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DIVISION OF MINES AND GEOLOGY
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Report of Investigations No. 22

TERTIARY GEOLOGIC HISTORY OF WESTERN OREGON AND WASHINGTON

By

PARKE D. SNAVELY, Jr. and HOLLY C. WAGNER

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FOREWORD

"Circum-Pacific Petroleum Exploration" was the central theme for the 47th Annual Meeting of The American Association of Petroleum Geologists held at San Francisco, California, March 26 to 29, 1962. Of the 29 papers presented around this theme, the review of the geologic history of western Oregon and Washington presented by Parke D. Snavely, Jr., is of particular interest to those concerned with petroleum exploration in the Pacific Northwest. As his talk contained new concepts concerning the Tertiary depositional history in western Oregon and Washington, many of his colleagues urged him to make these data available in published form. In making this talk available for publication, Mr. Snavely wishes to emphasize that his predilections are based upon broad regional considerations that undoubtedly will be revised in the light of future work.

The approval of the AAPG to publish this talk is gratefully acknowledged.

Marshall T. Huntting, Supervisor
Division of Mines and Geology

January 15, 1963

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TERTIARY GEOLOGIC HISTORY OF WESTERN OREGON AND WASHINGTON[1/]

By Parke D. Snavely, Jr., and Holly C. Wagner[2/]

INTRODUCTION

In attempting to recount the evolution of the Tertiary geosyncline that occupied western Oregon and Washington, one finds himself in a rather precarious position, for in most places the margins of the geosyncline are masked on the east by volcanic rocks of the Cascade Range and on the west by the Pacific Ocean (fig. 1). This concealment of the margins of the basin, together with the thick cover of soil and vegetation in the central part, results in a lack of precise stratigraphic data, and necessitates numerous broad generalizations in reviewing the geologic history. The validity of some of the generalizations made in this paper soon can be evaluated as new data become available from the aggressive petroleum exploration program now under way in offshore Oregon and Washington.

The authors wish to acknowledge the assistance of colleagues in the U.S. Geological Survey, the oil industry, and the universities who, through their published work or discussions, have illuminated many of the blind spots in the authors' knowledge of the geology of western Oregon and Washington. The authors are particularly indebted to Howard D. Gower and Dallas L. Peck for their contributions to this paper.

EARLY EOCENE

Western Oregon and Washington at the beginning of the Tertiary was the site of a eugeosyncline that occupied the present area of the Olympic Mountains and Coast Ranges and the Puget-Willamette lowland. This linear basin of deposition was about 400 miles long, extending southward from Vancouver Island to the Klamath Mountains. The eastern margin extended beneath the present site of the Cascade Range, and a western margin may have existed some miles west of the present coast line.

Early in the history of the geosyncline, a thick sequence of basaltic pillow lavas and breccia was erupted from numerous centers onto the floor of the rapidly subsiding eugeosyncline. The probable extent of this early Eocene volcanism is shown in figure 2.

1/ Publication authorized by Director, U.S. Geological Survey. The stratigraphic nomenclature used in this report has not been entirely adopted by the U.S. Geological Survey.

2/ Geologists, U.S. Geological Survey, Menlo Park, California.

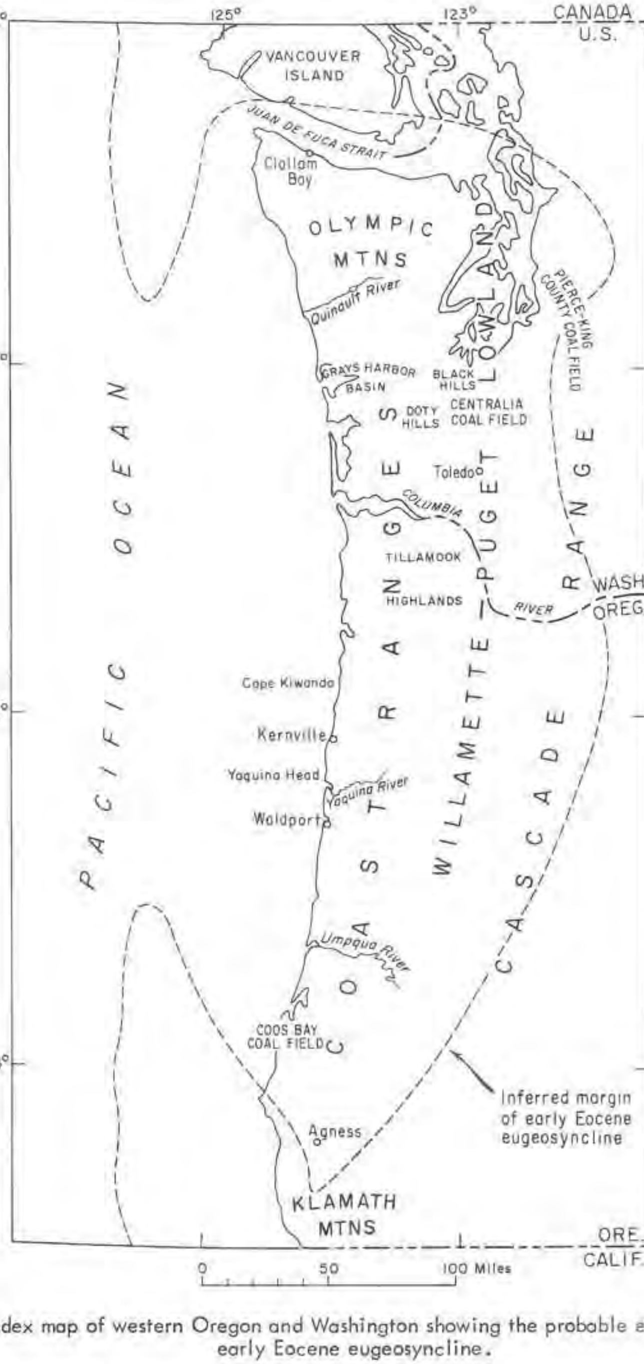

Figure 1. Index map of western Oregon and Washington showing the probable extent of the early Eocene eugeosyncline.

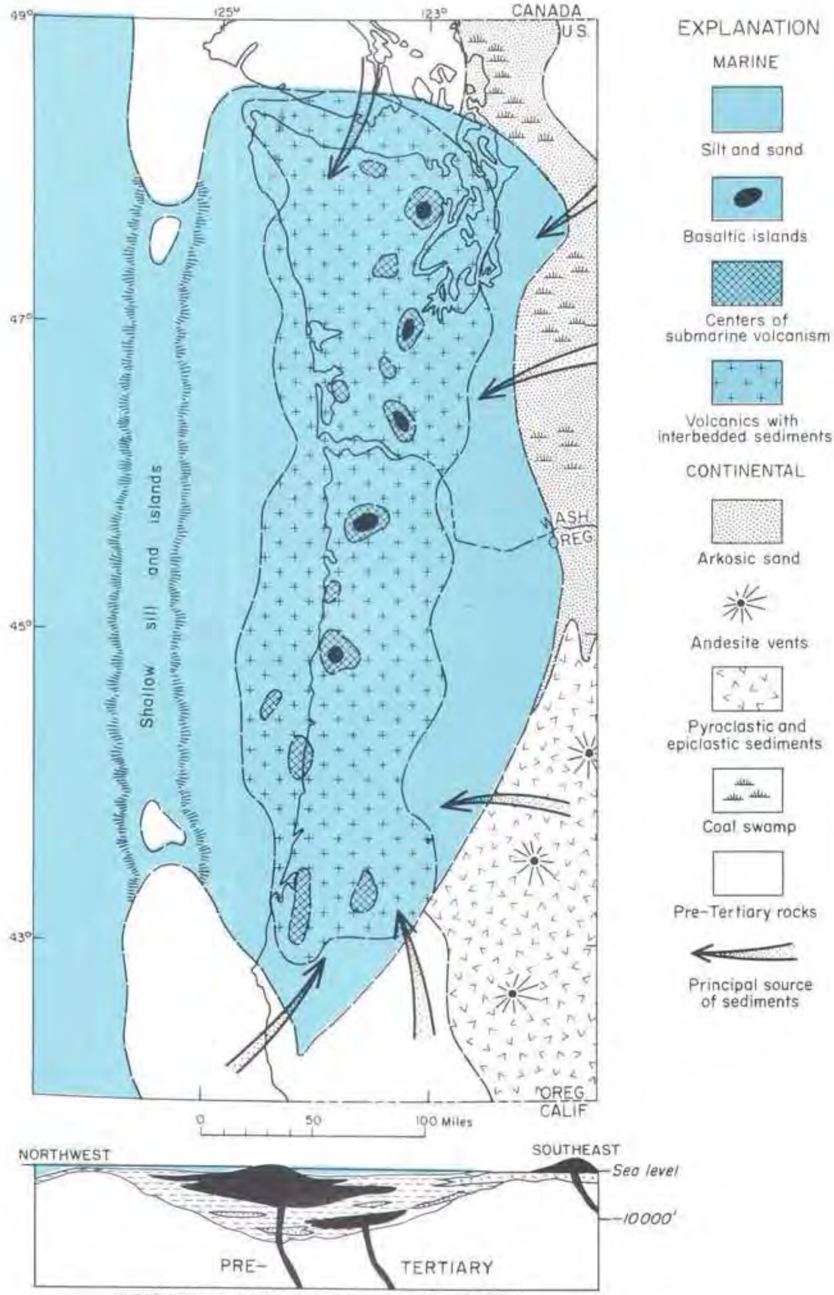

Figure 2. Paleogeologic map of western Oregon and Washington during early Eocene time.

Since volcanism occurred at different times in various parts of the geosyncline, volcanic rocks interfinger complexly with marine tuffaceous sedimentary rocks in different stratigraphic positions.

The volcanic sequence totals more than 15,000 feet in thickness on the Olympic Peninsula where the base is exposed. In the Oregon and Washington Coast Ranges the base is not exposed, and test wells have not penetrated beneath these volcanic rocks. Geological and geophysical data suggest that the sequence is probably more than 10,000 feet thick in many parts of the Coast Ranges. Although the volcanic rocks thin toward the margins of the geosyncline, there is probably no place in the Coast Ranges where Mesozoic strata can be reached by a drill without penetrating a thick section of lower Eocene flows or breccia. These basaltic lavas are estimated to have the largest volume of any volcanic unit in the Pacific Northwest, at least 60,000 cubic miles. This thick volcanic sequence is an excellent unit to contour geophysically, because of its wide distribution, high total magnetization, and conspicuous density contrast with overlying strata. Flood basalts, rather than those of the central vent type, were predominant, and most of the lava was erupted onto the sea floor from fissures and vents, either as flows or extrusive breccia. Interflow soil zones and interbedded locally derived mud-flow breccia and

Figure 3. Basaltic pillow lava in the Siletz River Volcanic Series showing typical radiating columnar jointing. Widow Creek quarry, State Highway 18, near Rose Lodge, Oregon Coast Range.

conglomerate show that volcanic islands formed in places — such as near latitude 45° — and that a part of the series was erupted on land. Locations of subaerial early Eocene volcanism are indicated in solid black on figure 2.

Well-developed pillow structures with radiating columnar joints (fig. 3) are common, as are zeolite-cemented breccias formed by steam explosion and autobrecciation during submarine extrusion.

The predominant rock type in this volcanic sequence, to which are referred the Umqua, Siletz River, and Tillamook volcanics in Oregon and the Crescent and Metchosin volcanics in western Washington, is aphanitic to porphyritic augite-rich basalt. These flows have been partly spilitized in the Olympic Peninsula, but zeolitization rather than spilitization is common in the Coast Ranges.

The volcanic units intertongue complexly with dark-gray fossiliferous tuffaceous siltstone that contains graded beds of volcanic, feldspathic, and lithic wackes. These impure sandstones contain more than 20 percent clay matrix, and in figure 4 are shown interbedded with siltstone of the Umpqua Formation. Beds of chert and Globigerina-bearing limy siltstone occur locally. Massive beds of sandstone and conglomerate are interbedded with tuffaceous siltstone in the southern part of the geosyncline, reflecting uplift and erosion of the rugged Klamath pre-Tertiary terrane.

Figure 4. Tuffaceous siltstone with interbedded volcanic sandstone in the Umpqua Formation. North of Agness, in the southern part of the Oregon Coast Range.

Figure 5. Interbedded argillite and graywacke of early Eocene age. Near Blue Mountain, in the northeastern part of the Olympic Mountains.

The presence of tuffaceous material and detrital grains of andesite in many of the sandstone beds suggests that a part of the detritus was derived from volcanic fields that lay east of the geosyncline. Current structures, the graded nature of many of the graywacke beds, and the high percentage of unstable rock fragments indicate rapid deposition, probably by turbidity currents that flowed generally northward and westward into the deeper parts of the basin.

In the Olympic Mountains, a thick sequence of argillite and graywacke (fig. 5) underlies and intertongues with the lower to middle Eocene Crescent volcanics. Direction of current movement, as indicated by sedimentary structures, suggests that at least a part of the coarser debris was derived from the north and northeast and spread laterally into a west-trending trough.

The northeast part of the geosyncline, during the early Eocene, was bordered by a broad low-lying swampy coastal plain. Across this plain meandered large streams that carried arkosic debris from pre-Tertiary highlands in northern Washington. These continental deposits are represented in parts of the Puget, Chuckanut, and Swauk Formations. Marine equivalents of these sandstone beds probably are present downdip from the outcrop area of the Puget sequence. Farther south along the eastern margin of the geosyncline, nearshore marine sands probably were deposited, but are buried under the present Cascade Range.

MIDDLE EOCENE

In middle Eocene time major uplift south of the geosyncline resulted in the influx into the basin of great quantities of arkosic, volcanic, and lithic detritus, derived from the Klamath pre-Tertiary terrane of metamorphic, igneous, and sedimentary rocks (fig. 6). Contemporaneous volcanic activity east of the geosyncline contributed andesitic material to the southern part of the basin. Where sediment-laden streams from these source areas reached the coast, large deltas and submarine fans were constructed. Periodic slumping of large masses of unconsolidated material at steep delta fronts moved the accumulated sands and silts into the deeper parts of the geosyncline. These mass movements are believed to have been transformed into turbidity currents, which flowed northward along the axial part of the geosyncline at least as far as latitude 45°. Pre-existing volcanic highs were buried, and as shown in the hypothetical section in figure 6, about 10,000 feet of rhythmic-bedded strata accumulated along the axis of the trough. This predominantly unfossiliferous sandstone sequence — the Tyee Formation — interfingers with argillaceous rocks toward the northeast, and with water-laid pyroclastic material and tuffaceous siltstone north of latitude 45°.

The Tyee Formation, shown in figure 7, consists of graded units 2 to 10 feet thick. These units range from medium-grained arkosic or lithic wacke in the lower part to carbonaceous siltstone in the upper part. The base of each recurrent graded unit is sharply defined and contains casts of sedimentary structures. Groove casts are the most common, but flute casts and brush marks occur locally. In places the siltstone in the upper parts of the graded units has been stripped off by the currents that transported the detritus represented in the overlying rhythmite. Intraformational breccias consisting of angular siltstone clasts set in a sandstone matrix are common.

The average direction of current flow, as revealed from measurements made on the orientation of sedimentary structures, is shown by the small arrows on figure 6. An analysis of measurements made on such structures suggests that the principal sources of sediments for the Tyee lay to the south and southeast. Northeast-trending current directions, in the southwest part of the geosyncline, suggest that the source of some of the detritus was a highland area that existed west of the present coast line. Whether other land masses along the west border of the geosyncline stood high enough to supply coarse detritus to the basin is conjectural. However, east-trending sedimentary structures found as far north as the Umpqua River suggest that a western land mass may have extended at least that far north. West-trending readings and the increase in volcanic material in the Tyee Formation in the southeast part of the geosyncline indicate that streams draining the adjacent volcanic fields contributed measurably to middle Eocene sedimentation.

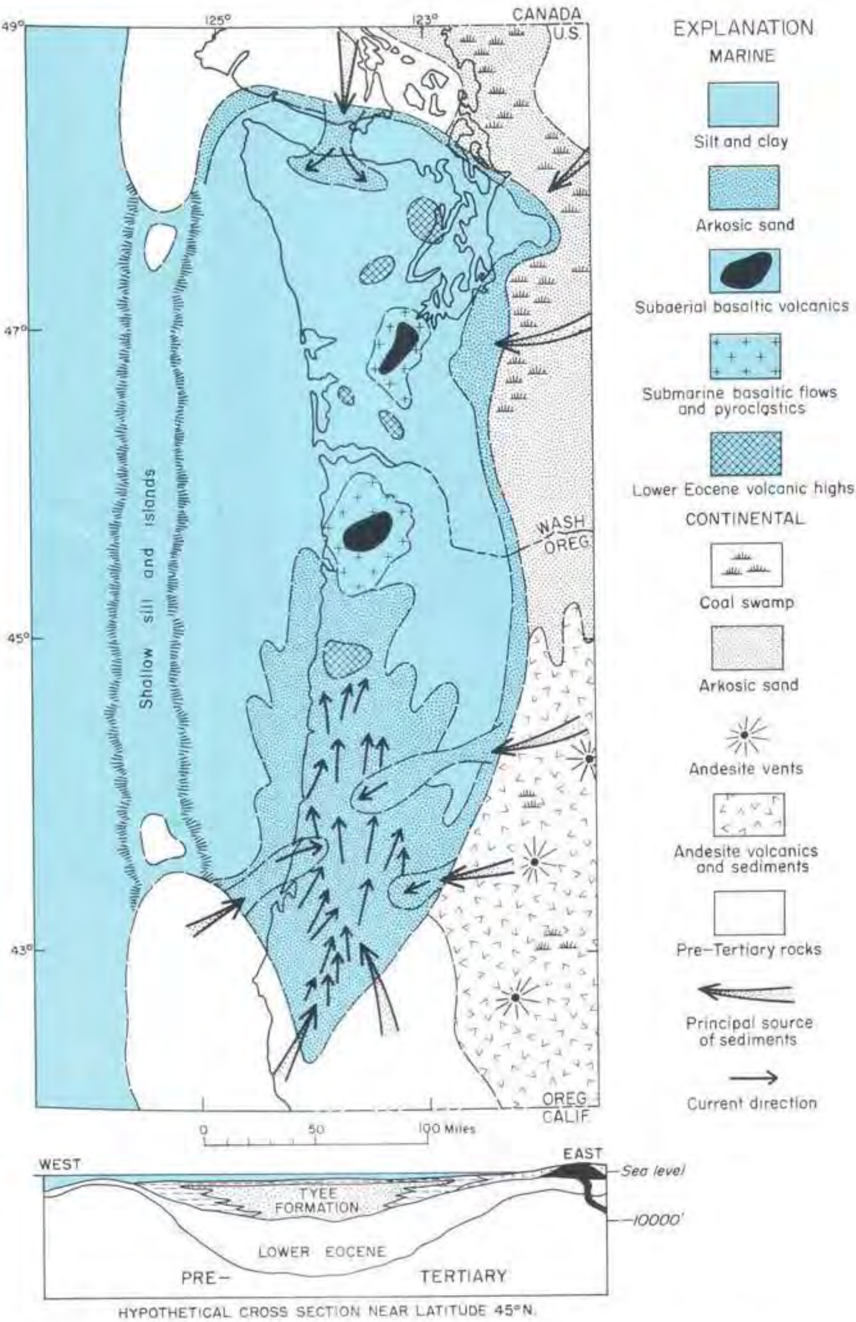

Figure 6. Paleogeologic map of western Oregon and Washington during middle Eocene time.

Figure 7. Tyee Formation showing graded units that range from medium-grained arkosic wacke in the lower part to siltstone in the upper part. Along the Siletz River about 9 miles southeast of Kernville, Oregon Coast Range.

It is interesting to note that current-direction readings, taken just south of the volcanic island that existed in the basin near latitude 45°, show northeast and northwest divergences. These divergences suggest that the turbidity currents were deflected around this area of volcanic accumulation.

During middle Eocene time more than 5,000 feet of nonmarine coal-bearing arkosic sands were deposited on a subsiding low alluvial plain that bordered the north-eastern part of the geosyncline. In places, these sands intertongued with marine silt toward the central part of the basin, but downwarping of the alluvial plain apparently kept pace with deposition, because most of the coarser clastic debris was confined to the continental environment. Within this continental sequence occur the principal coal fields of western Washington — extending from the Roslyn coal field just north of latitude 47° and east of the present Cascade Range to the Pierce and King Counties coal fields along the western flank of the range.

Volcanic activity persisted from early Eocene to middle Eocene time in two principal areas in the axial parts of the basin, one north of the Columbia River in the Doty-Black Hills area, and the other in the Tillamook Highland area south of the river.

Figure 8. Tuffaceous siltstone of the McIntosh Formation with light-gray tuff beds. Type locality along State Route 5, 3½ miles east of Tenino, Wash.

In these areas marine siltstone units of middle and early late Eocene age, such as the McIntosh Formation (fig. 8), intertongue with basalt flows and pyroclastic rocks.

In the northern part of the geosyncline, arkosic and lithic wackes derived from the Vancouver Island metamorphic and igneous terrane supplied coarse clastic material that intertongued with middle and lower upper Eocene marine silt. This sandstone sequence becomes increasingly more conglomeratic upward in the section, reflecting more intense orogenic activity in the source area in early late Eocene time.

Near the close of the middle Eocene, the southern part of the geosyncline was essentially filled by turbidity-current deposits. The Klamath source area apparently was eroded to a region of moderate relief and furnished less debris to the marine environment. At this time coal-bearing continental beds and nearshore bar-type sands were laid down along the southern part of the basin. Silt and clay, probably derived from an eastern source, became the dominant lithology in the central part of the geosyncline.

LATE EOCENE

At the beginning of late Eocene time (fig. 9), areas of local uplift and active volcanism divided the geosyncline into several separate basins and reduced the area of marine deposition. Late Eocene and younger Tertiary sediments accumulated in an open-

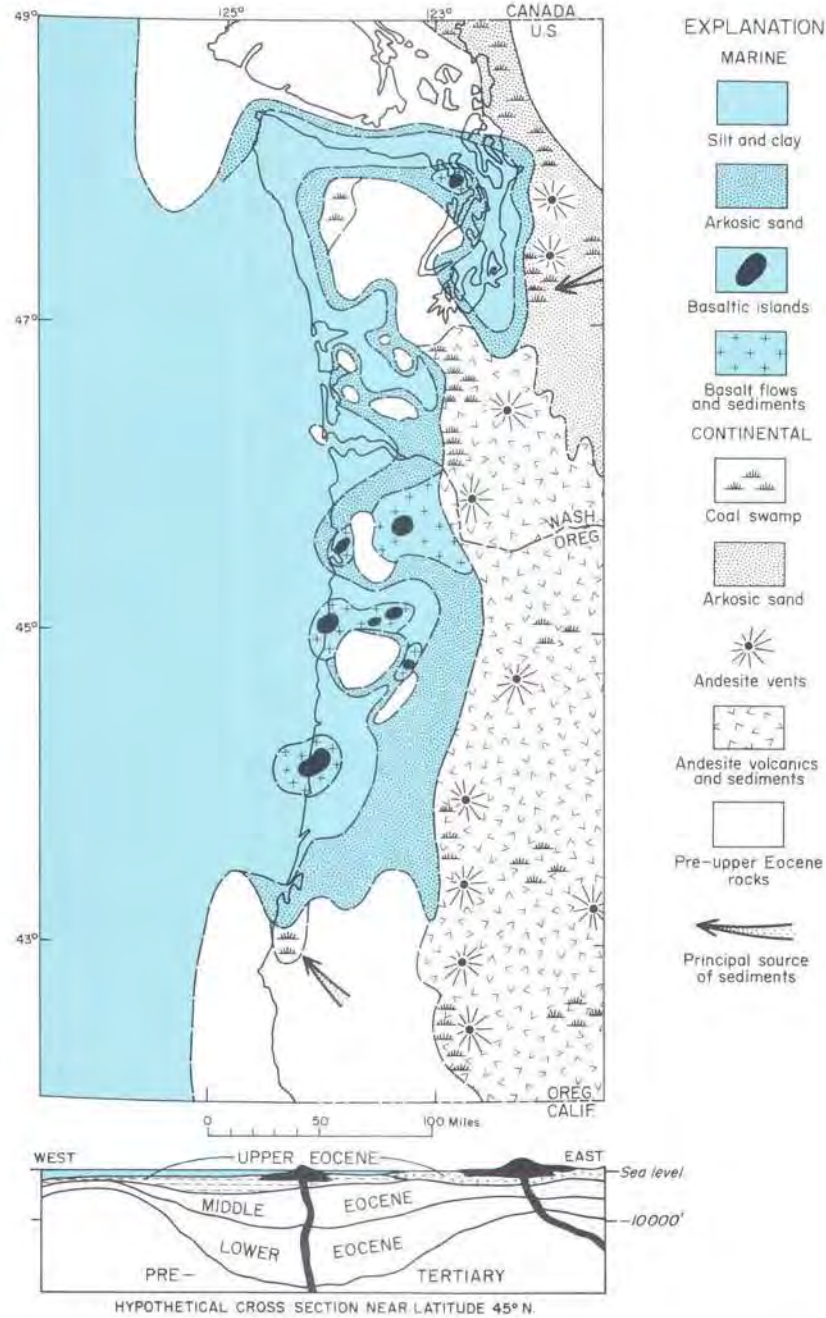

Figure 9. Paleogeologic map of western Oregon and Washington during late Eocene time.

margin geosyncline, and the axis of sedimentation shifted generally westward with time. Local unconformities are common along the margins of uplifts and volcanic build-ups, but in the deeper parts of the basins sedimentation was essentially continuous. Alkalic basalt was erupted from numerous centers within and adjacent to these basins, and andesite was extruded from vents that generally delimited the eastern extent of marine transgression.

Rather rapid, but intermittent, downwarping of the basins produced interfingering nearshore marine and coal-bearing nonmarine strata in a coastal belt 30 to 40 miles wide. A relatively uniform thickness of the coal beds over broad areas in the King County, Centralia, and Coos Bay coal districts indicates that in places coal swamps were widespread on the low-lying coastal plain. Volcanic activity along the eastern margin of the geosyncline contributed large quantities of pyroclastic and epiclastic debris to these coastal plain and nearshore marine deposits.

As shown in figure 10, the Big Dirty coal bed in the Centralia coal district contains ash beds as much as a foot thick interbedded with the coal. In the Centralia district, and in the King County area to the northeast, 3,000 to 3,500 feet of coal-bearing strata were deposited after early late Eocene volcanism ceased in these areas. However, to the south near the present Columbia River, volcanism continued throughout late Eocene time, and flows and pyroclastics intertongued with coal-bearing and

Figure 10. Upper part of the Big Dirty coal bed. K and K strip pit in eastern part of the Centralia-Chehalis coal district, Wash. Light-colored ash beds 1 to $2\frac{1}{2}$ feet thick are shown in the lower part of picture.

nearshore marine sediments. In the southernmost part of the geosyncline, in the Coos Bay embayment, more than 3,000 feet of coal-bearing nonmarine and brackish-water strata accumulated. These coal-bearing deposits graded northwestward into crossbedded shoreline sands, which in turn graded into marine thin-bedded arkosic sands and silts.

A nearshore environment probably existed along the eastern margin of the present Willamette Valley, but younger volcanic and continental deposits now conceal most of the late Eocene strand line. Along the southeastern margin of the geosyncline, however, upper Eocene beds, which were formed in shallow-water marine and brackish-water environments, crop out. These beds consist of massive arkosic and volcanic sandstones containing interbedded carbonaceous siltstone. These nearshore deposits intertongue eastward with a heterogeneous sequence of water-laid tuff, mud-flow breccia, and flows of andesitic composition derived from volcanic fields to the east. Coal-forming plant debris accumulated locally in this area, but not in sufficient thickness to form commercial coal beds.

Farther west, toward the open sea, organic-rich tuffaceous silts and clays were deposited in the deeper water. These argillaceous rocks, characterized by the Nestucca Formation shown in figure 11, are more than 5,000 feet thick and commonly are thin-bedded and in part glauconitic. Sandstone dikes and thin ash beds are common in the upper part of the sequence. Interbedded with these finer clastics are basaltic and arkosic

Figure 11. Tuffaceous siltstone with thin light-colored ash beds; upper part of the Nestucca Formation. Road cut along the Yaquina River, 3 miles southwest of Toledo, Oregon.

sandstones derived from erosion of structural islands of lower and middle Eocene volcanic and sedimentary rocks. For example, in the broad uplift in the area of the present Olympic Mountains, volcanics of the Crescent Formation furnished basaltic debris to the lower part of the Twin River Formation, and in the Oregon Coast Range the Tyee Formation contributed detritus to the Spencer and Nestucca Formations.

Alkalic basalt flows and breccias erupted from numerous centers onto the floor of the marine basin and produced chaotic mixtures of pillow lava, breccia, and siltstone. Islands formed where volcanic accumulations were thickest, and subaerial flows can be traced laterally into pillow lavas that are interbedded with marine tuffaceous siltstone.

Figure 12. Boulder and cobble conglomerate overlain by columnar-jointed subaerial alkalic basalt flow of late Eocene age. Eckman Creek quarry, 3 miles southeast of Waldport, Oregon.

In figure 12, beds of cobble and boulder conglomerate of late Eocene age are shown underlying a columnar-jointed subaerial basalt flow. Where marine erosion was active along the sea cliffs of the islands, such deposits are not uncommon. Pyroclastic material ejected from vents on these islands formed water-laid tuffs that intertongued with marine strata.

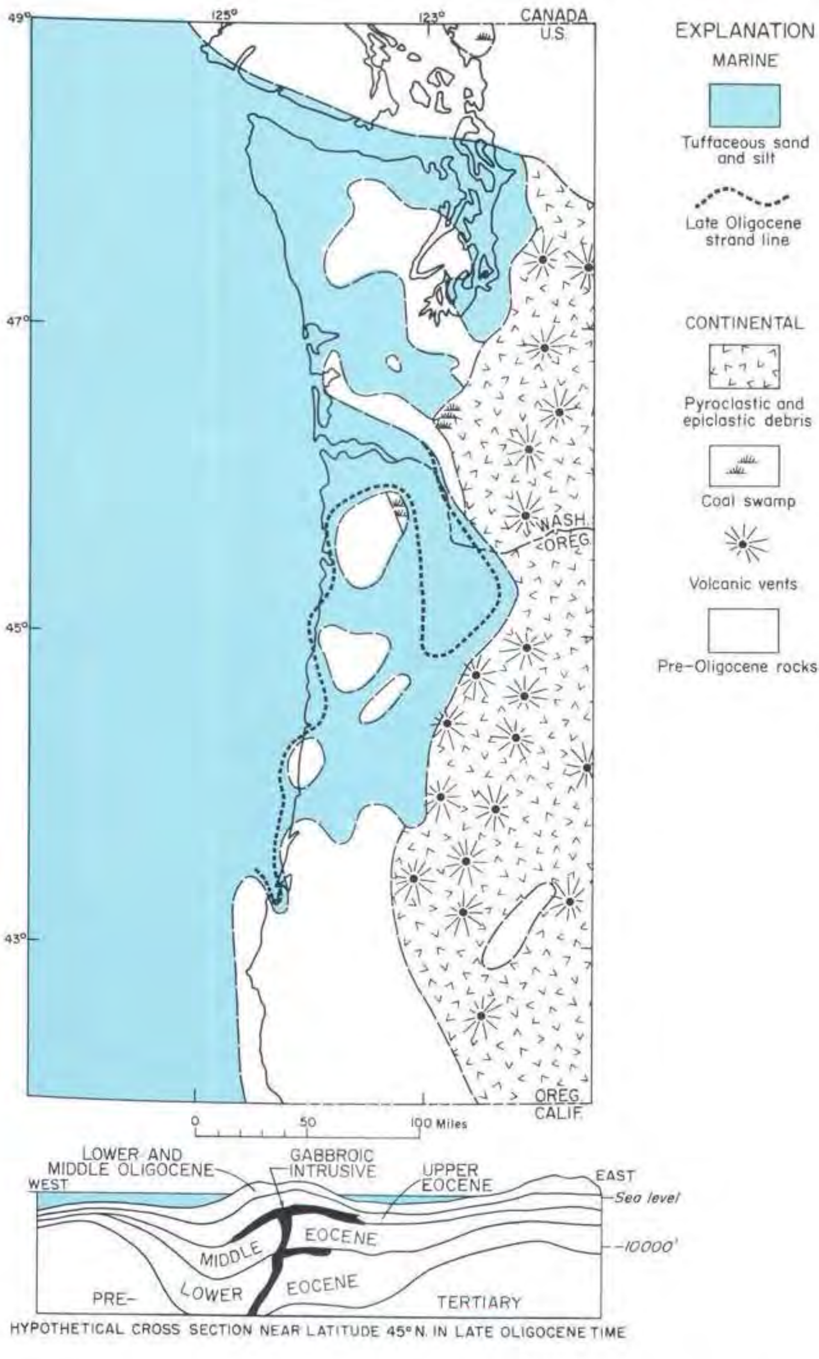

Figure 13. Paleogeologic map of western Oregon and Washington during Oligocene time.

OLIGOCENE

In early and middle Oligocene time mild regional uplift of the southern part of the geosyncline shifted the strand line northward from the late Eocene stand (fig. 13). Conversely, regional subsidence took place in the northern part of the geosyncline and, in places, marine Oligocene beds overlap upper Eocene strata and rest unconformably on lower Eocene volcanic rocks.

Vigorous pyroclastic volcanism adjacent to the eastern margin of the geosyncline brought about a marked change in the type of sediments that were being deposited in the marine basins. Streams, whose headwaters were constantly choked with pyroclastic debris, transported large quantities of this pumice-rich detritus to the nearshore marine environment. In places, these streams constructed steep-fronted deltas, and some of this material was carried by submarine landsliding into the deeper parts of the basin.

In most parts of the geosyncline, ash was rapidly and periodically deposited to form strata like those of the Lincoln Formation shown in figure 14. Typical Oligocene rocks consist of massive tuffaceous siltstone and fine-grained sandstone with intercalated beds of pumiceous lapilli tuff and glauconite.

Figure 14. Massive tuffaceous siltstone and fine-grained sandstone of the Oligocene Lincoln Formation, half a mile north of Galvin, Centralia-Chehalis coal district, Wash. The persistent ledge-forming beds are calcareous siltstone and sandstone. Height of cliff approximately 125 feet.

Adjacent to the eastern margin of the geosyncline, thick deposits of water-laid andesitic and dacitic tuffs with interbedded lava and ash flows buried the late Eocene coastal plain and brought to an end the widespread coal-forming environment. Coal swamps existed in only a few places. The extensive accumulation of volcanic material along the northern part of the present Cascade Range also cut off the streams that had carried arkosic detritus to the northern part of the basin throughout most of Eocene time.

In late Oligocene time only slight changes in the depositional environment took place in western Washington. Farther south along the present site of the Oregon Coast Range, however, the widespread emplacement of gabbroic sills, as much as 1,000 feet thick, was accompanied by broad uplift. As a result, late Oligocene marine deposition was restricted generally to the west flank of the uplift except in a marine embayment that extended into the northern part of the present Willamette Valley. The inferred position of the average late Oligocene strand line is shown by a heavy dashed line on figure 13. Westward-flowing streams draining the broad uplift in the Oregon Coast Range constructed deltas where they reached the coast. The crossbedded sandstone of the Yaquina Formation shown in figure 15 is typical of these deposits.

Two to three thousand feet of Oligocene strata were laid down in the eastern part of the geosyncline, whereas as much as 5,000 feet of tuffaceous sediments

Figure 15. Crossbedded arkosic sandstone of the upper Oligocene Yaquina Formation. Exposure in sea cliff at Seal Rocks, about 5 miles north of Waldport, Oregon.

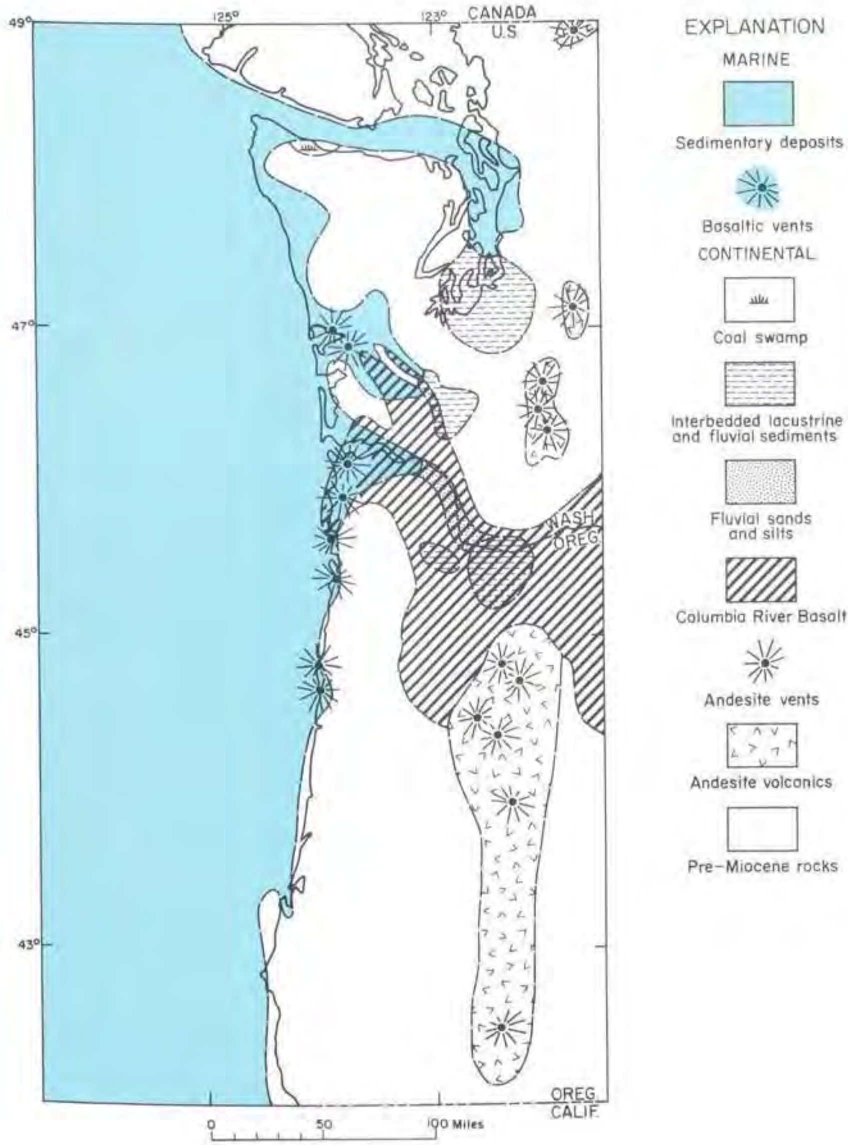

Figure 16. Paleogeologic map of western Oregon and Washington during Miocene time.

accumulated near the present coast line. In a west-trending trough that lay north of the ancestral Olympic Mountains, more than 10,000 feet of silts and clays were deposited. This trough was far removed from the volcanic vents of the Cascade Range, and only a small amount of pyroclastic material is found in this sequence.

MIOCENE

In early Miocene time deposition continued essentially uninterrupted in the same basins that received upper Oligocene sediments (fig. 16). In the early part of the middle Miocene time, however, the older Tertiary strata were folded and faulted along generally northeast structural trends in Oregon and along northwest trends in Washington. Erosion of the land areas elevated by this period of deformation furnished the coarse clastic debris that characterizes much of the sedimentary rock of middle Miocene age. During this tectonic activity, shallow marine bays encroached eastward along structural downwarps. The maximum known extent of marine transgression was in the Grays Harbor basin, and in a broad west-trending downwarp that existed just south of the present Columbia River. Along the Strait of Juan de Fuca, an embayment may have extended as far east as Puget Sound, but the only known middle Miocene rocks are the coal-bearing continental and nearshore marine strata exposed near Clallam Bay.

Figure 17. Massive concretionary arkosic sandstone and thin-bedded sandstone and siltstone of the middle Miocene Astoria Formation. Sea cliff exposure at Cape Kiwanda, Oregon.

Typical middle Miocene strata of the Astoria Formation are massive to thin-bedded arkosic sandstone and siltstone with intercalated water-laid volcanic ash (fig. 17). Basaltic sandstone and conglomerate derived from older volcanic highs also occur in the sequence.

The ancestral Columbia River, which flowed along a west-trending downwarp across western Oregon, transported quantities of arkosic and lithic sand and silt to the marine environment. Deposits of these sands have a higher percentage of heavy minerals than are present in upper Eocene and Oligocene rocks. Pyroclastic material ejected from volcanic vents along the ancestral Cascade Range also forms an important detrital component in the marine strata.

Overturned folds in slump structures (fig. 18), which are present in many places in the Astoria Formation, indicate that the deepest part of the basin of deposition lay west of the present coast line. Further indication of a westward deepening of the basin is the change from nearshore sandstones to thin-bedded sandstone and organic-rich siltstone toward the present coast, as in the Grays Harbor embayment.

Contemporaneously with middle Miocene deposition, basalt flows and breccias were extruded onto the sea floor from a north-trending group of vents and fissures located near the strand line. Thick accumulations of these volcanics formed small islands, and

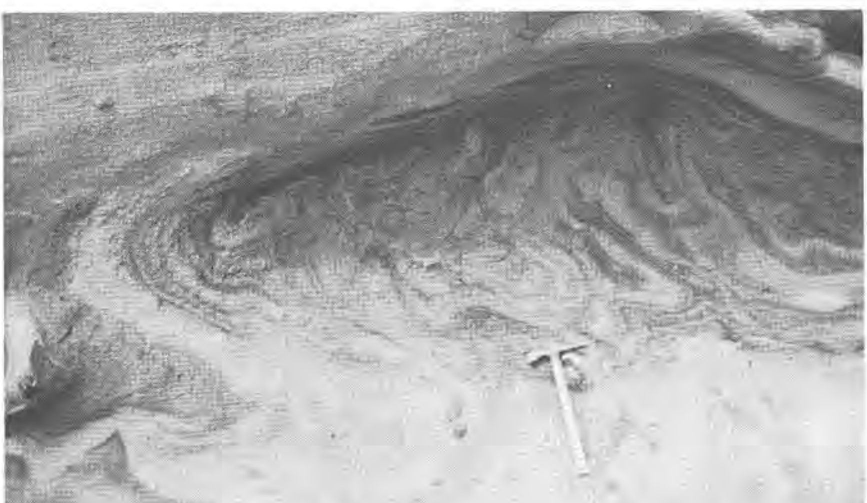

Figure 18. Penecontemporaneous slump structures in sandstone and siltstone beds of the Astoria Formation. Folds overturned to the west. Whale Cove, about 8 miles north of Newport, Oregon.

Figure 19. Yaquina Head, Oregon. An erosional remnant of middle Miocene basaltic volcanism.

the subaerial flows on these islands can be traced into pillow lavas that are interbedded with marine strata. Many of the headlands along the northern part of the Oregon Coast, such as Yaquina Head shown in figure 19, were local centers of middle Miocene volcanism.

The most widespread Miocene lavas, however, were the flood basalts that flowed down the Columbia River downwarp and spread south into the Willamette Valley and north into the Grays Harbor basin. These flows, which are referred to the Columbia River Basalt, lapped onto Tertiary highs and, where they reached the marine environment, formed thick accumulations of pillow lava and breccia. As a result of fluctuation of the Miocene shore line, subaerial flows intertongued with brackish-water and nearshore marine sands and silts.

In late Miocene time large shallow lakes formed in local structural basins along the Puget-Willamette lowland. Sedimentation in these basins kept pace with downwarping, and as much as 1,000 feet of lacustrine clay, fluvial sand, and volcanic mud-flow deposits accumulated. Thick beds of partially carbonized wood, as shown in the lake beds near the center of figure 20, are common. These strata are in large part composed of pumice-rich pyroclastic debris, derived from the venting of granodiorite plutons along the present site of the Washington Cascade Range. Hornblende andesite flows of local extent were also extruded from these Miocene vents. Farther south, along the crest of the ancestral

Figure 20. Lacustrine and fluvial sandstone and siltstone of the upper Miocene Wilkes Formation about 7 miles east of Toledo, Wash. Dark zone near middle of picture consists of carbonaceous siltstone with fragments of fossil wood.

Oregon Cascades, however, widespread flows of hypersthene andesite were extruded from a chain of strato-volcanoes. Near the close of the Miocene, marked regional uplift of the Coast Ranges and intense deformation in the Olympic Mountains further reduced the area of marine deposition in western Oregon and Washington.

PLIOCENE

Only the eastern fringe of marine Pliocene deposition is available for study in the Coos Bay and Grays Harbor structural embayments (fig. 21). In these basins more than 3,000 feet of shallow-water marine strata rest unconformably upon older Tertiary rocks. Slump structures in the Pliocene beds indicate that, as in Miocene time, the deeper part of the basin lay west of the present coast line.

Pliocene strata consist mainly of debris eroded from older Tertiary formations that bordered the basin; however, the ancestral Columbia River contributed much

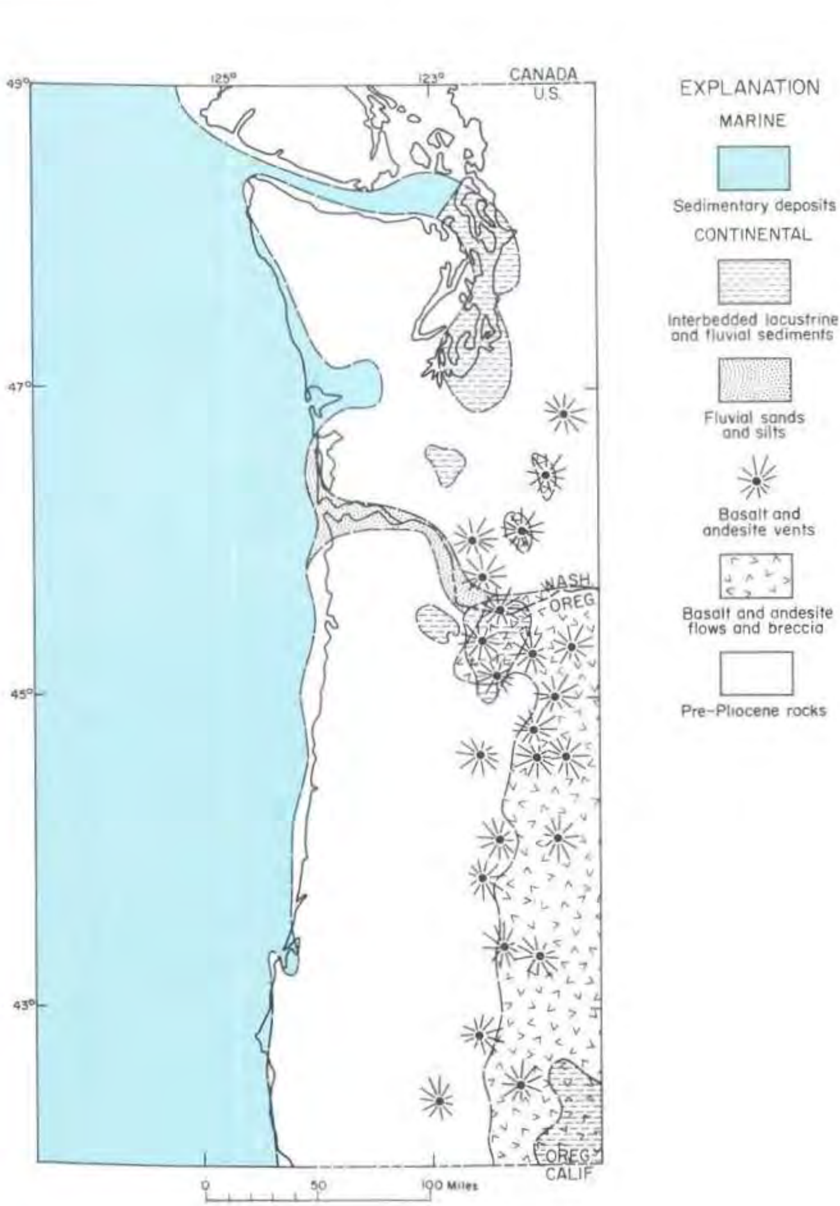

Figure 21. Paleogeologic map of western Oregon and Washington during Pliocene time.

arkosic material to these sediments. The rocks typically are massive to thick-bedded arkosic sandstones and siltstones, such as those of the Quinault Formation in Washington shown in figure 22.

Figure 22. Quinault Formation of Pliocene age. Channel sandstone cutting thin-bedded concretionary sandstone and siltstone beds. Sea cliff exposure just south of the Quinault River, Wash.

In the downwarp along the ancestral Columbia River, more than 500 feet of nonmarine massive to crossbedded quartzose sands and carbonaceous silts with interbedded gravels were deposited. In the depression along the Puget-Willamette lowland, downwarping and sedimentation that started in the late Miocene continued throughout most of the Pliocene.

During late Pliocene time the Olympic Mountains and the Coast Ranges probably attained their present elevations. Contemporaneous marine sedimentation undoubtedly occurred in the north-trending trough delimited by a gravity low that lies west of the present coast line. Inland, principally along the crest of the Cascade Range of Oregon,

Figure 23. Mount Hood, Oregon. A Quaternary andesitic cone. Looking south from the Hood River Valley.

open-textured olivine andesite and basalt were extruded from scattered shield volcanoes. This late Pliocene volcanism provided the platform on which were later constructed the andesitic cones that now characterize the Cascade Range and provide much of the scenic grandeur of the Pacific Northwest (fig. 23).