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Coccolith-bearing Late Middle Eocene Kerogen Shale, Tillamook Highlands, Northwest Oregon Coast Range

By

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INTRODUCTION

During reconnaissance geologic mapping in the Tillamook Highlands in the northern Oregon Coast Range (fig. 1), several thin interbeds of kerogen (oil) shale were recognized in a predominantly late middle Eocene volcanic sequence (Snavely and others, 1970). These "oil shales" occur in basaltic lapilli tuff, siltstone, and sandstone of the Yamhill Formation and lower Tillamook Volcanics in the drainages of the Wilson and Trask Rivers. The best exposures are north of the Wilson River along the southwest flank of a broad, northwest-trending faulted anticline (fig. 2). The pale yellowish-brown-weathering, laminated kerogen shale stands out in bold contrast to the iron-stained, reddish-brown lapilli-tuff in which they are interbedded. The purpose of this paper is to describe the stratigraphic setting, lithology, coccolith flora, and depositional environment of the oil shale. Although the Yamhill Formation that contains the oil shale is regionally extensive, the distribution of the oil shale lithology is only known in a few places outside of the Tillamook Highlands. It crops out in the southern part of the Washington Coast Range along the Grays River (Wolfe and McKee, 1968) and north of Grays Harbor along the headwaters of the Humptulips River (Rau, 1986) (fig. 3). These upper middle Eocene marine mudstones are potential source rocks for petroleum.

DISTRIBUTION AND STRATIGRAPHY

The main outcrop of kerogen shale occurs on the north side of the Wilson River in a 150- to 250-m sequence of feldspathic basaltic sandstone, siltstone, and lapilli tuff in the upper part of the Yamhill Formation. Here, the thin-bedded marine siltstones interfinger with basalt lapilli breccia and pillow basalt of the overlying Tillamook Volcanics (fig. 2). The oil-shale-bearing sequence is cut by a set of northwest- and northeast-trending faults, which make it difficult to trace the lateral extent of the units but it appears to thin to the east. Toward the south, similar petroliferous laminated mudstone in the upper part of the Yamhill Formation is found in the South Fork of the Trask River in T2S R9W. Another oil shale horizon occurs locally interbedded in pillow basalt, lapilli tuff, and minor basaltic sedimentary rocks of the lower part of the Tillamook Volcanics. Here, the oil shale fills depressions in the upper surface of pillow basalt flows. It is overlain by zeolitized pillow breccia, lapilli tuff, and basaltic siltstone, which in turn are overlain by subaerial basalt flows of the Tillamook Volcanics (fig. 4). There is an overall pattern of upward shoaling from the hemipelagic oil-shale-bearing strata to subaerial flows.

The oil-shale-bearing sequence consists of 5 to 20 meters of thin-bedded siltstone and feldspathic, basaltic sandstone with one or more beds 1 to 10 cm thick of carbonaceous, limy petroliferous paper-thin fissile claystone (fig. 4). The shales are dark-gray on fresh exposures and have physical properties typical of organic-rich black shales (Pettijohn, 1949). They weather light-brownish-gray and are laminated with coaly plant material (traces of pollen and spores), tuff fragments, fish scales and vertebrae, amorphous kerogen, and finely disseminated pyrite framboids (fig. 5). The fine-grained sandstone and siltstone beds that occur with the kerogen shales are up to 6 cm thick and graded. Micro-scour-and-fill channels and ripple marks occur near the top of some graded beds. Sole markings indicate northward current directions during deposition of part of the sequence.

Light-gray plates of carbonate, which are interpreted to be small flattened pelecypods (W. Sliter, oral commun., 1990), are aligned along laminae (fig. 4). Wignall (1989) has described infaunal bivalve shell pavements as a possible effect of hydrogen sulphide poisoning, marking bedding planes in the Kimmeridge Clay organic-rich shales in England.

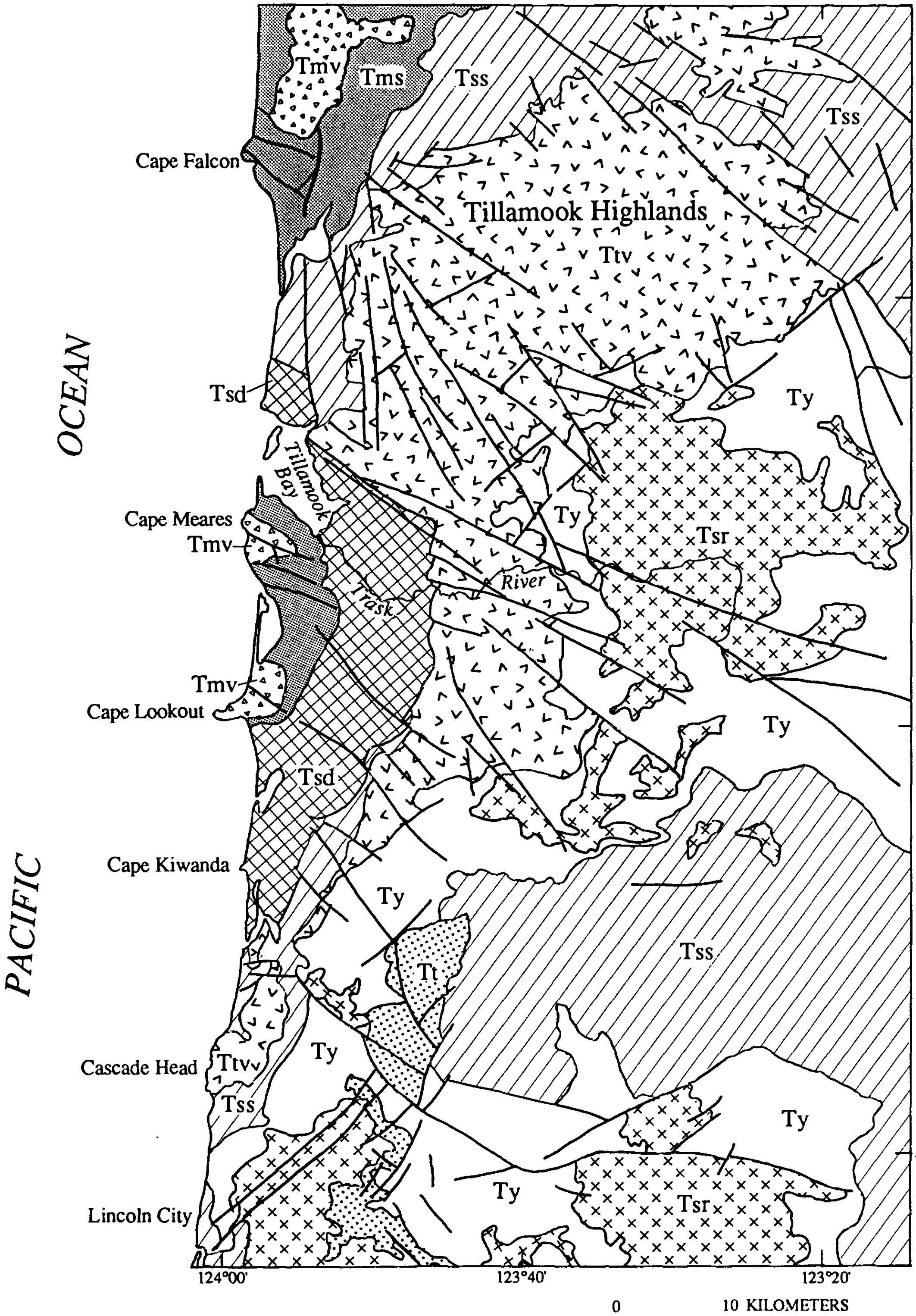

Figure 1.--Generalized geologic map of the central Oregon Coast Range (modified from Walker and MacLeod, 1991). Explanation of symbols: **Tmv** - basalt flows and breccia (middle Miocene); **Tms** - Marine sedimentary rocks (middle and lower Miocene); **Tsd** - Sedimentary rocks (Oligocene and upper Eocene); **Ttv** - Basalt flows and breccia, pillow lava and lapilli tuff (middle to upper Eocene); **Tss** - Undifferentiated sedimentary rocks (upper Eocene); **Ty** - Yamhill Formation (upper middle Eocene); **Tt** - Tyee Formation (lower middle Eocene) **Tsr** - Siletz River Volcanics (lower Eocene).

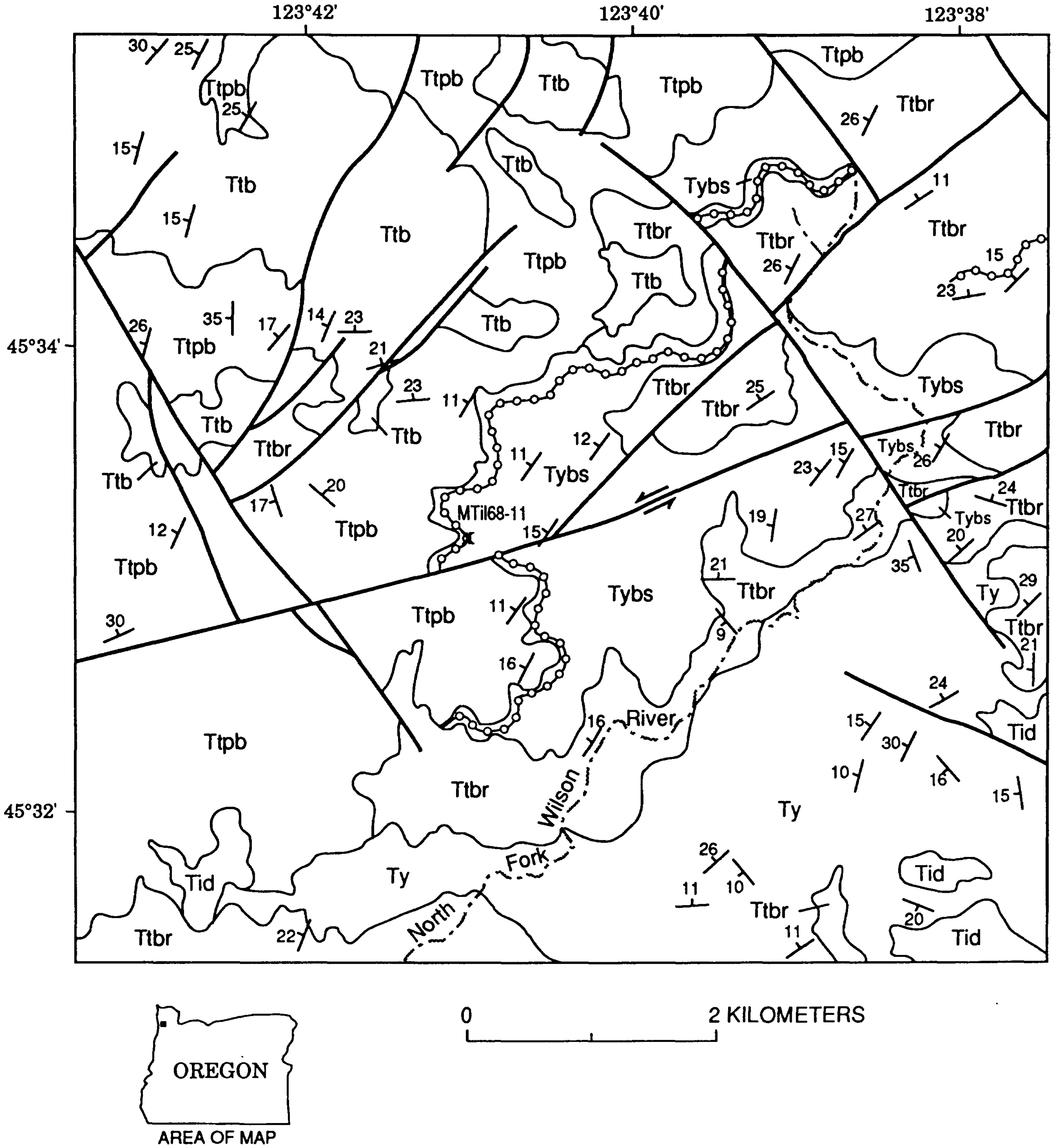

Figure 2.-- Generalized geologic map of upper Wilson River drainage basin, Tillamook Highlands, showing the location of oil shale unit (-o-o-o-) and sample MTil68-11. Explanation of symbols - Ty, middle Eocene Yamhill Formation; Tybs, Yamhill basaltic sandstone and siltstone (includes oil shale strata (-o-o-o-)); Tillamook Volcanics,- Ttbr, lapilli tuff; Ttpb, pillow basalt; Ttb, basalt flows; Tid, diabase sills

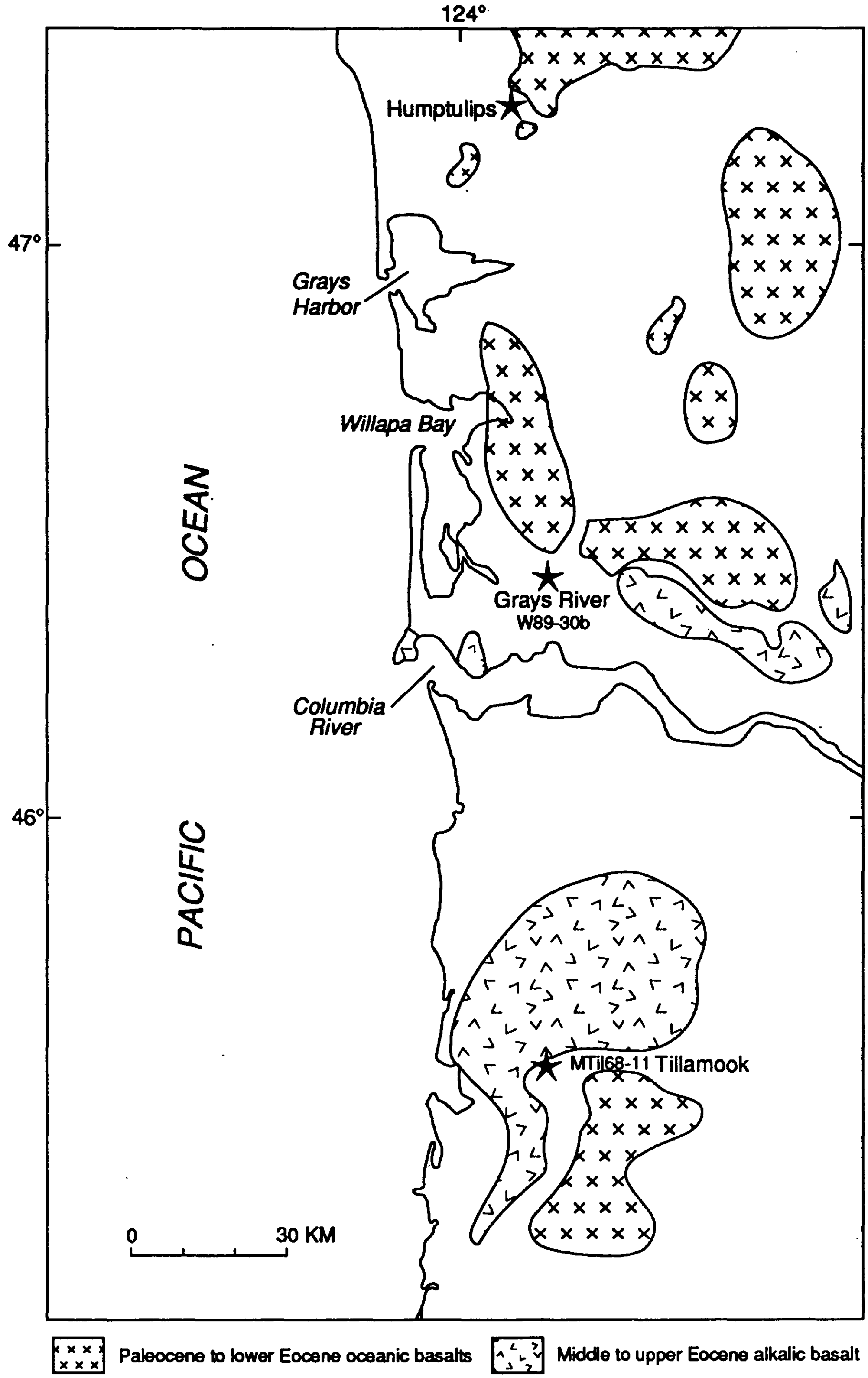

Figure 3.--Locations of *Braarudosphaera*-rich shale sites (★), relative to volcanic areas in coastal Oregon and Washington, and kerogen shale near Tillamook.

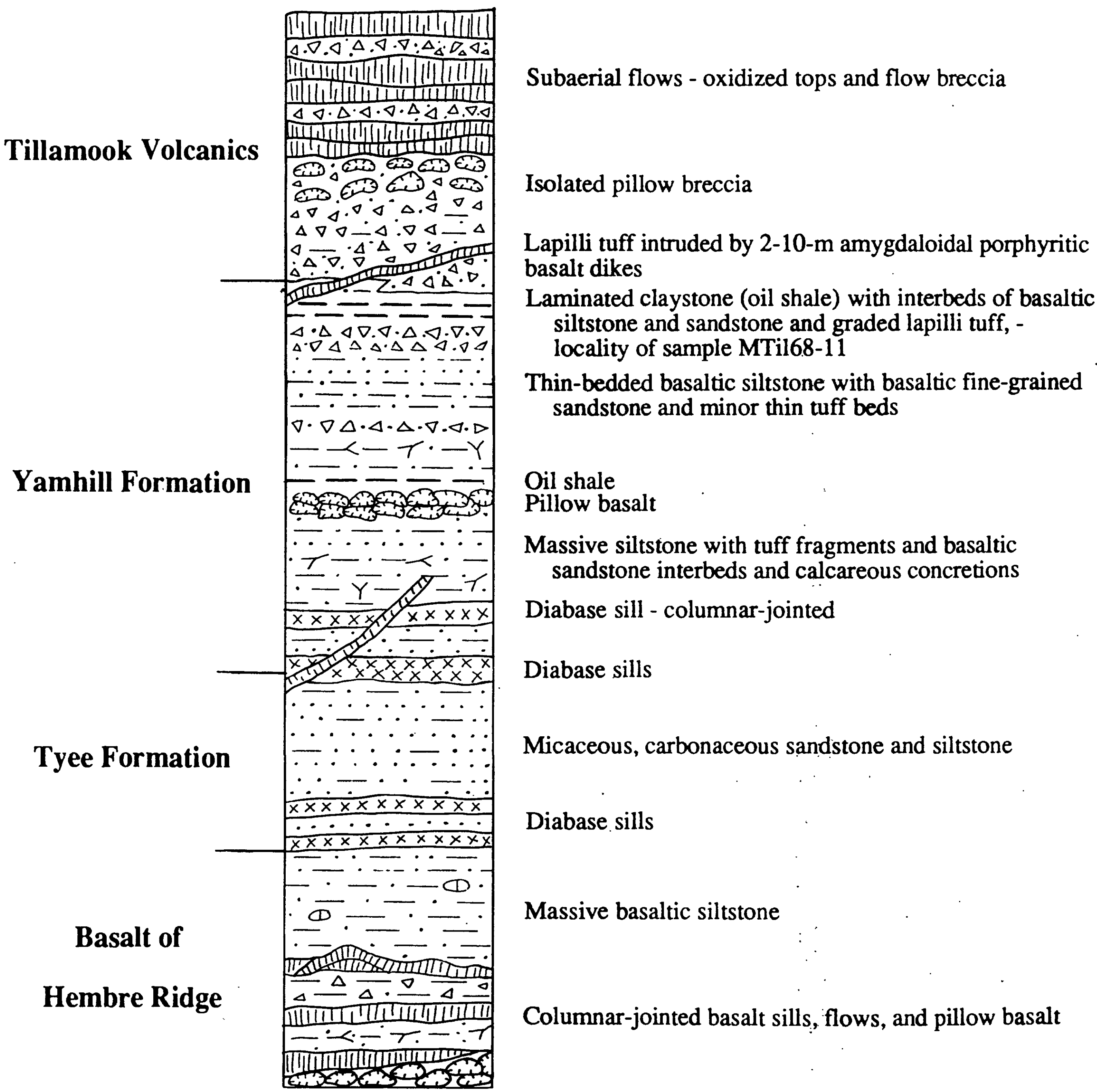

Figure 4.-- Generalized composite stratigraphic section of Tillamook Highlands area, south one-half Enright Quadrangle, Oregon

Figure 5.--Electron micrograph of oil shale collected at locality MTil68-11 (fig. 2). The round bright spots are framboids and a curved and hollow pelecypod is present near the center of the lower right-hand quadrant of the photo.

ORGANIC GEOCHEMISTRY

A single sample, MTil68-11-4 (fig. 2), was analyzed by Clark Geological Services; their determinations included thermal maturity and kerogen content by reflected and transmitted light and by Rock-Eval pyrolysis with determination of total organic carbon (TOC). As the lithologic characteristics of sample MTil68-11 appear to be typical of most of the oil shale in the Tillamook Highlands, we believe that the organic geochemical data (Table 1) also may be representative.

			Rock-Eval parameters							
Ro (pct)	TAI	T_{max}	HI	OI	TOC	S_1	S_2	S_3	S_1+S_2	PI
0.30	2.6[1](?)	427	466	12	2.14	0.45	9.97	0.26	10.42	0.04

Table 1. Vitrinite reflectance, thermal-alteration index, and Rock-Eval analysis of kerogen sample MTil68-11, located in the NW1/4NW1/4 sec. 15 T. 1 N. R. 8 W., Enright 15-minute quadrangle, Oregon. [R_o, vitrinite reflectance; TAI, thermal-alteration index; T_{max}, temperature of maximum yield of S_2; HI, hydrogen index (mg hydrocarbon/gram TOC); OI, oxygen (mg CO_2/gram TOC);TOC, total organic carbon/gram of rock; S_1, mg hydrocarbon/gram of rock; S_2, mg hydrocarbon/gram of rock; S_3, mg hydrocarbon/gram of rock; S_1+S_2, oil and gas potential; PI, productivity index $S_1/(S_1+S_2)$]

[1] Based upon one pollen grain that is probably recemented.

The sample contained abundant organic matter (2.14% TOC) which visual analysis showed to consist predominantly of aggregated amorphous kerogen. Based upon the visual analysis, this sample is interpreted to be oil prone. This interpretation is confirmed by the Rock-Eval pyrolysis results which suggest that the sample contains Type I-II oil prone kerogen (B. Lampley and J. L. Clark, written communication, 1986).

Vitrinite reflectance and T_{max} suggest that this sample, like most Tertiary samples analyzed in the Oregon Coast Range, is immature with respect to both oil and gas generation (Armentrout and Suek, 1985; Law and others, 1984; Snavely, unpublished data).

CORRELATION AND AGE

Regional geologic mapping in the Tillamook Highlands (Wells and others, 1983, 1993) and to the south in the Nestucca Bay 7 1/2-minute quadrangle (Snavely and others, 1990) and in the Hebo 7 1/2-minute quadrangle (Snavely and others, 1993) indicates that the submarine part of the Tillamook Volcanics intertongues southward with marine siltstone containing minor lapilli-tuff beds which are assigned to the Yamhill Formation of late middle Eocene age (Bukry and Snavely, 1988; Snavely and others, 1990, 1991). The Yamhill Formation in the Tillamook Highlands consists largely of thin-bedded, laminated, graded siltstone locally containing arkosic sandstone, tuff beds and minor oil shale. The Yamhill overlies a thick early middle Eocene pillow basalt sequence containing abundant interbeds of micaceous siltstone and fine arkosic sandstone in its upper part. To the south, in the Hebo quadrangle, the Yamhill contains tongues of pillow lava, tuff breccia, and mudflow deposits derived from volcanic centers in the Tillamook Highlands. Lapilli tuff beds in the Yamhill Formation extend as far south as latitude 45°15', and marine basaltic sandstone derived from the highlands extends as far south as latitude 45°N. In the Hebo quadrangle, the Yamhill Formation is underlain by turbidite sands of the Tyee Formation of early middle Eocene age and is unconformably overlain by upper Eocene siltstone of the Nestucca Formation. Along the west side of the Tillamook Highlands, the Tillamook Volcanics are unconformably overlain by basalt conglomerate and sandstone of late Eocene age (Wells and others, 1983, 1993).

COCCOLITH FLORA

The oil shale contains a coccolith flora assigned to *Discoaster bifax* Subzone CP14a (Bukry, 1973; Okada and Bukry, 1980) of late middle Eocene age. The Yamhill Formation that crops out along the Nestucca River to the south ranges in age from Subzone CP13b to CP14a of late middle Eocene age (Bukry and Snavely, 1988). This age assignment agrees well with K/Ar dates obtained from correlative basalts in the Tillamook Volcanics that range from about 44 to 40 Ma (Magill and others, 1981; Wells and others, 1993).

Coccoliths, the calcite skeletal elements of marine nannoplankton algae, are common to abundant in all eight shale beds at the MTil68-11 locality (fig. 6). The overlapping stratigraphic ranges of *Chiasmolithus solitus* with *Reticulofenestra umbilica* identify the transoceanic late middle Eocene *D. bifax* Subzone (CP14a) (Bukry, 1973; Bukry and Snavely, 1988). Although the diversity of 13 taxa is low (Table 2), the coccolith flora is distinctive because of the abundant occurrence of small *Braarudosphaera bigelowii*, especially the disaggregated trapezoidal crystallites from the diagnostic regular pentaliths that identify this species. *B. bigelowii* unicellar organisms produce regular dodecahedron complete skeletons which are typically preserved in sediments as the 12 individual pentaliths that compose the dodecahedron. Each of the pentaliths is composed of five identical trapezoidal crystallites. The Tillamook floras are distinctive because the

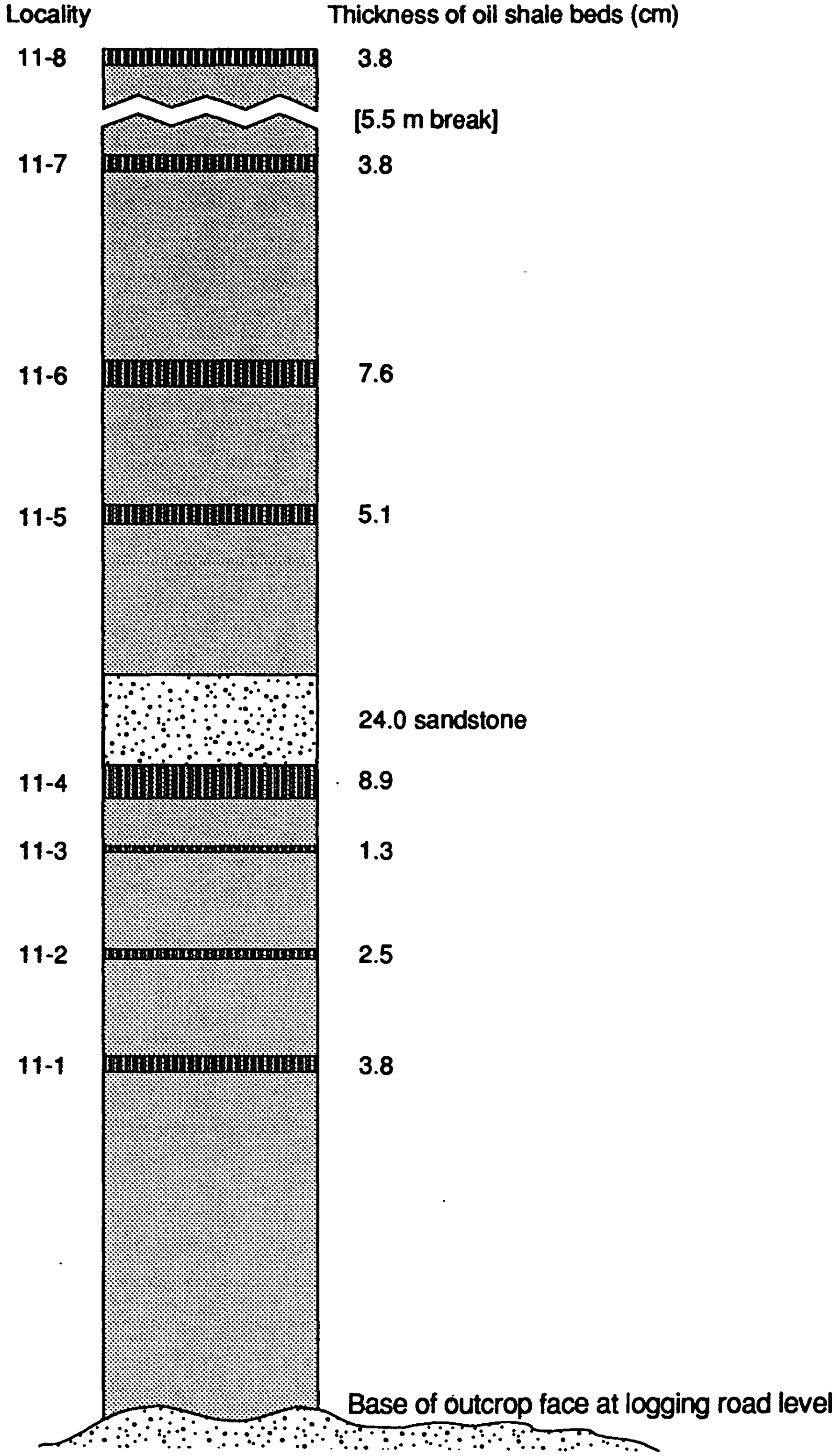

Figure 6.--Thickness (in centimeters) and position of kerogen shale beds in basalt sandstone, lapilli tuff, and siltstone of the Yamhill Formation at locality MTil68-11-1 to 11-8. A resistant sandstone bed occurs directly above 11-4. Beds 11-5 to 11-7 are moderately weathered; bed 11-8 is strongly weathered.

Taxa	Samples MTil68-11- 1	2	3	4	5	6	7	8
Braarudosphaera bigelowii	X	X	X	X	X	X	X	X
Chiasmolithus solitus	X	X	X	X	X			X
Coccolithus pelagicus	X			X	X	X		
Cyclicargolithus floridanus				X				X
C. pseudogammation	X	X	X	X				X
Discoaster bifax?							X	
Lanternithus minutus?	X		X					
Pemma stradneri	X		X	X	X		X	X
Pontosphaera distincta							X	
P. sp.	X	X			X	X	X	X
Reticulofenestra samodurovii			X		X	X	X	X
R. umbilica	X		X	X	X		X	X
Transversopontis sp.				X		X		

Table 2. -- Checklist of coccolith species in Tillamook kerogen shale samples.

majority of the *B. bigelowii* skeletons are disaggregated into their small trapezoidal crystallites, instead of the more usual pentalith preservation state.

Counts (n=300) of the various *B. bigelowii* skeletal preservation modes show constant distribution through the eight shale beds studied:

Sample	Skeletal mode (Trapezoid	—Subpentalith	—Pentalith	—Dodecahedron)
11-1	263	18	13	6
11-2	267	26	5	2
11-3	259	31	7	3
11-4	276	21	3	0
11-5	264	25	9	2
11-6	262	28	7	2
11-7	250	35	12	3
11-8	264	29	5	2
Average	263	27	8	2

Complete pentaliths and reconstituted equivalents (five trapezoidal crystallites) outnumber specimens of other coccolith taxa in the flora 3:1 to 12:1 in the eight shale beds.

A similar late middle to late Eocene (Zones CP14/CP15) kerogen shale flora with abundant *B. bigelowii* crystallites occurs in the Grays River Quadrangle of southwest Washington (fig. 3, Sample W89-30b; 46°24.25'N, 123°44.75'W). Less abundant *B. bigelowii* occurs farther north in organic siltstone (CP14/CP15) of the Humptulips Quadrangle in Washington. Again, all four *B. bigelowii* preservation modes occur with trapezoidal crystallites predominant. These occurrences suggest a northward extension of the *B. bigelowii* black organic shale lithofacies of 80 km to Grays River and 185 km to Humptulips. Coccolith floras of CP14 from nearby Yamhill localities south and west of the Tillamook Highlands (e.g., along the Nestucca River and Tony Creek) lack *B. bigelowii* (Snavely and others, 1993).

Subzone CP14a floras have been widely recognized on the Pacific Coast from San Diego to the Olympic Mountains and represent a period of important changes in global sea-level, volcanism, and plate motion (Bukry, 1991a). Short-term marine flooding of coastal volcanic terranes could have produced the special paleoceanographic and sedimentologic conditions for organic shales with abundant *B. bigelowii* (Bukry, 1974; Gallois, 1976). Blooms of *B. bigelowii* have been attributed to fresh-water influx or reduced salinity. Such conditions could result from coastal runoff, riverine additions, and increasing maritime precipitation. Major global episodes of potential freshening of surface waters, such as the K-T impact aftermath, major sea-level rise of the mid Oligocene, or Quaternary glacial-pluvial conditions are not needed to account for local hydrologic regimes such as the spring freshening of Gulf of Panama waters by rain and runoff that fosters annual blooms of *B. bigelowii* (Smayada, 1966). Since coccolith blooms have been associated with the generation of organic kerogen shales having oil-forming potential in the Jurassic of England (Gallois, 1976; Gallois and Medd, 1979; and Wignall, 1989) and the Oligocene of Germany (Müller and Blaschke, 1971), it is plausible that the Tillamook blooms of *B. bigelowii* represent locally enhanced freshening in a nearshore volcanic shelf basin which produced a similar coccolith and kerogen association. The large predominance of trapezoidal crystallities, instead of pentaliths, is unusual for open-ocean chalks (see Bukry, 1978; pl. 2) and suggests depositional, chemical, or thermal activity that degraded intercrystallite bonding. Physical concentration by strong current activity is unlikely in a reducing environment where whole coccospheres are associated with the crystallite majority. The Tillamook *Braarudosphaera*-rich kerogen shale has not been recognized to the south in southwestern Oregon or California (Barron and others, 1984; Bukry, 1991a, b). The lateral and vertical dimensions of this unusual lithofacies have yet to be determined in coastal northwest Oregon and Washington. But these initial results indicate a thin but widespread nearshore facies which has potential as a guide for reconstruction of stratigraphic and structural trends in this largely volcanic province because of its contrasting composition and weathering.

DEPOSITIONAL ENVIRONMENT

The preservation and concentration of the coccolith flora and the laminated or thin-bedded nature of the oil shales suggest deposition in a restricted marine shelf basin. Interbedding of the oil shale with submarine tuff breccia suggests that constructional volcanism in the basin may also have further controlled the basin geometry. The abundance of coccoliths suggests deposition in a low-energy, anoxic marine environment that lacked mixing at the sediment-water interface, and in the sediments themselves.

REGIONAL CORRELATIONS

Siltstone sequences that contain coccoliths assigned to the late middle Eocene Subzone CP14a are widespread in northwest Oregon and in western Washington as far north as the Olympic Peninsula. A siltstone sequence, the Aldwell Formation (Brown and others, 1960; Snavely and others, 1986), that unconformably overlies the Crescent Formation along the north flank of the Olympic Mountains contains coccoliths assigned to Subzone CP14a. In southwest Washington, coccoliths indicative of Subzone CP14a are found in the McIntosh Formation (Snavely and others, 1958), the Humptulips Formation (Rau, 1986), and in a number of informally named siltstone sequences in the Cape Disappointment-Naselle River area (Wells, 1989) and Unit B in the Grays River area (Wolfe and McKee, 1968).

South of the Tillamook Highlands along the west flank of the Oregon Coast Range, Yamhill Formation siltstone contains coccoliths assigned to Subzone CP14a that can be traced as far south as the latitude of Newport. In the southern Coast Range, siltstone strata referred to as the Sacchi Beach beds (Baldwin, 1974; Dott and Bird, 1979) that crop out along the coast from Coos Bay southward to Five Mile Point also contain a coccolith flora assigned to Subzone CP14a.

The concentration of coccoliths in these oil shales may have occurred during a condensed interval as defined on the global sequence stratigraphy chart of Haq and others (1987, fig. 2). They define a condensed section as an interval of depositional starvation when rapidly rising sea level moves the sediment depocenters landward. Because of a low terrigenous input, the condensed section is expressed as a zone of high pelagic concentration. Possible condensed intervals that may correlate with the Subzone CP14a of the oil shale are at 41.2 Ma and 43 Ma.

CONCLUSIONS

If the occurrence of oil shale is in part controlled by a global eustatic sea level change, the possibility is that oil shales like those in the Tillamook area may occur in the Washington and Oregon Coast Ranges in strata of similar age and environment of deposition. Although strata of the same age as the oil shale are widespread in western Oregon and Washington, and in several areas condensed sections occur in these strata (for example, thick tuff beds), oil shale units have not been recognized. Also, except in southwestern Washington and northwest Oregon, the Yamhill Formation unconformably overlies pre-early middle Eocene rocks. This suggests that the environment of deposition of the oil shale occurred in constructional or structural lows between late middle Eocene volcanic piles. Elsewhere where Yamhill strata unconformably overlaid older strata, strong currents along a more open coast line did not permit the slow accumulation of organic-rich pelagic sediments. However, ponded areas between individual eruptive centers would provide the proper depositional environment.

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