U.S. DEPARTMENT OF THE INTERIOR
U. S. GEOLOGICAL SURVEY

Geologic Map of the Tillamook Highlands, Northwest Oregon Coast Range (Tillamook, Nehalem, Enright, Timber, Fairdale, and Blaine 15 minute Quadrangles)

by
Ray E. Wells[1], Parke D. Snavely, Jr[1], N. S. MacLeod[2],
Michael M. Kelly[3], and Michael J. Parker[4]

Open File Report 94-21

1994

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1/ Menlo Park, CA 94025
2/ Vancouver, WA 98661
3/ now at Emcon Associates, Medford, OR 97504
4/ now at Arco Oil and Gas, Bakersfield, CA 93309

INTRODUCTION

The Tillamook map area consists of six 15' quadrangles extending from the Oregon coast eastward across the mountainous Eocene volcanic terrane of the northern Coast Range (Figure 1). The region is informally known as the Tillamook Highlands and is characterized by high rainfall, dense vegetation, and deeply weathered surface outcrops. The terrain is rugged, ranging from sea level to 3700'(1100m), but logging roads and rivers provide good access and bedrock exposure. Major forest fires in the 1930s and 1940s created spectacular exposures of the Tillamook Volcanics in the Highlands, but succesful reforestation has left only the most rugged peaks still exposed.

Previous geologic mapping in the Highlands examined the Tertiary marine stratigraphy of the Coast Range as part of a reconnaissance oil and gas investigation (Warren and others, 1945; Warren and Norbisrath, 1946). Generalized geology of selected areas is included in geologic hazards mapping by Schlicker and others (1972), Beaulieau (1973), and Nelson and Shearer (1969). A few student theses are also available (Cressey, 1974; Cameron, 1980; Cooper, 1981; Soper, 1974; Jackson, 1983). Adjacent regions have been mapped by Baldwin and Roberts (1952), Baldwin and others, 1955, Schlicker and Deacon (1967), Niem and Niem (1985), Snavely and Vokes (1949), and Snavely and others (1990, 1993). See Wells and others (1983) and Niem and Niem (1985) for additional references to geologic mapping in adjacent areas.

This digital geologic map was compiled from 1:62,500 scale reconnaissance mapping by Snavely and MacLeod during 1968-1970 and subsequent 1:48,000 and 1:24,000 mapping by Wells, Snavely, Kelly, and Parker during 1983-1989. The geology was originally compiled at 1:48,000 scale on a composite base made from 24 seven and a half minute quadrangles. The geology was subsequently scanned into ARCINFO, a proprietary geographic information system, to produce the digital map. The geology was composited with a scanned topographic base derived from the old 15 minute base maps to expedite Open File publication.

A major goal of our investigation was to establish the basic stratigraphy and structure necessary to guide energy, mineral, hydrologic, and geologic hazard investigations in northwest Oregon. The map area is centered on the Eocene Tillamook Volcanics and related rocks which form the core of the Coast Range uplift, and includes Tertiary marine strata ranging from Eocene to Miocene age on its eastern and western flanks (Figure 1). Most of the Eocene volcanic sequence consists of thick accumulations of submarine and subaerial basalt interbedded with deep water marine sedimentary rocks. At present, hydrocarbon exploration is concentrated in the shallow marine sequence which overlies the Tillamook Volcanics. About 30 km north of the map area is Mist, Oregon's only producing gas field. At Mist, the producing zones are in the shallow marine sandstones of the Eocene Cowlitz Formation above the Tillamook Volcanics. In the map area, repetitive basalt sequences dominate the stratigraphy, but arkosic sandstone that locally interfingers with Tillamook Volcanics to the northeast could be a potential reservoir at depth. Oil shales that are locally exposed in the Yamhill Formation beneath the Tillamook Volcanics may indicate petroleum source rock potential in the region.

Also of interest in the Tillamook Highlands are local areas of mineralization that are concentrated in previously unrecognized silicic flows and intrusions of the Tillamook Volcanics (see map). Semi-quantitative emission spectroscopic analyses of small quartz-sphalerite-pyrite veins in silicic flow breccias and fault zones indicate the presence of zinc, arsenic, silver, and gold (Table 1).

Another important goal of this study was to determine the tectonic environment of the Eocene Tillamook Volcanics, which comprise a large part of the northern Oregon Coast Range. These basalt flows interfinger with marine strata and are chemically and petrographically similar to oceanic island-type tholeiites. They have been interpreted as seamounts constructed in an oceanic environment (eg Snavely and others, 1970; Magill and others, 1981). Paleomagnetic data indicate that the Tillamook Volcanics have undergone large (46°) clockwise rotations, similar to those observed elsewhere in Oregon Coast Range Eocene strata (eg., Simpson and Cox, 1977). One widely held interpretation of this data is that the Tillamook seamounts were part of an oceanic microplate that rotated during its tectonic accretion to the continental margin (Magill and others, 1981). Alternatively, the basalts may have erupted in situ, in a marginal rift basin that formed and subsequently rotated during a period of oblique subduction of offshore oceanic plates (Wells and others, 1984; Snavely, 1987; Clowes and others, 1987). In the present study, our mapping shows that the volcanic sequence in the Tillamook area can be correlated with a similar sequence in southwest Washington (which was previously considered a separate microplate; Magill and others, 1981) and can be tied to the continental shelf. This supports a local origin for the Tillamook Volcanics.

The map area also covers several coastal embayments, including Nehalem, Tillamook, and Netarts Bay. Many coastal embayments appear to be structurally controlled (eg. Snavely and others, 1976a,b,c; Wells and others, 1983; Wells, 1989), and some exhibit deformation continuing into the Quaternary (Adams, 1984). In addition, many estuaries, including Netarts and Nehalem Bay, contain a record of episodic Holocene subsidence thought to represent coseismic deformation during large subduction zone earthquakes (e.g. Atwater, 1987; Peterson and Darienzo, 1988; Grant and Minor, 1991). Our new mapping confirms that Tillamook Bay and Netarts Bay are fault-bounded basins active in Neogene time and that Quaternary deformation has occurred at Netarts Bay (see also Wells and others, 1992).

ACKNOWLEDGEMENTS

Paleontologic age assignments of molluscan fauna have been given by Ellen James Moore, foraminifera by Weldon W. Rau, and coccoliths by David Bukry. Mike Gallagher and Cheryl Hummon provided able assistance in the field. We appreciate the comments of Angela Jayko on an earlier version of the map. Tracey Felger and Johanna Fenton compiled and edited the entire map in ARCINFO. We thank Allison Asbjornsen, Leo and Shannon Brosseau, Jim and Mary Winter and the residents of Tillamook, Netarts, and Oceanside for sharing their local knowledge and hospitality.

GEOLOGIC SUMMARY

The Tillamook map area crosses a broad, northeast-plunging structural arch in Tertiary volcanic and sedimentary strata that form the northern Oregon Coast Range (Figure 1). The core of the uplift consists of Eocene basalt and interbedded marine strata which were previously correlated with the Siletz River Volcanics of the central Oregon Coast Range (Wells and Peck, 1961). In this study, the Eocene volcanics have been divided into five units, and a distinction is made between the lower Eocene Siletz River Volcanics and the overlying Tillamook Volcanics of late middle Eocene age. Marine mudstone and sandstone are interbedded with all of the volcanic units and comprise most of the late Eocene to Miocene stratigraphic section which forms the flanks of the Coast Range uplift. Continental shelf and slope sequences predominate in the basins flanking the Coast Range uplift.

The oldest rocks in the map area are lower Eocene submarine tholeiitic basalts which are exposed in the deeply incised drainages of the Trask and Nestucca Rivers. They are correlated with the Siletz River Volcanics, which form the oceanic basement of the

Oregon Coast Range (Snavely and others, 1968). In the map area, the Siletz River Volcanics are interpreted to be the upper part of a seamount. Locally abundant vesicular porphyritic basalt, trachybasalt pillow flows, and red oxidized flow breccia, bombs, and cinders indicate contemporaneous nearby subaerial volcanism. Potassium-Argon ages of 57.1±1.5 Ma and 54.8±1.0 Ma were determined from pillow basalt in the Trask River, and an age of 52.9±1.0 Ma was determined from pillow basalt in the Nestucca River (Duncan, 1982). These ages are consistent with an early Eocene age (zones CP 11 and 9b, David Bukry, written communication, 1991) determined from interpillow calcareous nannoplankton collected from pillow flows in the Trask and Nestucca Rivers.

Overlying and interfingering with the Siletz River Volcanics is the siltstone of Trask River, a thin bedded lithic turbidite sequence correlative with the lower Eocene Umpqua Formation of the southern Oregon Coast Range and the Kings Valley Siltstone Member of the Siletz River Volcanics on the east flank of the Coast Range (Bukry and Snavely, 1988). The turbidites are locally folded and overlain by another pillow basalt sequence here named the basalt of Hembre Ridge, which is composed of aphyric, low potassium tholeiite (K_2O<0.2%), quite different from the evolved compositions of the older flows. These flows form columnar jointed sheet flows and filled lava tubes which appear to interfinger complexly with widespread aphyric diabase sills of the same composition. The diabase sills intrude the overlying deep marine strata of the middle Eocene Tyee and Yamhill Formations. In the map area, the Tyee formation consists mostly of thin bedded, laminated siltstone with local thin sequences of turbidite sandstone containing abundant muscovite. The overlying Yamhill Formation also consists largely of thin bedded siltstone and is difficult to distinguish from older strata, especially where intruded by the widespread diabase sills. The upper part of the Yamhill Formation is basaltic and interfingers with basalt breccia and sandstone of the Tillamook Volcanics. Kerogen-rich, laminated oil shales are locally interbedded in the upper part of the Yamhill Formation (Snavely and others, 1993).

The most widespread unit in the map area is the upper middle Eocene Tillamook Volcanics, a largely basaltic subaerial flow sequence that forms the rugged high topography north of the Wilson River. The Tillamook Volcanics are a bimodal petrochemical assemblage consisting of high-titanium tholeiitic to alkalic subaerial basalt flows and lesser dacite and rhyolite resting on a submarine apron of pillow basalt, breccia, and basalt lapilli tuff. In the center of the map area, the submarine facies of the Tillamook Volcanics rests on and interfingers with middle Eocene deep-water marine siltstone of the Yamhill Formation. Radiometric ages for the Tillamook Volcanics are quite variable, ranging from 35 to 46 ma (Magill and others, 1981; McKelwee and others, 1984, 1985a,b; and this paper). The most reasonable ages cluster between 42-44 Ma (R. A. Duncan, personal communication, 1992) and are consistent with interfingering of the volcanics with marine siltstone containing nannoplankton assigned to zone CP 14a (David Bukry, written communication, 1988). All paleomagnetic sites in the subaerial flow sequence in the map area are of reversed polarity (Magill and others, 1981), suggesting that it was erupted quickly, possibly within one polarity interval.

The Tillamook Volcanics are interpreted as the remains of an Eocene oceanic island constructed in deep water and resting on an older submarine volcanic and sedimentary sequence. The location of this island appears to be along the continental margin because petrologically related volcanics of similar age interfinger to the northeast with shallow water, continentally-derived sedimentary rocks (Wells, 1981). The map area presents an unusual opportunity to examine a complete section through an oceanic island. Up to 10 km of gently north-dipping subaerial flows are exposed in the map area and probably represent the cumulative thickness of overlapping shield volcanoes. Three petrographic facies are recognized in the basalt: 1) augite ± olivine ± plagioclase-phyric flows, 2) aphanitic, aphyric flows, and 3) abundantly plagioclase-phyric flows with subordinate olivine and pyroxene. Although flow tops are commonly weathered and oxidized, sedimentary interbeds are uncommon. Along the Nehalem River, thick flow-banded rhyolite and dacite flows occur near the top of the basalt section and make up about 5 percent of the total volcanic sequence. A compositional gap in the Tillamook Volcanics is observed in chemically analyzed samples; andesitic compositions between 54 and 62 percent $Si0_2$ are rare.

Fluvial to shallow marine basalt boulder and cobble conglomerate and oyster-bearing sandstone overlie the subaerial flows and represent rapid erosion of the volcanic island following the end of constructional volcanism. Thin bedded late Eocene mudstone of the Nestucca Formation overlies the epiclastic apron and subaerial flows and indicates subsidence of the volcanic edifice, probably due to loading and thermal cooling of the lithosphere, as is inferred for most oceanic islands.

A regional unconformity in latest Eocene time separates the thin-bedded mudstones from overlying thick bedded to massive, bioturbated tuffaceous mudstones of the late Eocene to early Miocene Alsea Formation. The influx of tuffaceous debris on the outer shelf and slope environments marks the inception of widespread volcanism in the Cascade arc to the east. Subsequent deposition of the Astoria Formation in early and middle Miocene time records a change to shallower water environments and the progradation of carbonaceous, micaceous, arkosic deltaic and shallow marine strata across the forearc.

At about 15 Ma, Grande Ronde Basalt flows of the Columbia River Basalt Group flowed into the northern coastal regions through an ancestral Columbia River drainage (e.g. Snavely and others 1973; Choiniere and Swanson, 1979; Niem and Niem, 1985; Beeson and others, 1985). In the northwestern part of the map area, the flows form pillow palagonite complexes and invasive sill-like bodies up to 300 m thick at Neahkahnie Mountain (cf. Beeson and others, 1979 and Niem and Niem, 1985). Invasive sills of Grande Ronde Basalt also cap the ridges between Nehalem Bay and Tillamook Bay where they intrude the upper Eocene and Oligocene marine sedimentary sequence.

Beginning in the late middle Miocene, the northern Oregon Coast Range was uplifted in a broad, northeast-plunging arch (Figure 1). Along the axis of the uplift, no strata younger than Eocene are preserved in the map area, although the concordant summits of Coast Range mountains may represent remnants of a late Tertiary erosional surface. Following coastal uplift, the locus of marine deposition shifted westward onto the present continental shelf, where late Miocene, Pliocene and Quaternary strata are deposited. Quaternary terrace deposits in coastal embayments and on headlands record several interglacial highstands of sea level and are locally deformed (Wells and others, 1992).

Quaternary landslides are abundant in the Tillamook Highlands. Some, such as the large Cape Meares slide, are presently active, but others appear to be ancient slides formed during the Pleistocene. Large landslides have previously dammed the Wilson River, Miami River, Foley Creek, and tributaries of the Nestucca River. Some of these landslides could be studied to assess their possible relationship to inferred large earthquakes along the Oregon Coast. Large landslides and debris flows initiated by heavy rainfall have dammed the Wilson River and closed state Highway 6 several times in the last 20 years (Beaulieu, 1973; Oregon State Department of Transportation, 1991). Highway 6 east of Tillamook is particularly susceptible to slides because it situated on a north-facing slope that is underlain by north-dipping mudstones and basalt flows.

The coastline has also undergone substantial modification in the past 40 years. The topographic base shows the coast line as of 1953, whereas the geology layer shows the coastline as of 1980. The building of jettys at the mouth of Tilamook Bay may have influenced subsequent patterns of erosion and deposition.

CORRELATION WITH WASHINGTON STRATA

The north-dipping basalt-dominated stratigraphic sequence of the Tillamook Highlands is similar to the south-dipping sequence observed north of the Columbia River in southwest Washington (Wolfe and Mckee, 1968; Wells, 1981; Walsh and others, 1987). In Washington, oceanic basalt basement of the Crescent Formation is of the same age and composition as the basalt of Hembre Ridge in the Tillamook Highlands. The overlying Eocene deep water siltstone of the McIntosh Formation is correlative with the Yamhill Formation in Oregon and is intruded by regional late middle Eocene diabase sills similar to those in the Tillamook Highlands. Subaerial high titanium tholeiites of the Grays River Volcanics of Walsh and others (1987) are approximately the same age and composition as the Tillamook Volcanics (McKelwee and others, 1984, 1985a,b; Phillips and others, 1989). However, the Washington high titanium suite (Grays River Volcanics of Walsh and others, 1987; aka Goble Volcanics of Livingston, 1966 and Wells, 1981) interfingers with and overlies the Eocene Cowlitz Formation, whereas the Tillamook Volcanics is overlain by strata correlated with the Cowlitz Formation and thus may be slightly older.

STRUCTURE

The Tillamook map represents a view into the core of the northeast-plunging Coast Range uplift, with strata dipping 15-20° to the west, north, and east. The uplift is an asymmetric arch, with a broad west limb and a short, fault bounded east limb. The highest elevations occur along the eastern edge of the uplift. Open northwest-trending folds are superimposed on the arch and are subparallel to abundant northwest-striking faults, which commonly have subhorizontal slickensides and evidence of some right lateral motion. An apparent conjugate set of northeast striking faults with oblique sinistral slip is locally well developed in the upper South Fork of the Trask River, upper Gales Creek, and in the Nestucca River drainage. Older northeast-striking faults and folds are also common in the Siletz River Volcanics.

A major northwest-trending fault zone forms the north side of Tillamook Bay, where southwest-striking Tillamook Volcanics are truncated, folded and deformed along fault parallel trends. The Tillamook Bay fault zone trends southeast as en echelon segments 30 km across the Coast Range to link up with the Yamhill River fault zone north of McMinnville. The Tillamook Bay fault zone in part controls the formation of Tillamook Bay; about 4 km of vertical stratigraphic separation occurs across the fault with the bay side down. About 20 km of sinistral separation on the top of the Tillamook Volcanics is observed across the fault zone, although both right and left-oblique slickensides are locally observed on fault surfaces. A significant component of sinistral slip is likely, based on consistent sinistral separation of the east flank of the Coast Range, and the changing sense of vertical separation along strike to the SE. A similar but much smaller fault zone bounds the north end of Netarts Bay. The headlands north of the bay form the hanging wall above several northeast-dipping thrust faults, some of which may have had Quaternary displacement (Wells and others, 1992).

A family of north-striking high angle faults with normal-dextral offset is well developed in the highlands between Nehalem and Tillamook Bay. Small, high angle west-northwest fault segments link between the north-trending faults and may accommodate sinistral reverse motion. Although the fault pattern is unlike the conjugate strike slip pattern in the Astoria basin to the north and the Hebo area to the south (Niem and Niem, 1985; Snavely and others, 1990, 1993), it implies similar north-northeast shortening and west-northwest extension. An exception is the Tillamook Bay fault zone which has apparent major sinistral slip. Paleomagnetic studies indicate that the Tillamook Volcanics are rotated clockwise 46° (Magill and others, 1981); the fault zone could represent the boundary between large, clockwise rotating blocks caught in a dextral shear couple along the obliquely convergent plate boundary (Wells and Coe, 1985). Tillamook Bay may represent localized subsidence along the margin of the rotating block, whereas adjacent headlands may indicate localized zones of uplift. Similar west-northwest sinistral faults are also found offshore (Goldfinger and others, 1992), suggesting that dextral shear rotation may continue westward to the deformation front (see also model of England and Wells (1991).

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Qb **Beach and dune deposits (Holocene)**--Unconsolidated, moderately well sorted, fine to medium-grained quartzo-feldspathic beach sand and well sorted, cross bedded fine grained sand comprising active and inactive dune ridges; locally includes basalt gravel and boulder deposits derived from rocky headlands and fine fluvial and lacustrine mud and sand behind coastal dune ridges

Qf **Fluvial and estuarine deposits (Holocene)**--Unconsolidated, clay, silt, sand and gravel alluvium deposited along rivers and streams; includes stabilized tidal flat mud, sand, and peat in Nehalem and Tillamook Bay; may locally include poorly sorted alluvial fan deposits along valley margins

Qls **Landslide deposits (Holocene and Pleistocene)**--Poorly sorted angular to subrounded bedrock clasts in weathered muddy matrix, forming hummocky topography with closed depressions and poor drainage; also includes coherent bedrock glide blocks and colluvial aprons of angular cobbles and boulders at the base of steep slopes

Qt **Older fluvial and estuarine deposits (Pleistocene)**--Alluvial clay, silt, sand and gravel forming elevated terraces above present flood plains; includes some bay mud and sand along Tillamook and Nehalem Bay

QTg **Basalt boulder and gravel deposits (Pleistocene or Pliocene)**--Grande Ronde Basalt clasts in old channel fills on the slopes of Cape Lookout

VOLCANIC AND SEDIMENTARY ROCKS

Twfs **Wanapum Basalt - Frenchman Springs Member (middle Miocene)--** Dark gray to light gray, plagioclase-phyric tholeiitic basalt, as columnar jointed flows, pillow basalt, and breccia; restricted in outcrop to small, isolated patches near Cape Meares and Cape Lookout in the Tillamook embayment; chemically similar to Ginkgo or Sentinel Gap flows of Beeson and others (1985) in Willamette Valley and Columbia Plateau

Tcm **Sandstone at Cape Meares (middle Miocene)--**Light gray to yellow-orange, friable,well-sorted, micaceous lithic arkose; commonly with hummocky cross-stratification and convolute lamellae; crops out in isolated patches above Grande Ronde Basalt and is locally overlain by Frenchman Springs Member of the Wanapum Basalt; correlative with Sandstone of Whale Cove in the Newport embayment (Snavely and others, 1976 a,b,c) and unnamed sandstone in the Astoria basin (Niem and Niem,1985)

Tgr **Grande Ronde Basalt (middle Miocene)**--Dark gray to light gray, aphyric, tholeiitic basalt, as columnar jointed subaerial flows, submarine pillow basalt, and isolated pillow breccia; includes interbedded palagonitic hyaloclastite breccias, commonly cemented by clays, zeolite, or calcite; locally includes interbeds of basalt conglomerate and micaceous, carbonaceous mudstone and sandstone. Flows include low MgO and high MgO chemical types and belong to the N_2 and upper R_2 magnetozones of the Grande Ronde Basalt of the Columbia Plateau and lower Columbia River (Swanson and others, 1979; Niem and Niem, 1985; Wells and others, 1989; Tolan and others, 1989). Unit correlates with Depoe Bay Basalt of Snavely and others (1973) in Newport embayment

Astoria Formation (middle and lower Miocene)

Tac **Cannon Beach member of Niem and Niem (1985) (middle and lower Miocene)**--Well bedded, laminated to massive micaceous siltstone and mudstone; rhythmically bedded, graded micaceous, carbonaceous fine feldspathic sandstone interbedded in lower part; commonly with low-angle cross lamination in coalescing channel deposits; up to 600 m thick in Tillamook quadrangle; contains bathyal foraminiferal assemblage referable to Saucesian stage of Kleinpell (1938) (W. W. Rau, written communication, 1968); conformably overlies Angora Peak member of Niem and Niem (1985)

Tacs **sandstone unit** --Thin to medium bedded, plane laminated, fine grained, graded, micaceous, lithic arkose; forms upper part of Cannon Beach member of Niem and Niem (1985) in Cape Meares area

Tan **Netarts Bay member (middle and lower Miocene)--**Light gray to tan, coarse to fine grained, friable, massive to graded micaceous, carbonaceous, lithic arkosic sandstone forming coalescing low-angle channel complexes; commonly with siltstone rip-ups and pebbly interbeds; locally contains clastic dikes and submarine channel wall slump blocks greater than 10m across; interpreted as outer shelf and upper slope distributary channel complex; contains bathyal foraminiferal assemblage referable to Saucesian stage of Kleinpell (1938) (W. W. Rau, written communication, 1968)

Tam **mudstone unit--** pale gray to brownish-gray, carbonaceous, tuffaceous, finely micaceous mudstone at base of Netarts Bay member; commonly laminated and thin bedded; locally massive and pebbly; may represent facies transitional between nearshore delta and slope mudstones

Taa **Angora Peak member of Niem and Niem (1985) (middle and lower Miocene)**--Massive and thick bedded to laminated, fine to coarse grained, micaceous, feldspathic sandstone, lithic sandstone and pumiceous pebbly sandstone; commonly with tabular, trough, and hummocky cross stratification; locally channelled with molluscan shell hash and allochthonous coals in channel deposits. Unit is interpreted as deltaic and shallow marine sequence. Molluscs are referable to Pillarian and Newportian stages of Addicott (1976, 1981; see also Cooper, 1981). Unit is up to 200 m thick, conformably overlies the mudstone of Sutton Creek and disconformably overlies the Alsea Formation in the adjacent quadrangle to the south

Tms **Mudstone of Sutton Creek (lower Miocene)--**laminated to massive, micaceous, carbonaceous siltstone and tuffaceous mudstone; locally contains turbidite sandstone beds in upper part; Molluscs are referable to Pillarian and Newportian stages of Addicott (1976, 1981; see also Cooper, 1981); unit is about 300m thick

Tmst **tuff beds**--pale gray to white, laminated to massive, redeposited silicic tuff beds up to 10m thick in lower part of Sutton Creek mudstone

Tbc **Sandstone of Bewley Creek (lower Miocene and Oligocene?)--** Massive to thick bedded medium to coarse grained, micaceous, crossbedded, coarse feldspathic or lithic sandstone and pumiceous pebbly sandstone, well-developed large-scale foreset bedding in places; locally channelled. Unit interpreted as deltaic and shallow marine facies; similar to Yaquina Formation of Newport embayment (Snavely and others, 1976a,b,c), although petrography indicates a more potassium feldspar-rich source for the sandstone of Bewley Creek, similar to the Angora Peak member of the Astoria Formation (Parker, 1990). Molluscs are referable to Juanian and Pillarian stages (E. J. Moore in Parker, 1990; Addicott, 1976, 1981); foraminifera are referrable to the Saucesian stage of Kleinpell (1938) (W. W. Rau, written communication, 1989). Unit may be correlative with upper Saucesian part of the Yaquina Formation in Newport embayment to the south, or it may represent a pre-Angora Peak unit of the Astoria Formation not recognized in the Astoria basin to the north (Parker, 1990)

Tbcm **mudstone unit**--thin bedded to massive micaceous mudstone interbeds in the sandstone of Bewley Creek

Tal **Alesa Formation (lower Miocene and Oligocene)**--Tuffaceous siltstone, thick bedded to massive and bioturbated, containing abundant white tuff beds, calcareous concretions, and sparse thin feldspathic sandstone beds. Bedding is best developed in lower part of unit, upper part of unit is more massive; sparse phosphatic nodules occur near base of unit. Unit is about 600 m thick and rests unconformably on the Nestucca Formation. Benthic foraminifera are referred to the lower Saucesian, Zemorrian, and Refugian stages of Kleinpell (1938) and Schenck and Kleinpell (1936) (W. W. Rau, written communication, 1968, 1988). Unit is correlated with type Alsea Formation in the Newport basin 50 km to the south (Snavely and others, 1976a b c) and is correlative in part with Smugglers Cove formation of Niem and Niem (1985) in adjacent quadrangle to the north

Tals **Feldspathic sandstone**--friable, thick bedded, medium- to coarse-grained, feldspathic sandstone; beds up to 4 m thick are commonly channelized with pebbly lag deposits, unit is locally cross laminated and graded, with siltstone ripups and load features; tuff interbeds up to 2 m thick are common. Sandstone unit occurs in lower half of Alsea Formation and is up to 300 m thick; benthic foraminifera referable to the lower (?) Zemorrian stage of Kleinpell (1938) occur in siltstone interbeds within the sandstones (W. W. Rau, written communication, 1968)

Tsg **Sandtone of Garibaldi (lower Miocene or Oligocene?)**--Massive to well bedded medium- to coarse-grained carbonaceous, feldspathic litharenite; unit is rhythmically layered and graded, locally channelized with polymict conglomerate and coarse sand commonly containing pumice lumps; interbedded with tuffaceous siltstone and laminated fine micaceous arkose; top of unit becomes finer grained and more tuffaceous. Correlation of unit is uncertain; it overlies the Nestucca Formation of late Eocene age and is intruded by middle Miocene Grande Ronde Basalt, which has baked and altered the unit. It is lithologically similar to the deltaic Oligocene and lower Miocene sandstones of Bewley Creek and of the Angora peak member west of Tillamook, but facies in the sandstone of Garibaldi suggest deposition in deeper water

Tpg **Pittsburgh Bluff Formation (upper Eocene)--**Massive to thick bedded gray to tan weathering feldspathic litharenite; contains foraminifera referrable to the Refugian stage of Schenck and Kleinpell (1936) in adjacent map area (Niem and Niem, 1985)

Tk **Keasey Formation (upper Eocene)--**Laminated to bioturbated and massive, pale gray tuffaceous, fossiliferous mudstone; contains foraminifera referrable to the Refugian stage of Schenck and Kleinpell (1936) (W.W. Rau, written communication, 1988) and a Molluscan assemblage referrable to the type Keasey Formation (Warren and others, 1945)

Tn **Nestucca Formation (upper Eocene)**--Thin bedded, laminated dark gray tuffaceous mudstone with fine- to coarse-grained, graded arkosic and basaltic sandstone interbeds, locally glauconitic and fossiliferous, thin tuff beds and calcareous concretions are common. Locally contains arkosic sandstone dikes and exhibits soft sediment deformation. Unit is bleached and hydrothermally altered over large areas adjacent to Miocene and Eocene(?) basalt intrusions. Foraminifera (except in areas of alteration) are referred to upper Narizian stage of Mallory (1959) by W. W. Rau (written communication, 1982). Unit is correlative in part with adjacent Hamlet formation of Niem and Niem (1985), although coccoliths referable to nannofossil zones CP14a and CP14b suggest an older age for at least part of the Hamlet formation (David Bukry in Niem and Niem, 1985). Unit is lithologically similar to Nestucca Formation in the type area (Snavely and Vokes, 1949) but no coccoliths referable to the CP15 nannofossil zone have been recognized, as in the type area (Snavely and others, 1990)

Tnbs **basaltic sandstone--**basaltic sandstone and conglomerate beds in the upper part of the Nestucca Formation associated with basalt at Cascade Head in southwest part of map area

Tchb **Basalt of Cascade Head (upper Eocene)--**aphyric and plagioclase-augite porphyritic basalt flows and flow breccia. Restricted to small exposure in southwest part of map area; major exposures are to south at Cascade Head

Tc **Cowlitz Formation (upper Eocene)--**Light gray to tan, friable, plane laminated, hummocky cross stratified, micaceous, carbonaceous, fine to medium grained arkose and lithic arkose, locally concretionary; also laminated thin bedded mudstone becoming more massive and locally tuffaceous upsection; contains foraminifera referrable to the uppermost Narizian stage (W.W. Rau, written communication, 1988)

Tbs **Basaltic sandstone at Roy Creek (upper and upper middle Eocene)**--Basalt boulder conglomerate of variable thickness, locally exceeding 50 m, overlain by coarse to fine, massive to well bedded basaltic sandstone and siltstone, total thickness locally exceeds 300 m. Conglomerate is very well rounded, clast supported, and contains basalt, basaltic andesite, and locally abundant dacite and rhyolite boulders. Unit is derived from and largely overlies subaeral basalt flows of the Tillamook Volcanics, although interfingering with Tillamook subaerial and submarine flows is common. Sandstone is fossiliferous, with large oyster shells and other molluscs which, in partly correlative Roy Creek member of the Hamlet formation to the north, are characteric of the type upper Eocene Cowlitz Formation of southwest Washington (Warren and others 1945; E. Moore, in Niem and Niem, 1985). Lower part interfingers with basalt flows of Tillamook Volcanics ranging in age from 41 to 46 Ma

Tillamook Volcanics (upper middle Eocene)--Subaerial and submarine high titanium tholeiitic to alkalic basalt flows, commonly plagioclase-augite-and olivine phyric; also basaltic andesite and lesser dacite and rhyolite flows. Volcanics subdivided into:

Tbpu **Upper plagioclase-porphyritic basalt--**Abundantly plagioclase-phyric subaerial flows with lesser aphyric and augite-phyric flows, forms upper part of upper shield-building sequence

Tbu **Upper porphyritic basalt flows--**Abundantly augite ± plagioclase ± olivine-phyric flows, with lesser aphyric flows; comprises a major part of subaerial flows. Flows are commonly 3-10 m thick and have platy to crudely columnar jointed flow interiors and oxidized, weathered flow tops. Basalt flows form base of upper shield-building sequence

Tbru **Upper submarine basalt lapilli tuff and breccia --**Thick bedded to massive, locally graded plagonitic tuff, crystal lithic tuff, and basalt lapilli tuff, commonly cemented by zeolite or calcite, with interbedded pillow basalt, pillow breccia, basaltic sandstone, mudstone, and polymict mudflow breccia.

Tbpl **Lower plagioclase-porphyritic basalt--**Abundantly plagioclase-phyric subaerial flows with lesser aphyric and augite-phyric flows; commonly near the top of the lower shield building sequence

Tba **Aphyric basalt--**Mostly thin, platy to columnar jointed aphyric subaerial flows with fewer porphyritic flows in the upper part of the lower shield building sequence

Tsf **Subaerial dacite, rhyodacite, and rhyolite--**Commonly plagioclase ± hornblende ± biotite-phyric flows with $Si0_2$ ranging from 63-72%. Forms massive to flow banded, stony flows up to 100m thick, with well developed basal flow breccias, eroded tops and locally interbedded epiclastic and pyroclastic debris. Coalescing siliceous flows along the Nehalem River are up to 600 m thick and may represent late stage differentiates at the top of the underlying shield-building flow sequence. Augite-phyric basalt flows overlying the silicic flows to the east and north probably represent distal flows from a younger shield volcano to the northeast. A whole rock K-Ar age of about 41 Ma was obtained from flow banded rhyolite at the top of the Tillamook Volcanics in the Tillamook quadrangle, (L.B.Pickthorn, written communication, 1983)

Tts **Epiclastic silicic tuff and tuff breccia--**Includes white to buff, thin bedded, laminated marine(?) tuff beds, coarse sandy fluvial tuffs, and poorly sorted polymict tuff breccias that may represent mudflows from silicic flow edifices; locally may include block and ash avalanche deposits from growing silicic domes and thick flow breccias beneath flow complexes

Tbl **Lower porphyritic basalt flows--**Abundantly augite ± plagioclase ± olivine-phyric flows, with lesser aphyric flows; comprises major part of subaerial flow sequence. Flows are commonly 3-10 m thick and have platy to crudely columnar jointed flow interiors and oxidized, weathered flow tops. These flows form the base of lowermost shield volcano complex that extends from the coast eastward nearly to the town of Timber (40 km), and which rest on submarine flows, breccias, and deep marine mudstone. Total thickness of subaerial flows exceeds 10 km in Enright quadrangle where adjacent shields are overlapping. Sedimentary interbeds are rare except along margins of shield volcanoes. Subaerial flows are overlain and locally interfinger with conglomerate and basaltic sandstone of Roy Creek and thin bedded tuffaceous siltstone of the Nestucca Formation, which contain foraminifera referable to the upper part of the Narizian stage of Mallory (1959) and coccolith flora referable to CP zones CP14a and b (David Bukry in Niem and Niem, 1985). Marine siltstone at the base of the subaerial flows in adjacent quadrangles to the east contain foraminifera referable to both lower and upper Narizian stages (W. W. Rau written communication, 1983); and coccolith flora referable to CP zone 14a (David Bukry written communication, 1988). Reliable K-Ar radiometric ages on subaerial flows and feeder dikes in the Enright 15' quadrangle range from 46.0±0.9 m.y. to 43.2±0.6 Ma, averaging 44.3±1.3 Ma. (Magill and others, 1981)

Tpb **Submarine basalt--**High titanium tholeiitic to alkalic pillow basalt and pillow breccias, commonly augite ± plagioclase ± olivine-phyric. Pillow basalt lies stratigraphically beneath subaerial flows of the Tillamook volcanics and is interbedded with basalt lapilli breccia, sandstone, and mudstone containing foraminifera referable to the Narizian stage of Mallory (1959), (W. W. Rau, written communication, 1988); and coccolith flora referable to the CP14a subzone (upper middle Eocene; David Bukry, written communication, 1988)

Tbr **Submarine basalt tuff and breccia--**Thick bedded to massive, locally graded palagonitic tuff, crystal lithic tuff, and basalt lapilli tuff, commonly cemented by zeolite or calcite, with interbedded pillow basalt, pillow breccia, basaltic sandstone, mudstone, and polymict mudflow breccia. Crystal-rich tuffs contain abundant euhedral augite and/or plagioclase up to 3 cm long. Breccia unit forms submarine foundation for Tillamook volcanics; they are overlain by pillowed and subaerial flow units and cut by numerous feeder dikes for the breccias and flows. Unit is locally interfingered with flows and basaltic sandstone along the margins of the subaerial flow sequence. Thickness of breccia is variable, up to 1700 m. Interbedded marine siltstone in adjacent quadrangles contain foraminifera referable to both lower and upper parts of the Narizian stage of Mallory (1959) (W. W. Rau, written communication, 1987) and coccolith flora referable to CP zone 14a (David Bukry, written communication, 1988)

Ty **Yamhill Formation (upper middle Eocene)**--Massive to thin bedded, laminated, dark gray siltstone commonly containing thin tuff beds, thin arkosic sandstone beds, calcareous concretions, fish scales and carbonaceous plant fragments; locally contains interbeds of paper-thin laminated, black, kerogen-rich "oil shale" near the top of the section where it is interbedded with submarine basalt lapilli breccias of the Tillamook Volcanics (Snavely and others, 1993b). Microfauna and flora are rare, possibly because of carbonate leaching during intrusion of abundant diabase sills; foraminifera are assignable to the lower Narizian or upper Ulatisian stage (W. W. Rau, written communication, 1970), and calcareous nannoplankton to CP zones 13c and 14a (David Bukry, 1988); unit may locally include thin bedded siltstone of Tyee age (CP zone 12b) as screens between abundant sills in southeast part of map area

Tybs **basaltic mudstone--**thin bedded, laminated, graded mudstone, siltstone and lesser sandstone; unit interfingers with submarine basaltic tuff and breccia of the basal Tillamook Volcanics

Tys **Sandstone--**Indurated, light gray micaceous, tuffaceous, lithic arkose beneath Tillamook Volcanics; locally exposed along Gales Creek fault zone

Tyt **Lower tuff unit**--Very tuffaceous, thick to thin bedded mudstone near base of Yamhill Formation containing numerous silicic tuff beds up to 10m thick

Tet **Tyee Formation (lower middle Eocene)**--Thin bedded, graded siltstone and lithic arkosic sandstone turbidite sequence; turbidites contain abundant muscovite; unit generally overlies pillow basalt of Hembre Ridge, but locally appears to be interbedded with uppermost pillows; stratigraphic relationships are difficult to determine because upper and lower contacts with adjacent units are intruded by diabase sills. Contains foraminifera referrable to the Ulatisian stage (W.W. Rau, written communication, 1968) and nannoplankton referrable to CP zone 12a or b (David Bukry, written communication, 1988); correlative with Tyee Formation of the central Oregon Coast Range (Snavely and others, 1976)

Thpb **Basalt of Hembre Ridge (lower middle and lower Eocene)**--Submarine low potassium tholeiitic pillow basalt, sheet flows and filled lava tubes, commonly aphyric to slightly plagioclase-phyric, amygdaloidal, with smectite clays and zeolite vesicle fillings; includes submarine basalt lapilli breccia, pillow breccia, and basaltic sandstone and mudflow breccia. Siltstone interbeds in upper part of pillow sequence contain foraminifera referrable to the Ulatisian stage (W.W. Rau, written commmunication, 1968) and nannoplankton referrable to CP zone 12a or b; unit overlies and is locally interbedded with sandstone of Trask River which contains nannoplankton referrable to CP zone 11 (David Bukry, written communication, 1988)

Ths **basaltic sandstone**--thin bedded, laminated, graded fine sandstone, siltstone and mudstone; unit interfingers with submarine pillow basalt, tuff, and breccia; contains coccolith flora referrable to CP zone 11 or 12a (David Bukry, written communication, 1988)

Trsk **Sandstone of Trask River (lower Eocene)**--Thin bedded, plane laminated, fine grained, dark gray indurated turbidite sandstone and siltstone; locally concretionary and cut by carbonate veins and fracture fillings; exhibits large scale soft sediment folding as well as post-lithification deformation; thickness is variable, up to 800m; apparently it is deposited on a surface of high relief on the Siletz River Volcanics; unit contains nannoplankton referrable to CP zone 11; correlative with Umpqua Formation in the southern Coast Range and Kings Valley Siltstone Member of the Siletz River Volcanics (Bukry and Snavely, 1988; Vokes and others, 1954)

Siletz River Volcanics (lower Eocene)--

Tsbr **Basalt lapilli breccia unit**--Submarine and subaerial basalt lapilli breccia, pillow breccia, mudflow breccia, and basaltic sandstone and conglomerate; beds are massive to thick bedded; clasts commonly are plagioclase and pyroxene-phyric with greenish-brown smectitic clay alteration and zeolite and calcite veins and amygdules; locally oxidized red, with subaerial bombs and cinders; unit locally interfingers with overlying Sandstone of Trask River which contains nannoplankton referrable to CP zone 11 (David Bukry, written communication, 1988)

Tsb **Subaerial basalt flows**--Columnar jointed basalt with red oxidized weathered flow tops; overlain by submarine basalt lapilli tuff and intruded by diabase sills; poorly exposed in the Fairdale quadrangle; correlated with Siletz River Volcanics based on its position beneath regional diabase sill complex

Tspb **Pillow basalt**--Submarine pillow basalt flows, filled lava tubes, and interbedded flow breccias; augite and plagioclase-phyric in upper part, commonly amygdaloidal,with zeolite and smectite vesicle fillings and slickensided shear surfaces containing clay, calcite, zeolite, quartz, and pyrite; sedimentary interbeds contain foraminifera referrable to lower Ulatisian or Penutian stages (W. W. Rau, written communication, 1970) and nannoplankton referrable to CP zones 11 and 9b (David Bukry, written communication, 1988) Potassium-Argon ages of 57.1±1.5 Ma and 54.8±1.0 Ma were determined from pillow basalt in the Trask River and an age of 52.9±1.0 Ma was determined from pillow basalt in the Nestucca River (Duncan, 1982).

INTRUSIVE ROCKS

Tifs **Wanapum Basalt Frenchman Springs Member (middle Miocene)**--Irregular dike-like bodies of plagioclase-phyric basalt in the Tillamook Bay fault zone; chemically similar to the Frenchman Springs Member of the Wanapum Basalt of the Columbia Plateau (Swanson and others, 1979); here interpreted as invasive, plateau-derived flows which have intruded soft marine sediments (see Beeson and others, 1979; Niem and Niem, 1985; and Wells and others, 1989)

Tigr **Grande Ronde Basalt (middle Miocene)**--Sheet-like and irregular bodies of aphyric, columnar jointed tholeiitic basalt and diabase intruded into and overlain by baked sedimentary strata; physically and chemically identical to low MgO chemical types of the N_2 magnetozone of the Grande Ronde Basalt of the Columbia Plateau and correlative with Depoe Bay Basalt of Snavely and others (1973). Here interpreted as invasive, plateau-derived flows which have intruded soft marine sediments (see Beeson and others, 1979; Niem and Niem, 1985; and Wells and others, 1989)

Teib **Basalt sills (late Eocene)**--Aphyric and plagioclase-phyric crudely columnar jointed gray-green basalt and diabase, commonly amygdaloidal with smectite clay alteration and vesicle fillings. Unit intrudes basaltic sandstone and late Eocene mudstone of the Nestucca Formation above the Tillamook Volcanics. Unit is laterally equivalent to Cole Mountain Basalt of Niem and Niem (1985) in adjacent quadrangles to the north, where it is interpreted to be of late Eocene age

Tiab **Porphyritic basalt (late middle Eocene)**--Augite-olivine-plagioclase porphyritic basalt sills; probably related to Tillamook Volcanics; a whole rock K-Ar age of 39.4±1.2 Ma was determined from a sill south of the Nestucca River (L. B. Pickthorn, written communication, 1987)

Tis **Silicic dikes (late middle Eocene)**--Commonly plagioclase ± hornblende ± biotite-phyric dacite and rhyolite ranging in silica content from 63 to 73%. Dikes are vertical, north-northwest to west-northwest trending, up to 25 m thick and 1 km long. Silicic dikes are compositionally similar to dacite and rhyolite flows of the Tillamook Volcanics and cut subaerial Tillamook flows and all older units

Tib **Basalt dikes and sills (late middle Eocene)**--Aphyric to abundantly plagioclase, augite, and olivine-phyric basalt dikes and sills, mostly as north-northwest to west-northwest-trending swarms cutting subaerial Tillamook flows and all older units. Dikes are compositionally and petrographically similar to Tillamook flows and represent feeder vents for the Tillamook Volcanics. Dikes are up to 10 m wide and 5 km long; some composite dikes have multiple episodes of intrusion ranging in composition from basalt to dacite. A reliable K-Ar age of 43 Ma from a dike in the adjacent Blaine 15' quadrangle is similar in age to the flows (average age 44 Ma, Magill and others, 1981)

Tid **Biotite pyroxene diorite (late middle Eocene)**--Hypabyssal sill or stock of uralatized pyroxene plagioclase diorite with a few percent biotite; intrudes silicic flows of Tillamook Volcanics and in turn is intruded by many basalt and dacite dikes presumably feeding other Tillamook flows; Zircon separated from the diorite gives a fission track age of 42.6±3.6 Ma (J. A. Vance, written communication, 1987)

Tidb **Diabase (middle Eocene)**--Aphyric to plagioclase-phyric, amygdaloidal diabase with smectite clays and zeolite vesicle fillings; locally pillowform with radial columnar joints, more commonly tabular bodies with well developed columnar joints and a layered appearance; sills are cut by the regional dike swarm that fed Tillamook Volcanics but intrude strata as young as Yamhill Formation, suggesting a minimum age of about 43 Ma; unit may include some basalt and diabase correlative with the Tillamook Volcanics

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Table 1. Semiquantitative emission spectroscope analyses of quartz-sulfide veins in Tillamook volcanics

Lab No.		M180353	M-180354	M-180355	M180356
Field No.		W87-51	W87-52	W87-53	W87-54
FE	%-S	10.	7.	7.	7.
MG	%-S	0.15	0.1	0.2	0.2
CA	%-S	>.1.5	>1.5	>1.5	1.5
TI	%-S	0.015	0.07	0.02	>0.15
MN	PPM-S	2000.	5000.	3000.	1000.
AG	PPM-S	200.	2.	100.	150.
AS	PPM-S	1500.	1500.	15000.	15000.
AU	PPM-S	15.	<7.	15.	15.
B	PPM-S	<2.	<2.	<2.	<2.
BA	PPM-S	15.	70.	50.	100.
BE	PPM-S	<0.7	<0.7	<0.7	<0.7
BI	PPM-S	<7.	7.	<7.	<7.
CD	PPM-S	700.	100.	>700.	700.
CO	PPM-S	10.	15.	20.	10.
CR	PPM-S	<0.7	5.	<0.7	5.
CU	PPM-S	1500.	200.	700.	1500.
LA	PPM-S	<7.	<7.	<7.	<7.
MO	PPM-S	<2.	<2.	<2.	<2.
NB	PPM-S	<10.	<10.	<10.	<10.
NI	PPM-S	15.	15.	3.	10.
PB	PPM-S	300.	100.	300.	700.
PD	PPM-S	<1.	<1.	<1.	<1.
PT	PPM-S	<5.	<5.	<5.	<5.
SB	PPM-S	<20.	<20.	<20.	<20.
SC	PPM-S	<1.	<1.	<1.	<1.
SN	PPM-S	<2.	<2.	<2.	<2.
SR	PPM-S	30.	100.	50.	20.
TE	PPM-S	<300.	<300.	<300.	<300.
U	PPM-S	-	-	-	-
V	PPM-S	7.	15.	5.	20.
W	PPM-S	<50.	<50.	<50.	<50.
Y	PPM-S	<7.	10.	<7.	<7.
ZN	PPM-S	>5000.	2000.	>50000.	>50000.
ZR	PPM-S	30.	150.	20.	150.
SI	%-S	7.	15.	5.	10.

All samples from fault breccia in dacite; Sec 2; T2N, R8W.

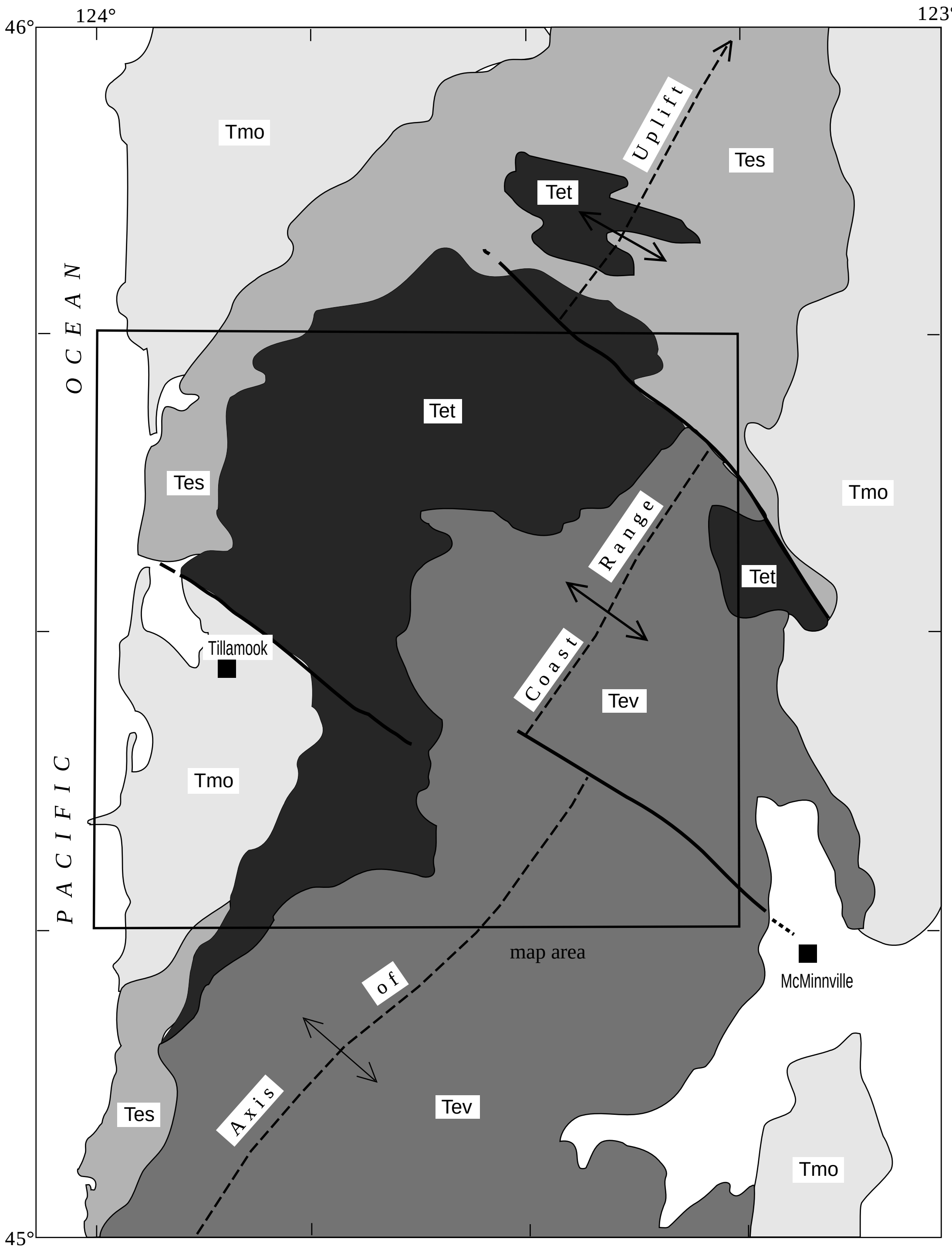

Figure 1 Geologic setting of Tillamook Highlands map area in northern Oregon Coast Range. Tmo represents Miocene and Oligocene sedimentary and volcanic rocks; Tes Eocene sedimentary rocks; Tet Eocene Tillamook Volcanics; and Tev middle and early Eocene volcanic and sedimentary rocks.