboratories, Inc. Dallas, Texas

APPENDIX F. POROSITY AND PERMEABILITY OF COWLITZ FORMATION CORES*

TEXACO "CLATSKANIE NO. 1"

DEPTH (FEET)	PERMEABILITY (MILLIDARCIES)	POROSITY (PERCENT)	OIL SAT. (PERCENT)	WATER SAT. (PERCENT)	ROCK CLASSIFICATION
2124	82.0	24.5	0	91	Sandstone, arkosic
2132	8.0	20.3	0	91	Siltstone
2623	30.7	25.3	-	-	Sandstone, arkosic
2626	39.0	22.9	-	-	Sandstone, arkosic
2629	106.0	27.2	-	-	Sandstone, arkosic
2632	22.0	24.5	-	-	Sandstone, arkosic
2636	0.0	8.3	-	-	Siltstone
2638	29.0	21.5	-	-	Sandstone, arkosic
2642	9.0	21.1	-	-	Siltstone
2645	10.5	21.0	-	-	Siltstone
2648	8500.0	25.7	-	-	Sandstone, arkosic
2653	722.0	25.1	-	-	Sandstone, arkosic
2690	0.0	10.4	-	-	Siltstone
2694	1.2	19.5	-	-	Siltstone
2697	4.5	20.0	-	-	Siltstone
2699	17.0	27.9	-	-	Sandstone, arkosic
2702	1.4	22.4	-	-	Siltstone
2705	1.9	21.3	-	-	Siltstone
2708	1.7	15.8	-	-	Siltstone
2815	440.0	21.5	-	-	Sandstone, arkosic
2820	0.90	25.0	-	-	Siltstone
2835	0.87	20.3	-	-	Siltstone
5120	0.58	13.7	0	57	Sandstone, silty
5132	0.0	12.5	0	99	Siltstone, sandy
5442	0.0	7.1	0	100	Sandstone, silty
5455	0.0	8.5	0	100	Sandstone, silty

*Samples run in Texaco's Technical Service and Research Laboratory, 1947.

APPENDIX G. POROSITY AND PERMEABILITY OF COWLITZ FORMATION CORES*

TEXACO "CLARK & WILSON NO. 1"

DEPTH (FEET)	PERMEABILITY (MILLIDARCIES)	POROSITY (PERCENT)	OIL SAT. (PERCENT)	WATER SAT. (PERCENT)	ROCK CLASSIFICATION
1810.0	3.0	37.8	-	-	Sandstone, arkosic, micaceous
2015.6	81.1	29.0	0	125.0	Sandstone, arkosic, micaceous
2019.0	53.0	30.8	0	102.0	Sandstone, arkosic, micaceous
2020.0	28.5	36.7	0	87.0	Sandstone, arkosic, micaceous
2023.0	26.5	39.0	0	78.0	Sandstone, arkosic, micaceous
2028.6	10.2	29.7	0	94.0	Sandstone, arkosic, micaceous
2033±	59.7	30.8	-	-	Sandstone, arkosic, micaceous
2037.0	-	too friable	0	11.1	Sandstone, arkosic, micaceous
2039.0	-	too friable	0	18.6	Sandstone, arkosic, micaceous
2046.0	0	10.0	0	87.5	Sandstone, clayey
2050.0	19.4	30.2	0	100.1	Sandstone, arkosic, clayey
2054.0	6.4	29.2	0	92.9	Sandstone, arkosic, clayey
2058.0	3.6	27.9	0	99.0	Sandstone, arkosic, clayey
2060.0	3.5	29.4	0	97.0	Sandstone, arkosic, clayey
2063-4	6.5	29.0	0	109.1	Sandstone, arkosic, clayey
2066-7	6.0	26.7	0	106.1	Sandstone, arkosic, clayey
2070.6	5.1	25.5	0	120.0	Sandstone, arkosic, clayey
3066.0	23.2	23.0	0	118.6	Sandstone, arkosic, micaceous
3068.0	18.0	22.2	0	102.0	Sandstone, arkosic, micaceous
3070.0	46.2	21.7	0	112.5	Sandstone, arkosic, micaceous
3073.0	65.0	23.1	0	96.5	Sandstone, arkosic, micaceous
3075.0	18.1	19.2	0	108.0	Sandstone, arkosic, micaceous
3077.0	84.6	23.9	0	89.8	Sandstone, arkosic, micaceous
3081.0	22.0	27.4	0	99.5	Sandstone, arkosic, micaceous
3082.0	521.6	29.5	0	99.6	Sandstone, arkosic, micaceous
3085.0	806.1	27.9	0	89.0	Sandstone, arkosic, micaceous
3088.0	348.4	25.9	0	91.1	Sandstone, arkosic, micaceous
3090.0	379.4	29.4	0	82.3	Sandstone, arkosic, micaceous
3093.0	49.6	24.1	0	117.9	Sandstone, arkosic, micaceous
3099.0	45.2	28.1	0	93.5	Sandstone, arkosic, micaceous
3103.0	553.8	32.2	0	72.2	Sandstone, arkosic, micaceous
3105.0	1,302.3	26.2	0	95.5	Sandstone, arkosic, micaceous
3112.0	566.7	29.4	0	93.1	Sandstone, arkosic, micaceous
3122.0	717.6	26.9	0	84.5	Sandstone, arkosic, micaceous
3212.0	-	too friable	0	8.4	Sandstone, arkosic, micaceous

TEXACO "CLARK & WILSON NO. 1" Continued

DEPTH (FEET)	PERMEABILITY (MILLIDARCIES)	POROSITY (PERCENT)	OIL SAT. (PERCENT)	WATER SAT. (PERCENT)	ROCK CLASSIFICATION
3214.0	-	too friable	0	11.2	Sandstone, arkosic, micaceous
3219.0	56.4	26.3	0	118.3	Sandstone, arkosic, micaceous
3224.0	251.1	27.5	0	86.4	Sandstone, arkosic, micaceous
3226.0	163.9	25.5	0	93.2	Sandstone, arkosic, micaceous
3229.0	151.5	26.4	0	118.8	Sandstone, arkosic, micaceous
3232.0	-	too friable	0	16.7	Sandstone, arkosic, micaceous
3234.0	290.8	23.1	0	135.7	Sandstone, arkosic, micaceous
3236.0	95.2	24.0	0	135.0	Sandstone, arkosic, micaceous
3239.0	398.5	29.4	0	91.6	Sandstone, arkosic, micaceous
3285.0	73.9	22.8	0	102.6	Sandstone, arkosic, micaceous
3287.0	276.7	26.5	0	87.2	Sandstone, arkosic, micaceous
3290.0	192.0	25.3	0	87.2	Sandstone, arkosic, micaceous
3296.0	144.0	26.2	0	82.4	Sandstone, arkosic, micaceous
3300.0	488.4	29.0	0	74.1	Sandstone, arkosic, micaceous
3304.0	499.0	27.1	0	85.4	Sandstone, arkosic, micaceous
3310.0	134.9	25.5	0	77.4	Sandstone, arkosic, micaceous
4830.0	-	too friable	-	-	Sandstone, silty, tuffaceous
5935.0	-	too friable	-	-	Sandstone, silty, tuffaceous
7378.0	-	too friable	-	-	Sandstone (?), hard, silty
7726.0	0	2.6	-	-	Siltstone, sandy
7832.0	0	0.8	-	-	Siltstone, sandy
7865.0	0	12.8	-	-	Siltstone, sandy
7895.0	-	too friable	-	-	Sandstone (?)
7900.0	0	15.8	-	-	Siltstone, sandy
7905.0	-	too friable	-	-	Sandstone, arkosic, micaceous
7930.0	-	too friable	-	-	Sandstone, arkosic, micaceous
7931.0	0	4.6	-	-	Siltstone, sandy
7935.0	-	too friable	-	-	Sandstone, arkosic, micaceous
7938.0	-	too friable	-	-	Sandstone, arkosic, micaceous
7940.0	0	4.7	-	-	Siltstone, sandy
7948.0	-	too friable	-	-	Sandstone, arkosic, micaceous
7972.0	-	too friable	-	-	Sandstone, arkosic, micaceous
7975.0	-	too friable	-	-	Sandstone, arkosic, micaceous
7985.0	-	too friable	-	-	Sandstone, arkosic, micaceous
8005.0	0	2.4	-	-	Siltstone, sandy
8023.0	0	4.0	-	-	Sandstone, arkosic, hard, tight
8060.0	0	3.0	-	-	Sandstone, arkosic, hard, tight
8163.0	0	10.9	0	145.5	Sandstone, arkosic, hard, tight

TEXACO "CLARK & WILSON NO. 1" Continued

DEPTH (FEET)	PERMEABILITY (MILLIDARCIES)	POROSITY (PERCENT)	OIL SAT. (PERCENT)	WATER SAT. (PERCENT)	ROCK CLASSIFICATION
8166.0	0	4.2	0	94.7	Sandstone, arkosic, hard, tight
8170.0	0.94	13.5	0	69.0	Sandstone, arkosic, hard, tight
8174.0	0	7.5	0	206.5	Sandstone, arkosic, hard, tight
8177.0	0	8.6	0	99.5	Sandstone, arkosic, hard, tight
8182.0	0	10.3	-	-	Sandstone, arkosic, hard, tight
8189.0	0	5.3	-	-	Sandstone, arkosic, hard, tight
8191.0	0	8.8	-	-	Sandstone, arkosic, hard, tight
8193.0	0	11.4	-	-	Sandstone, arkosic, hard, tight
8195.0	0	11.3	-	-	Sandstone, arkosic, hard, tight
8198.0	0	8.8	-	-	Sandstone, arkosic, hard, tight
8201.0	0	11.0	-	-	Sandstone, arkosic, hard, tight
8204.0	0	1.7	-	-	Sandstone, arkosic, hard, tight
8225.0	0	0.4	-	-	Siltstone

* Samples run in Texaco's Technical Service and Research Laboratory, 1947.

APPENDIX H. POROSITY-PERMEABILITY OF SPENCER FORMATION SAMPLES[1]

SAMPLE LOCATION	PERMEABILITY (MILLIDARCIES)	POROSITY (PERCENT)	LAB NO.	ROCK CLASSIFICATION
SE¼ Sec. 20, T. 1S., R. 4W.	184	36.0	-	Sandstone, fine to very fine
SE¼ Sec. 32, T. 1S., R. 4W.	202	32.2	-	Sandstone, fine to very fine
NE¼ Sec. 16, T. 2S., R. 4W.	1130	31.7	-	Sandstone, fine to very fine
SE¼ Sec. 30, T. 3S., R. 4W.	812	41.3	-	Sandstone, fine to very fine
NW¼ Sec. 30, T. 3S., R. 3W.	736	41.2	-	Sandstone, fine to very fine
NW¼ Sec. 24, T. 3S., R. 4W.	1850	41.1	-	Sandstone, fine to very fine
NE¼ Sec. 1, T. 3S., R. 4W.	2200	40.7	-	Sandstone, fine to very fine
NW¼ Sec. 15, T. 2S., R. 4W.	4510	41.5	-	Sandstone, fine to very fine
SE¼ Sec. 32, T. 1S., R. 4W.	3510	32.9	-	Sandstone, fine to very fine

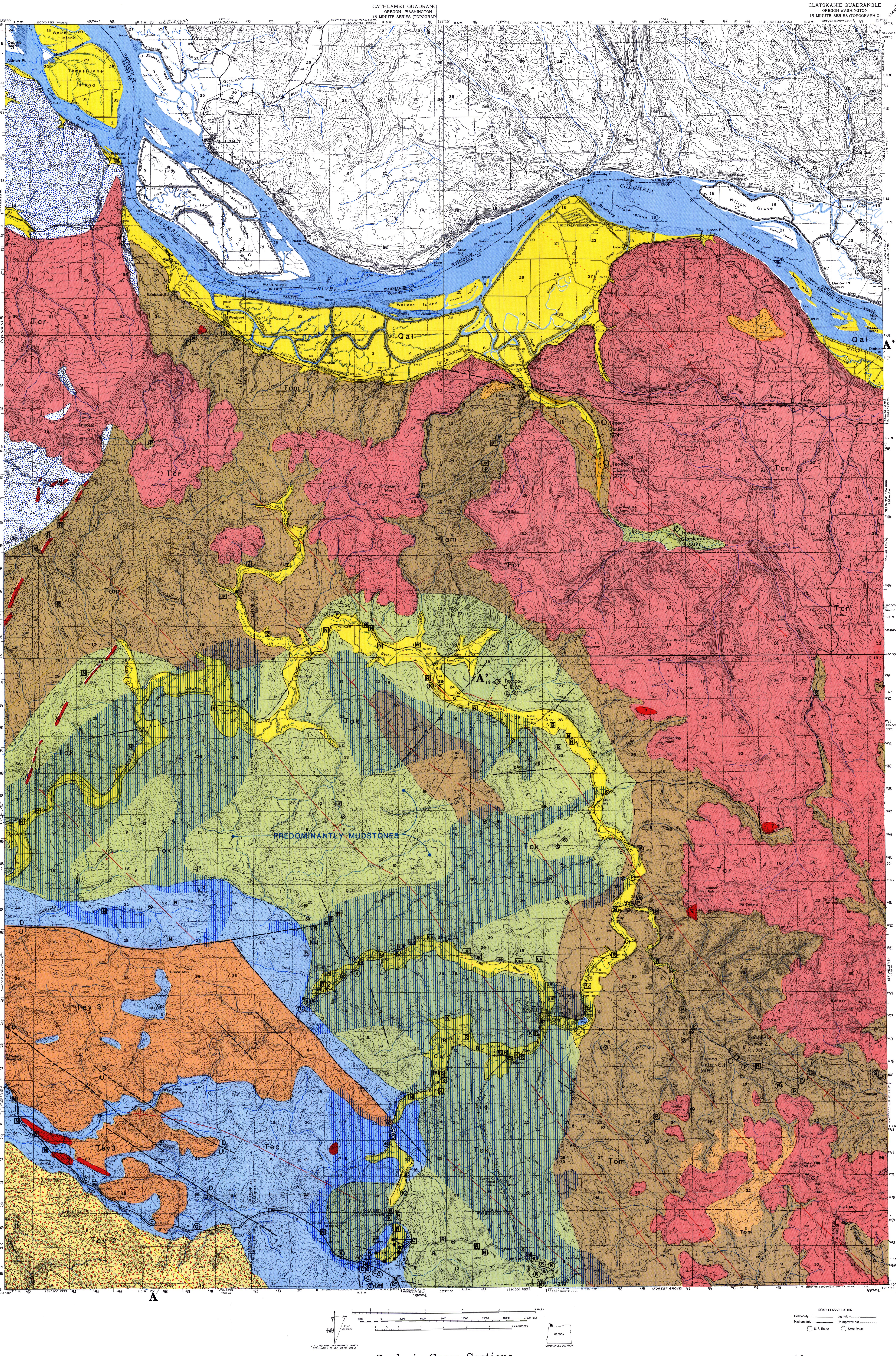
SIEVE ANALYSIS: 70% - very fine sand, 25% - silt, and 5% - fine size. Clay, if present, represents less than 2% of the samples tested.

[1] Schlicker, H. G., 1962. Samples taken during 1962 in Washington and Yamhill Counties. Analyses by Oilwell Research, Inc., Long Beach, California.

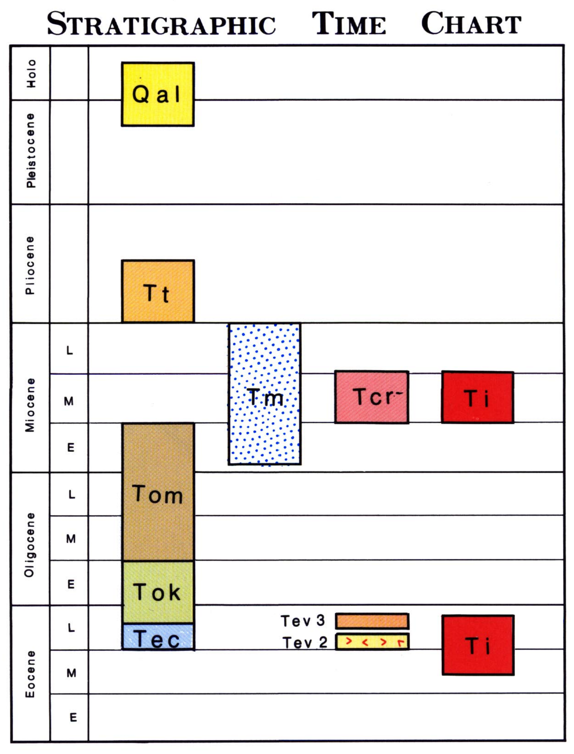
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
R. E. CORCORAN, STATE GEOLOGIST

GEOLOGIC MAP of the UPPER NEHALEM RIVER BASIN OREGON

OIL AND GAS INVESTIGATION No. 5
PROSPECTS FOR NATURAL GAS PRODUCTION AND UNDERGROUND STORAGE OF PIPE-LINE GAS IN THE UPPER NEHALEM BASIN, OREGON



Stratigraphic Time Chart



Qal Alluvium: *silt, sand, and gravel in the lowlands.*

Tt Troutdale terrace gravels: *containing cobbles of quartzite, granite, and besalt.*

Tm Miocene marine siltstone and sandstone: *overlying and interbedded with the Columbia River Basalt.*

Tcr Columbia River Basalt: *dark-gray to black, aphanitic; some localized breccias and pyroclastics.*

Tom Middle Oligocene to lower Miocene sandstone and siltstone undifferentiated: *deposited under marine to brackish water, near-shore environment. The upper portion includes the Scappoose Formation of Warren and Norbisrath, 1946, and the lower portion contains the Pittsburg Bluff Formation described by Schenck, 1927. The lower section contains occasional thin limestone layers and a few thin seams of sub-bituminous coal.*

Tok Keasey Formation: *dark greenish-gray mudstone predominant, some micaceous siltstone, sandstone, and dark micaceous shale. It also contains thin limestone beds and concretionary limestone layers.*

Tec Cowlitz Formation: *the upper protion consists chiefly of argillaceous, micaceous, arkosic sandstone and siltstone. The lower portion becomes finer grained; contains interbedded shale and some black carbonaceous shales. Goble Volcanics are intercalated with the upper and lower members of the Cowlitz sediments.*

Tev 3 Goble Volcanics: *(intercalated with the Cowlitz) basaltic flow rock and pillow basalt of marine and subaerial origin; some pyroclastics. Beaulieu, 1972, divided the Eocene volcanics into three units.*

Tev 2 Tillamook Volcanics: *basalt and basaltic flow breccia; some pyroclastics; some interbedded marine sedimentary rocks. Tillamook Volcanics are equivalent to the Crescent and Metchosin volcanics of western Washington. Unit Tevl, Beaulieu, 1972, is equivalent to the Siletz River Volcanics, middle to lower Eocene age.*

Ti Intrusive Rock: *Basaltic intrusive rock of late Eocene and middle Miocene age, including dikes and sills.*

GEOLOGIC SYMBOLS

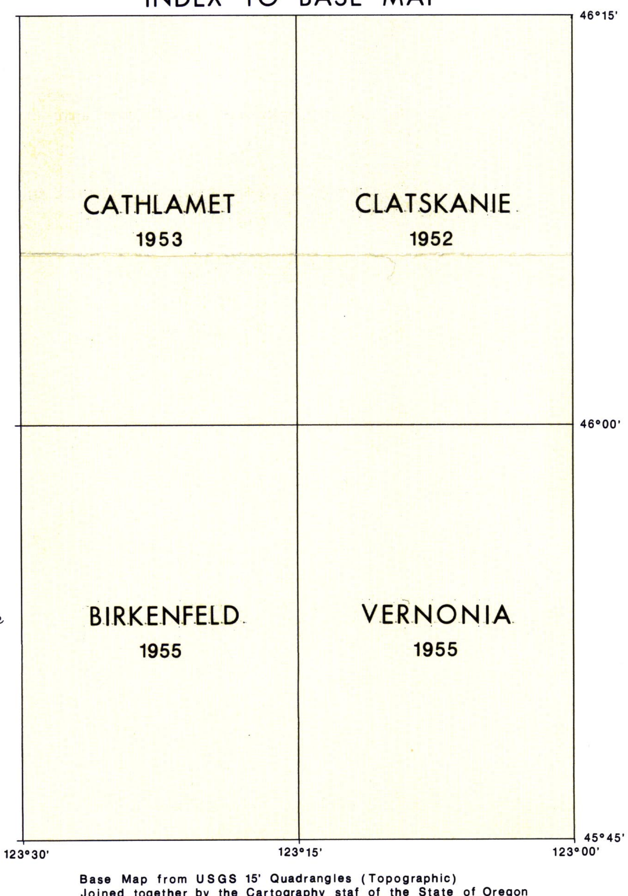
Contacts
Definite contact
Approximate contact
Concealed contact

Faults
Definite fault
Approximate fault
Concealed fault

Anticline, approximate trace
Syncline, approximate trace
Strike and dip of bed and flows
Microfauna age
Megafauna age
Fossil location (undated)
Core holes
Deep test hole

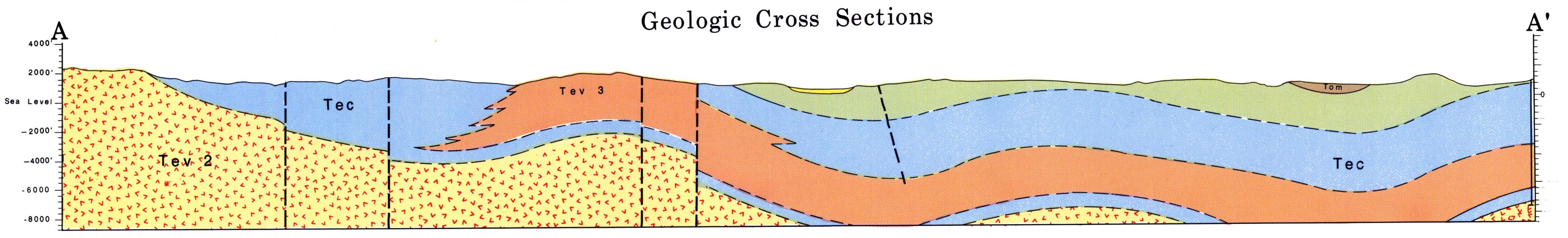
UR upper Refugian
R Refugian
LR lower Refugian
UN upper Narizian
N Narizian
LN lower Narizian
UZ upper Zemorrian
Z Zemorrian
UK upper Keasey
K Keasey
C Cowlitz
UE upper Eocene
S Scappoose
P Pittsburg Bluff

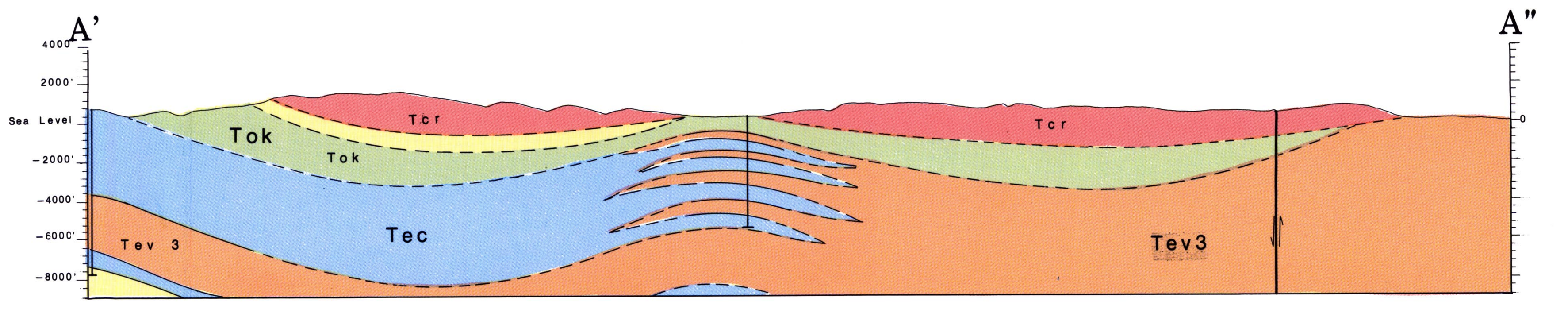
INDEX TO BASE MAP



Base Map from USGS 15' Quadrangles (Topographic)
Joined together by the Cartography staf of the State of Oregon
Department of Geology & Min. Inds. 1976

Geologic Cross Sections





Control by USC&GS, USCE, and State of Oregon
Topography from aerial photographs by multiplex methods
Aerial photographs taken 1953. Field check 1955
Polyconic projection. 1927 North American datum
10,000-foot grid based on Oregon coordinate system, north zone
Dashed land lines indicate approximate locations
Unchecked elevations are shown in brown
1000-meter Universal Transverse Mercator grid ticks, zone 10, shown in blue

Geology by V. C. Newton, Jr.

Cartography by S. R. Renoud and C. A. Schumacher, 1976.