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WELL STRATIGRAPHY AND CORRELATIONS, WESTERN WASHINGTON AND NORTHWESTERN OREGON

By

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INTRODUCTION

This report of well stratigraphy and correlation was constructed as an aid to evaluate the energy resources of western Washington and northwest Oregon. The stratigraphy and lithology of rocks penetrated in twenty-three wells from this region (fig. 1) are briefly described and are graphically displayed beside geophysical logs (sheets 1 and 2). A table of foraminifera recovered from the strata in each well is also presented (tables 1-23). Paleontologic and lithologic data and interpretations provide the basis for biostratigraphic zonation (fig. 2; based largely on Rau, 1981), correlations between wells, and inferring paleobathymetry and depositional environments. The wells were drilled in several different Cenozoic basinal and uplift settings (fig. 3), and correlations between units (fig. 4) provide an important tool in reconstructing paleogeography and tectonic history.

In evaluating regional stratigraphy, this report should be used as a complement to the numerous other reports and charts that are cited in the well descriptions. Most of these reports are based on descriptions of outcrop sections and geologic mapping. Notable reports with charts that rely extensively on well information include Rau (1958) and Rau and McFarland (1983) for southwestern Washington, and Niem and Niem (1985) and Niem and others (1990, 1992) for northwestern Oregon. Most of the well reports and logs used in this report are on file with the Washington Division of Geology and Earth Resources in Olympia, Washington, and with the Oregon Department of Geology and Mineral Industries in Portland, Oregon.

Paleobathymetric inferences (Tables 24, 25) are based on benthonic foraminiferal biofacies lists included in Enbysk (1960), Ingle (1980), McDougall (1980), and the extensive regional experience of W.W. Rau. Paleobathymetric lists provided by Ingle (1980) are from the southern California borderland where the inferred depth ranges may be somewhat different than for the Pacific Northwest because of the different dimensions and temperature of relevant water masses. This uncertainty and the possibility of downslope redeposition of microfossils make these paleobathymetric inferences somewhat inexact.

The type of sample analyzed for each borehole is given with the stratigraphic description. Except for a few boreholes for which cores were available, samples are from well cuttings. Down-hole contamination of samples is therefore possible, however no evidence of this potential problem was recognized.

ACKNOWLEDGMENTS

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1

PORT ANGELES OIL AND GAS COMPANY SUTTER NO. 1

The Port Angeles Oil and Gas Company Sutter No. 1 well was drilled in 1961 on the northern Olympic Peninsula, Clallam County, Washington (SE 1/4, sec. 15, T. 30 N., R. 5 W.), about 6.6 miles (10.6 km) east of Port Angeles. The well is located a few hundred meters south of the axis of the Swamp Creek anticline (Brown and others, 1960) in the eastern part of the Tofino-Fuca basin (fig. 3; Snavely and others, 1980; Johnson and others, 1998). Total depth was 6,223 ft (1,897 m). The description below is based on analysis of geophysical logs and mud logs, and on 36 samples collected from cuttings and analyzed by W.W. Rau (table 1).

Pleistocene sand, gravel, and clay were encountered in the uppermost 180 ft (55 m) of the well. These poorly consolidated deposits unconformably overlie an upper Eocene to Oligocene section of sedimentary bedrock that extends to total depth. Two units are recognized in this section based entirely on biostratigraphic information. The upper unit extends to a depth of about 2,700 ft (823 m) and consists of fossiliferous siltstone, mudstone, and sandstone with local concretionary zones and a few ash beds. Foraminifera in this upper interval are assigned to the Oligocene Zemorrian Stage (fig. 2). Among significant Zemorrian taxa are *Cassidulina crassipunctata, Anomalina californiensis, Anomalina glabrata, and Sphaeroidina variabilis* (Rau, 1981).

The lower unit, which extends from about 2,700 ft (823 m) to total depth consists of interbedded siltstone, mudstone, and less commonly sandstone. Foraminifera in this interval typify the upper Eocene to lower Oligocene Refugian Stage (fig. 2). Particularly significant species include *Uvigerina cocoaensis, Ceratobulimina washburnei, Eponides yeguaensis, and E. kleinpelli* (Rau, 1981).

Zemorrian foraminifera reflect deeper depositional environments than the Refugian foraminifera. The Zemorrian fauna suggest a range of bathyal depths from lower bathyal to upper bathyal (table 24). Diagnostic lower bathyal species include *Melonis pompilioides* and *Uvigerina garzaensis* (table 25; Ingle, 1980; McDougall, 1980). Middle bathyal species are *Eponides duprei, Stilostomella adolphina,* and agglutinated type *Karreriella washingtonensis.* Upper bathyal species include *Gyroidina orbicularis planata, Cassidulina crassipunctata, Cassidulina galvinensis, Bulimina ovata, and Epistomina eocenica.*

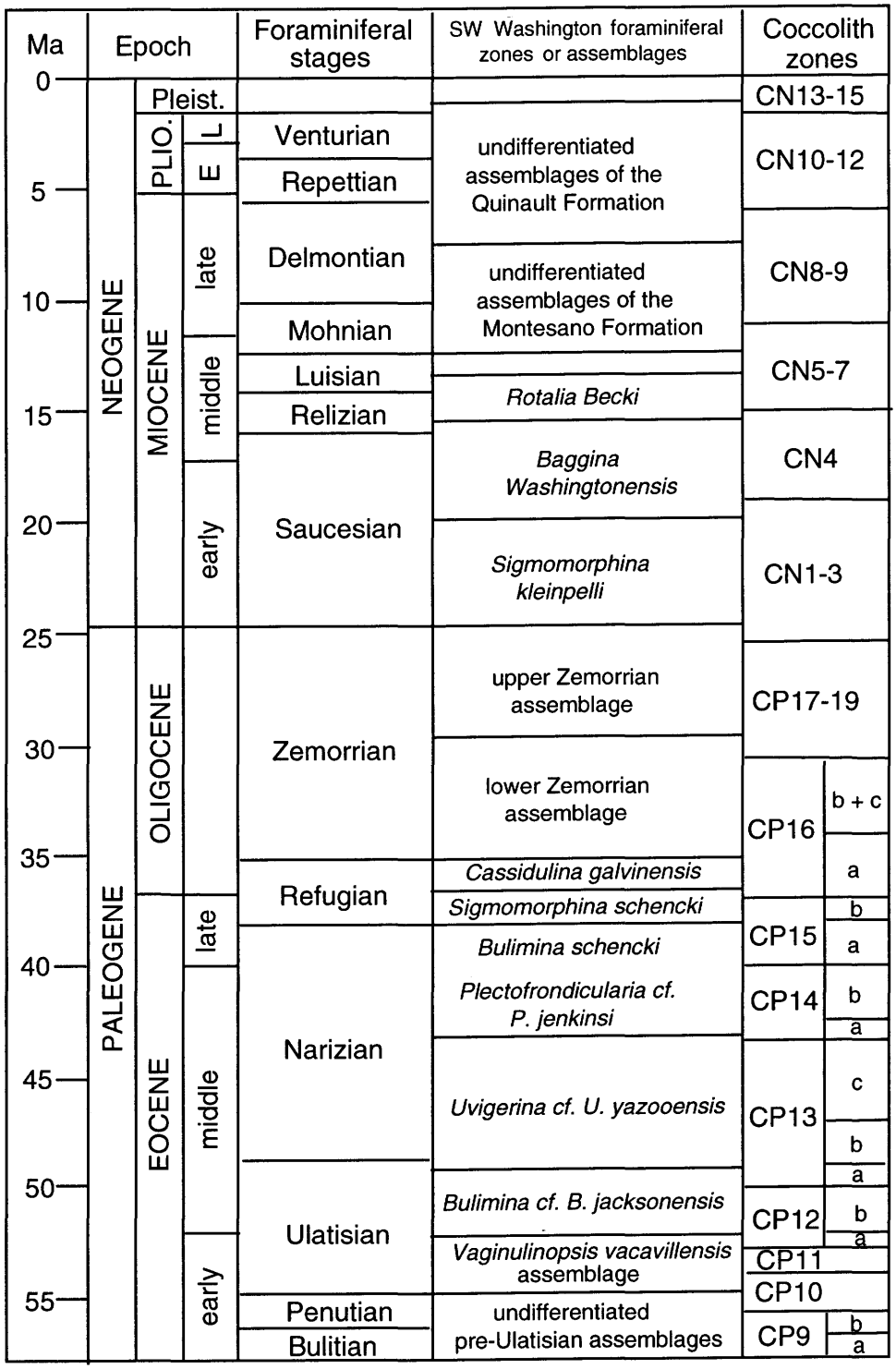

Figure 2. Correlation of relative and absolute time scales for Cenozoic rocks in southwestern Washington and northwestern Oregon, based on Armentrout (1981), Rau (1981), Berggren and others (1985), Prothero and Armentrout (1985), Almgren and others (1988), Bukry (1981), and Niem and Niem (1992). Southwest Washington foraminiferal zonation is after Rau (1981). McDougall (1980) presented a different upper Eocene biostratigraphic zonation based on work in Oregon.

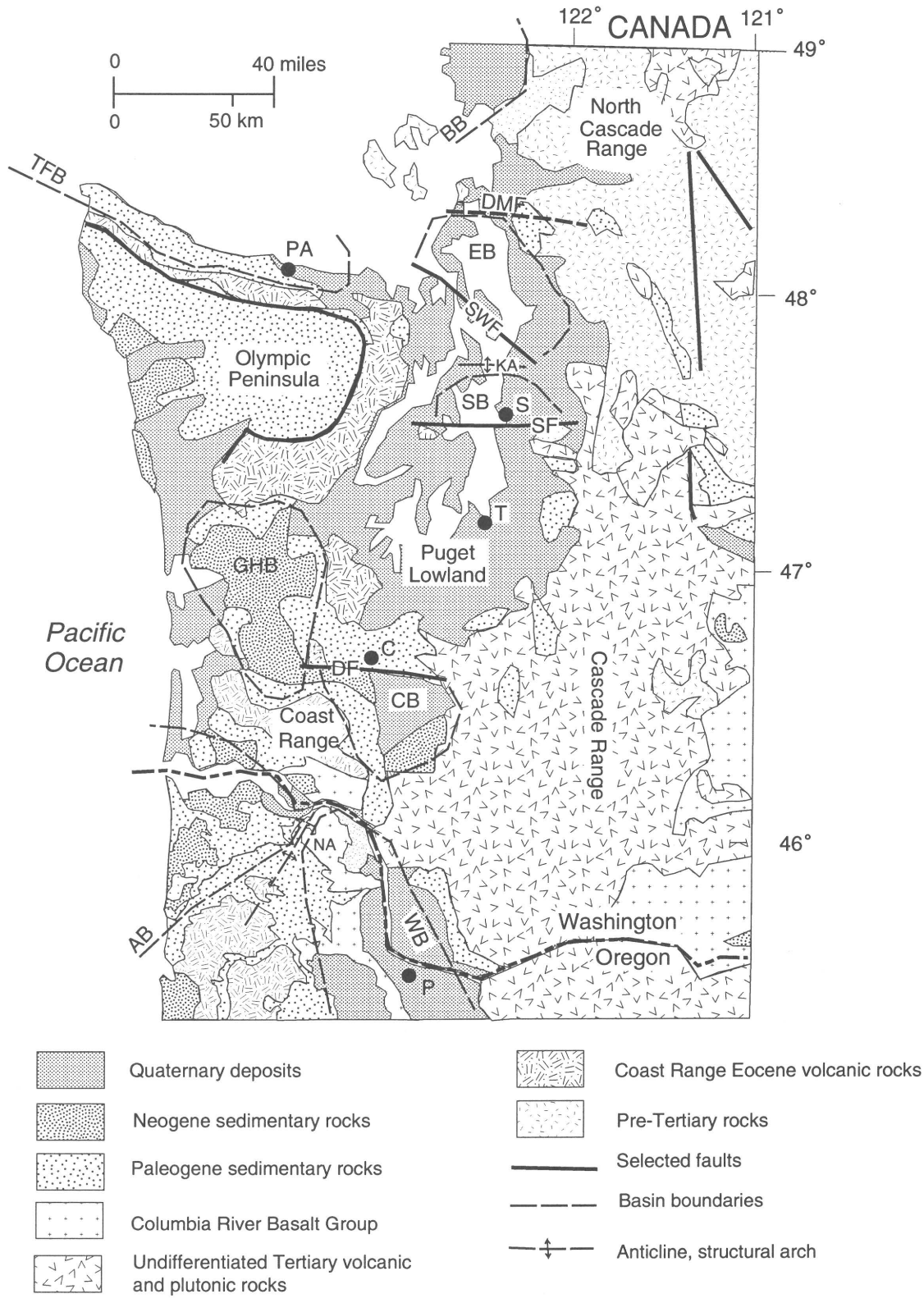

Figure 3. Schematic geologic map of western Washington and northwest Oregon modified from Schuster (1992) and Walker and MacLeod (1991). Abbreviations as follows: AB = Astoria basin; BB = Bellingham basin; C = Centralia; CB = Chehalis basin; DF = Doty fault; DMF = Devils Mountain fault; EB = Everett basin; GHB = Grays Harbor basin; KA = Kingston arch; NA = Nehalem arch; P = Portland; PA = Port Angeles; S = Seattle; SB = Seattle basin; SF = Seattle fault; SWF = southern Whidbey Island fault; T = Tacoma; TFB = Tofino-Fuca basin; WB = Willamette basin.

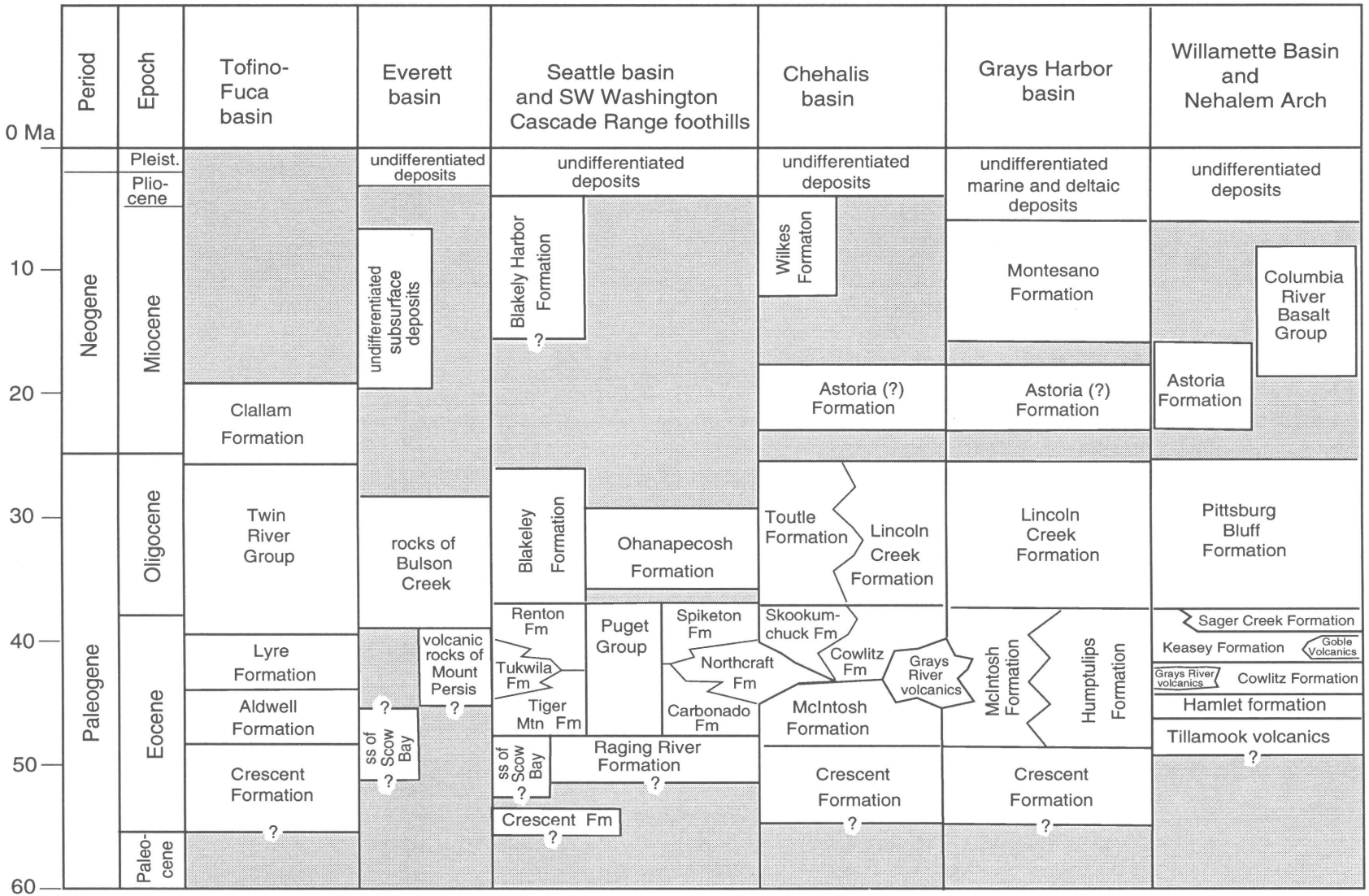

Figure 4. Correlation chart showing stratigraphy in basinal areas described from boreholes in this report. Shaded areas show intervals of nondeposition and (or) erosion. Based on this report and Snavely and others (1958, 1993a), Rau (1967, 1973), Frizzell and others (1983), Frizzell and Easterbrook (1983), Rau and Armentrout (1983), Rau and others (1983), Snavely and Lander (1983), Rau (1986), Niem and Niem (1992), Niem and others (1992, 1994), and Johnson and others (1994, 1996).

Key species in Refugian strata such as *Guttulina problema, Eponides kleinpelli,* and *Uvigerina cocoaensis* suggest paleobathymetric ranges from neritic to upper bathyal (table 25; Ingle, 1980; McDougall, 1980). The planktonic genus *Globigerina,* the most shallow-water tolerant of the planktonic genera, is consistently present in both the Zemorrian and Refugian parts of the section.

Given the likelihood of downslope redeposition of foraminifera, the distribution of key species throughout the sequence suggests deepening upwards from upper bathyal to outer neritic water depths in the Refugian part of the section to lower to middle bathyal depths in the Zemorrian part of the section.

Rau (1964) presented measured sections and biostratigraphic data from nearby outcrops on the northern Olympic Peninsula. Brown and others (1960) also provided lithologic descriptions of correlative Refugian and Zemorrian Stage strata from the Port Angeles area, which they assigned to the Twin River Formation. Subsequently, the Twin River Formation was elevated to Group status (Snavely and others, 1980). Farther west on the northwest flank of the Olympic Peninsula, Snavely and others (1980) defined the Hoko River, Makah, and Pysht Formations within the Twin River Group, but similar subdivisions have not yet been applied in the Port Angeles area. Thus, strata in the Sutter No. 1 well are here considered an undifferentiated part of the Twin River Group (fig. 4, Tofino-Fuca basin). To the east on the northeast flank of the Olympic Peninsula, strata correlative with the Refugian Stage part of the Twin River Group include the Quimper Sandstone and Marrowstone Shale (Armentrout and Berta, 1977). Correlative strata in the Everett basin and Seattle basins belong to the rocks of Bulson Creek (informal name) and the Blakeley Formation, respectively.

2

STANDARD OIL COMPANY OF CALIFORNIA ENGSTROM COMMUNITY NO. 1

The Standard Oil Company of California Engstrom Community No. 1 well was drilled in 1958 on central Whidbey Island, Island County, Washington (SE 1/4. sec. 17, T. 30 N., R. 2 E.). It is located on the southwest margin of the Everett basin (fig. 3), slightly northeast of the basin-bounding southern Whidbey Island fault (Gower and others, 1985; Johnson and others, 1996). Total depth was 7,353 ft (2,241 m). The description below is based on analysis of well cuttings (by W.W. Rau; table 2) and geophysical logs.

Strata penetrated in the upper 550 ft (168 m) of the borehole were neither logged nor sampled. Strata between 550 ft (168 m) and 2,055 ft (626 m) consist of poorly consolidated clay, sand, silt, and minor tuff. These rock types are mixed in varied proportions between 550 ft (168 m) and about 970 ft (296 m) and between about 1,740 ft (530 m) and 2,055 ft (626 m). Clay is the dominant lithology between 970 ft (296 m) and 1,740 ft (530 m). These strata are of inferred Quaternary age and were probably deposited in a variety of glacial and interglacial nonmarine and marginal marine environments. Clay-dominated intervals probably formed in pro-glacial lacustrine and glacio-marine environments; intervals of mixed lithology or dominantly sand are inferred to be mainly of alluvial plain or glacial outwash origin.

Between about 2,055 ft (626 m) and 3,000 ft (914 m), the borehole penetrated a more indurated interval consisting commonly of mottled mudstone, minor sandstone, and rare conglomerate. Lignitic coal is in several beds between 2,660 ft (811 m) and 3,000 ft (914 m), indicating a nonmarine depositional environment for that part of the section. This interval is below an unconsolidated Quaternary section and above a fossiliferous Oligocene section, but is otherwise undated. We tentatively assign it a Miocene age. The nearest exposures of Miocene sedimentary rocks are about 31 mi (50 km) to the south on the south flank of the Seattle basin and include nonmarine rocks of the Blakely Harbor Formation (fig. 4; Fulmer, 1975; Johnson and others, 1994) and unnamed nonmarine sedimentary rocks described by Yount and Gower (1991). Pliocene strata have not been described in this part of the Puget Lowland. Because of the uncertainty involving the age of this unit, the nature of its upper and lower contacts (for example, gradational, unconformable) could not be determined.

The interval between 3,000 ft (914 m) and 7,353 ft (2,241 m) consists of siltstone and less common interbedded sandstone, silty sandstone, and shale. Macerated carbonaceous material, concretions, and rare marine fossils are in these strata. The highest marine fossil noted is at 3,180 ft (969 m) and foraminifera characteristic of the Oligocene Zemorrian Stage (fig. 2) are at depths from 3,260 ft (994 m) to about 7,100 ft (2164 m). Significant Zemorrian taxa are *Buccella mansfieldi oregonensis, Cassidulina crassipunctata, Anomalina californiensis,* and *A. glabrata* (Rau, 1981). Although the boundary is gradational, taxa representing the upper Eocene to lower Oligocene Refugian Stage (fig. 2) make their highest occurrence at about 7,100 ft (2,164 m) and are present down to total depth (7,353 ft; 2,241 m). The highest occurrence of *Ceratobulimina washburnei* in this interval is particularly significant (Rau, 1981). The foraminifera assemblages in both the Zemorrian and Refugian intervals suggest deposition at bathyal water depths, shallowing upward from upper middle bathyal water depths to upper bathyal water depths (table 24). Species significant to this interpretation include *Gyroidina orbicularis planata, Anomalina californiensis, A. glabrata,* and *Cassidulina crassipunctata* (table 25; Ingle, 1980).

Because of their location within the Everett basin, the upper Eocene to Oligocene rocks described above are assigned to the rocks of Bulson Creek (fig. 4; Marcus, 1980).

This unit is exposed 19 mi (30 km) to the northeast on the north flank of the basin where it consists of an undated lower alluvial sequence and an upper, fossiliferous Refugian interval. These strata dip south into the subsurface of the Everett basin where they are overlain by a thick section of rocks assigned to the Zemorrian Stage (Standard Oil Company of California Silvana Community No. 12-1). The rocks of Bulson Creek are correlative with the Blakeley Formation (fig. 4) which crops out 31 mi (50 km) to the south on the south flank of the Seattle basin (Fulmer, 1975; McLean, 1976), and with the Refugian Marrowstone Shale and Quimper Sandstone that crop out just 6 mi (10 km) to the west on the northeast Olympic Peninsula (Whetten and others, 1988).

Table 24. Paleobathymetric zones (after Ingle, 1980):

Zone	Inferred water depth
nonmarine	above sea level
littoral	tidal area
inner neritic	low tide to 50 m
outer neritic	50 to 150 m
upper bathyal	150 to 500 m
upper middle bathyal	500 to 1,500 m
lower middle bathyal	1,500 to 2,000 m
lower bathyal	2,000 to 4,000 m
abyssal	deeper than 4,000 m

Table 25. List of benthonic foraminifera considered diagnostic of neritic and bathyal depositional environments in the study area. Based on Enbysk (1960), Ingle (1980, McDougall (1980) and extensive regional experience of W.W. Rau.

Neritic depositional environments
Amphistegina spp.
Buccella spp.
Buccella mansfieldi oregonensis
Cassidulina cf. *C. subglobosa*
Cibicides hodgei
Cibicides kleinpelli
Cibicides lobatulus
Cibicides mcmastersi
Cibicides natlandi
Discorbis cf. D. baintoni
Elphidium spp.
Elphidium cf. E. minutum
Elphidium californicum
Elphidium smithi
Elphidium yeguaensis
Eponides aff. E. mexicanus
Eponides kleinpelli
Eponides yeguaensis
Florilus cf. F. incisum
Florilus cf. F. inflatum
Globocassidulina globosa
Nonion spp.
Nonion planatum
Nonion cf. N. applini
Pullenia cf. P. salisburyi
Quinqueloculina spp.
Quinqueloculina imperialis
Quinqueloculina minuta
Quinqueloculina cf. Q. triangularis
Valvulineria willapaensis
Bathyal depositional environments
Anomalina glabrata
Anomalina californiensis
Anomalina cf. A. garzaensis
Anomalina dorri aragonensis
Bolivina marginata adelaidana
Bolivina basisenta oregonensis
Bulimina corrugata
Bulimina cf. B. jacksonensis
Bulimina microcostata
Bulimina ovata cowlitzensis
Bulimina aff. B. instabilis
Bulimina sculptilus
Buliminella subfusiformis
Cassidulina galvinensis
Cassidulina cf. C. californica
Cassidulina galvinensis
Cassidulina crassipunctata
Cassidulina transluscens
Cibicides cf. C. coalingensis
Cibicides cf. C. pachyderma
Cibicides cf. C. spiropunctatus
Cibicides ouachitaensis alhambrensis
Epistomina eocenica
Eponides duprei ciervoensis
Globobulimina cf. G. pacifica
Globobulimina pupoides
Gyroidina orbicularis planata
Gyroidina soldanii octocamerata
Karreriella elongata
Karreriella washingtonensis
Melonis pompilioides
Plectofrondicularia spp.
Plectofrondicularia cf. P. vaughani
Plectofrondicularia searsi
Pleurostomella acuta
Pleurostomella cf. P. nuttalli
Praeglobobulimina cf. P. pupoides
Praeglobobulimina cf. P. bradburyi
Pullenia bulloides
Pullenia cf. P. eocenica
Siphogeneria spp.
Siphogenerina kleinpelli
Sphaeroidina variabilis
Stilostomella spp
Stilostomella adolphina
Uvigerina gallowayi
Uvigerina cocoaensis
Uvigerina gallowayi
Uvigerina garzaensis
Uvigerina cf. U. yazooensis
Uvigerinella californica ornata
Uvigerinella obesa impolita
Valvulineria araucana
Valvulineria tumeyensis
Valvulineria cf. V. williami
Valvulineria jacksonensis welcomensis

3

STANDARD OIL COMPANY OF CALIFORNIA SILVANA COMMUNITY NO. 12-1

The Standard Oil Company of California Silvana-Community No. 12-1 well was drilled in 1958 in northwestern Snohomish County, Washington (SE 1/4, sec. 12, T. 31 N., R. 4 E.). The well is located on the north flank of the Everett basin, about 16 km south of the basin-bounding Devils Mountain fault (fig. 3; Whetten and others, 1988; Johnson and others, 1996). The discussion below is based on an examination of 12 cores dispersed throughout the well from 900 ft (274 m) to total depth of 7,419 ft (2,261 m), well cuttings, geophysical logs, and a paleontologic report contributed by Standard Oil Company of California.

Poorly consolidated sand, gravel, and clay believed to be Pleistocene glacial and interglacial deposits were encountered in the upper 900 ft (274 m) of the borehole. This interval unconformably overlies a thick sequence of mainly sandstone, sandy siltstone, and conglomerate that extends to 7,350 ft (2,240 m). Sandstone and conglomerate dominate from 900 ft (274 m) to about 6,600 ft (2012 m). Sandstone in cores from this interval is fine-grained to conglomeratic, low-angle bedded or cross bedded, includes abundant carbonaceous material, is commonly friable, and generally lacks fossils. The sedimentology of these rocks suggests a mainly nonmarine origin, although pelecypod fragments are present in cores from depths of 2,986 ft (910 m) to 3,006 ft (916 m) and 3,361 ft (1,024 m) to 3, 372 ft (1,028 m), and foraminifera were recovered from core in the interval between 2,082 ft (635 m) and 2,096 ft (639 m). The foraminiferal assemblage from this interval consists of four taxa and is characteristic of the Oligocene Zemorrian Stage (fig. 2; table 3), the definitive taxon being *Buccella mansfieldi oregonensis* (Rau, 1981). The occurrence of *Buccella* and *Quinqueloculina* spp. indicate a neritic environment of deposition (table 25; Enbysk, 1960; Ingle, 1980). This sandstone-rich interval apparently represents a time when the shoreline fluctuated back and forth across the borehole site.

The interval encountered between 6,600 ft (2,012 m) and 7,350 ft (2,240 m) is mainly siltstone, although sandstone is present between 6,945 ft (2,117 m) and 7,045 ft (2,147 m). Siltstone in core from the interval between 6,762 ft (2,061 m) and 6,781 ft (2,067 m) contains foraminifera characteristic of the upper Eocene to lower Oligocene Refugian Stage (fig. 2). Of the five taxa recovered from core, *Sigmomorphina schencki* is the most indicative of this time interval (Rau, 1981). Collectively, this assemblage suggests deposition in upper bathyal water depths (table 25).

Strata penetrated between 900 ft (274 m) and 7,350 ft (2,240 m) are assigned to the rocks of Bulson Creek (Marcus, 1980) which crop out about 4-11 mi (6-17 km) to the north on the north flank of the Everett basin. Rocks in these exposures dip south toward the Silvana Community No. 1 borehole, consist of coarse-grained nonmarine to shallow marine deposits, and unconformably overlie a diverse pre-Tertiary basement comprising greenstone, graywacke, chert, and argillite (Whetten and others, 1988). The rocks of Bulson Creek are correlative with the Blakeley Formation (fig. 4), which crops out 65 km to the south on the south flank of the Seattle basin (Fulmer, 1975; McLean, 1976), and with the Refugian Marrowstone Shale and Quimper Sandstone that crop out 22 mi (35 km) to the west on the northeast Olympic Peninsula (Whetten and others, 1988).

Between 7,350 ft (2,240 m) and 7,419 ft (2,261 m), the borehole encountered altered basaltic volcanic rocks. We infer that these volcanic rocks are pre-Tertiary greenstone similar to that which crops out on the north and east margins of the Everett basin (Whetten and others, 1988). Johnson and others (1996) used gravity data to estimate a depth to basement of 6,000 to 10,000 ft (2 to 3 km) at the borehole site, consistent with this inference.

4

STANDARD OIL COMPANY OF CALIFORNIA SOCAL-WHIDBEY NO. 1

The Standard Oil Company of California Socal-Whidbey No. 1 well was drilled in 1972 on southern Whidbey Island, Island County, Washington (NE 1/4, sec. 27, T. 29 N., R. 3 E.). It is located on a structural arch within the southern Whidbey Island fault zone (fig. 3; Gower and others, 1985; Johnson and others, 1996). Total depth was 6,693 ft (2,040 m). The description below is based on analysis of mud log and geophysical log data, and paleontologic analysis (by W.W. Rau) of 48 samples collected from cuttings and sidewall cores (table 4).

Poorly consolidated clay, sand, and gravel inferred to be Pleistocene glacial and interglacial deposits were encountered in the upper 600 ft (183 m) of the borehole. This interval unconformably overlies a thick sequence of siltstone and sandstone that extends to a depth of 6,000 ft (1,829 m). Siltstone dominates between 600 ft (183 m) and 4,000 ft (1,219 m), whereas silty sandstone and sandstone are the major rock types between 4,000 ft (1,219 m) and 6,000 ft (1,829 m). Foraminifera in the interval between 600 ft (183 m) and 4,200 ft (1,280 m) that typify the Oligocene Zemorrian Stage (fig. 2) include *Buccella mansfieldi oregonensis, Cassidulina crassipunctata, Anomalina californiensis, Anomalina glabrata, Sphaeroidina variabilis, and Bolivina marginata adelaidana* (Rau, 1981). Foraminifera characteristic of the upper Eocene to lower Oligocene Refugian Stage (fig. 2) extend from depths of 4,260 ft (1,298 m) to 5,960 ft (1,817 m). Particularly significant among these Refugian species are

Ceratobulimina washburnei, Valvulineria willapaensis, Melonis halkyardi, and *Eponides kleinpelli* (Rau, 1981). The foraminifera assemblages in both Refugian and Zemorrian Stage rocks indicate deposition at upper and upper middle bathyal water depths. Among the taxa supporting this conclusion are *Gyroidina orbicularis, Cassidulina crassipunctata, Cassidulina galvinensis,* and *Epistomina eocenica* (table 25; Ingle, 1980).

These Zemorrian and Refugian strata are assigned to the Blakeley Formation (fig. 4), which crops out about 25 mi (40 km) to the south on the south flank of the Seattle basin. Johnson and others (1994, 1996) have traced the Blakeley Formation northward on seismic reflection data from the Seattle basin over the Kingston arch and into the southern Whidbey Island fault zone. Although correlative strata of similar facies in the Everett basin on the northeast side of the southern Whidbey Island fault (for example, in the Standard Oil Company of California Engstrom Community No. 1 borehole) are here assigned to the rocks of Bulson Creek (Marcus, 1980), the Blakeley and the Bulson Creek units were clearly once part of the same depositional basin.

Indurated siltstone was penetrated between depths of 6,000 ft (1,829 m) and 6,100 ft (1,859 m). Volcanic rocks with siltstone interbeds were encountered from 6,100 ft (1,859 m) to 6,500 ft (1,981 m), and mainly sandstone was encountered from 6,500 ft (1,981 m) to total depth at 6,693 ft (2,040 ft). These strata contain foraminifera referred to the lower Eocene undifferentiated lower part of the Ulatisian Stage and (or) the Penutian Stage (fig. 2). The middle Eocene Narizian Stage is missing in the borehole, indicating the presence of a significant intra-Eocene unconformity. Significant taxa in the Ulatisian and (or) Penutian section include *Vaginulinopsis vacavillensis, Tritaxilina colei, Cibicides venezuelana,* and *Globorotalia aragonensis*. The benthic fauna indicate deposition at upper bathyal depths. The consistent presence of *Globigerina* spp. throughout the well and the presence of *Globigerina linaperta, G. primitiva,* and *Globorotalia aragonensis* in the Ulatisian-Penutian interval indicate warm surface waters to a depth of greater than 300 ft (91.5 m), which is required by the genus *Globorotalia* to complete its life cycle (Leckie, 1987).

Strata in this lower unit are correlative with the volcanic Crescent Formation and the sandstone of Scow Bay (fig. 4), which crop out about 12.5 mi (20 km) to the west on the northeastern Olympic Peninsula and have also been penetrated 12.5 mi (20 km) to the southwest in the Mobil Kingston No. 1 well. The lower sequence in the Whidbey No. 1 well may include the interfingering or unconformable contact between the Crescent Formation and sandstone of Scow Bay.

5

STANDARD OIL COMPANY OF CALIFORNIA ALDERWOOD NO. 1

The Standard Oil Company of California Alderwood No. 1 well was drilled in 1947 in southwestern Snohomish County, Washington (SW 1/4. sec. 35, T. 28 N., R. 4 E.). It is located on a structural arch that is within the southern Whidbey Island fault zone (Gower and others, 1985; Johnson and others, 1996). Total depth was 11,002 ft (3,353 m). The description below is based on analysis of mud logs and geophysical logs, examination of cores (stored in Olympia at the Washington Division of Geology and Earth Resources), a paleontologic report provided by Standard Oil Company of California, and an additional paleontologic analysis conducted by W.W. Rau (table 5).

Poorly consolidated sand, gravel, and clay interpreted as Pleistocene glacial and interglacial deposits were encountered in the upper 360 ft (110 m) of the borehole. Below these inferred Pleistocene deposits, three biostratigraphic units are recognized. The upper unit extends from 360 ft (110 m) to 880 ft (268 m) and consists of mudstone and siltstone. Foraminifera recovered in this interval belong to the Oligocene Zemorrian Stage (fig. 2) with key species including *Sphaeroidina variabilis, Anomalina californiensis,* and *Uvigerina gallowayi* (Rau, 1981). The presence of *Karreriella washingtonensis, Uvigerina garzaensis, U. gallowayi,* and *Sphaeroidina variabilis* indicates deposition in middle bathyal water depths (table 25; Ingle, 1980; McDougall, 1980).

The second biostratigraphic unit extends from depths of 880 ft (268 m) to 5,220 ft (1,591 m). Mudstone and siltstone are dominant rock types between 880 ft (268 m) and 1,980 ft (604 m). Sandstone and sandy siltstone predominate between 1,980 ft (604 m) and 4,030 ft (1,228 m), although minor conglomerate is at 2,300 to 2,320 ft (701 to 707 m). Sandstone dominates between 4,030 ft (1,228 m) and 5,220 ft (1,591 m), with conglomerate present at 4,882 to 4,907 ft (1,488 to 1,496 m). Sandstone and siltstone throughout the entire unit are commonly tuffaceous and a few beds are fossiliferous. Strata in the entire interval are also commonly fractured and sheared. Foraminifera recovered from this biostratigraphic unit characterize the upper Eocene to lower Oligocene Refugian Stage (fig. 2). *Sigmomorphina schencki* is a key indicator for the upper Refugian (Rau, 1981). Significant lower Refugian species recovered from the lower part of the unit (3,289 to 5,220 ft (1,002 to 1,591 m)) include *Valvulineria willapaensis* and *Melonis halkyardi* (Rau, 1981). Limited data warrants only a tentative assignment of the Refugian strata to middle bathyal water depths.

Strata belonging to both the Refugian and Zemorrian Stages are here assigned to the Blakeley Formation (fig. 4) which crops out about 30 km to the south on the south flank

of the Seattle basin (Fulmer, 1975; McLean, 1976). Correlative rocks assigned to the rocks of Bulson Creek crop out about 22-34 mi (35-55 km) to the north on the north flank of the Everett basin, and were penetrated in the Standard Oil Company of California No. 12-1 Silvana Community well.

Strata in the well assigned to the Blakeley Formation unconformably overlies a unit of sedimentary and less common volcanic rock that extends from 5,220 ft (1,591 m) to total depth. Sedimentary rock is mainly sandstone, sandy siltstone, and siltstone; carbonaceous mudstone is also present but uncommon. Beds are commonly tuffaceous and sparsely fossiliferous. Volcanic rock and volcanic conglomerate (commonly altered) forms intervals as much as about 150 ft (46 m) thick and is at 8 or more different intervals. Five geochemical analyses of altered to fresh volcanic rock indicate a mix of basalt (four samples) and andesite (1 sample) compositions (S.Y. Johnson, unpublished data). Many beds in this lowest unit are intensely sheared and fractured. Ulatisian Stage (fig. 2) foraminifera were recovered from this unit at depths of 5,220 to 5,249 ft (1,591 to 1,600 m), 7,205 to 7,228 ft (2,196 to 2,203 m), and 10,257 to 10,395 ft (3,126 to 3,353 m). Diagnostic Ulatisian species include *Vaginulinopsis mexicana var.* C, *Nodosaria latejugata*, and *Cibicides cf. C. venezuelanus* (Rau, 1981). The middle Eocene Narizian Stage is missing in the well, indicating the presence of a significant intra-Eocene unconformity. This unconformity was also noted in the Standard Oil Company of California Whidbey No. 1 well, just 15 km to the northwest. Foraminifera in this interval suggest deposition at neritic depths (Ingle, 1980) with particularly significant taxa including *Elphidium californicum, Eponides aff. E. mexicanus*, and *Quinqueloculina spp.*

Ulatisian strata penetrated in this well are assigned to the sandstone of Scow Bay (fig. 4), the best exposure of which is 35 km to the west-northwest on Indian and Marrowstone Islands (Armentrout and Berta, 1977). At this locality, both Ulatisian and Narizian strata have been assigned to this unit and are believed to have been deposited at upper bathyal water depths. Johnson and others (1996) discussed similarities in sandstone composition between correlative strata of this borehole, outcrops at the type locality, and probable correlative strata of the Raging River Formation (fig. 4; Johnson and O'Connor, 1994), which crop out about 50 km to the southeast on the south flank of the Seattle basin. Strata assigned to the sandstone of Scow Bay also are in the Mobil Oil Corporation Kingston No. 1 well and the Standard Oil Company of California Socal-Whidbey No. 1 well. As in the Whidbey No. 1 well, volcanic interbeds are inferred to be flows and volcaniclastic rocks of the upper part of the basaltic Crescent Formation (fig. 4). The one andesitic volcanic interbed could reflect alteration or differentiation of a Crescent basalt or, alternatively, derivation from an incipient Cascade Range volcanic center.

6

MOBIL OIL CORPORATION KINGSTON NO. 1

The Mobil Oil Corporation Kingston No. 1 well was drilled in 1972 on the northern Kitsap Peninsula, Kitsap County (NE 1/4, sec. 26, T. 27 N., R. 2 E.), Washington, and was located on the Kingston arch, a structural uplift on the north flank of the Seattle basin (fig. 3; Johnson and others, 1994). Total depth was 8,648 ft (2,637 m). The description below is based on analysis of well cuttings (by W.W. Rau; table 6) and geophysical logs.

Strata penetrated in the upper 1,720 ft (524 m) of the borehole consist of poorly to semi-consolidated clay, sand, and gravel. Gravel is most abundant between about 300 and 630 ft (91 and 192 m). These strata are of Pleistocene age and were probably deposited in a variety of glacial and interglacial nonmarine and marginal marine environments.

Rocks referred to as the lower part of the Blakeley Formation (fig. 4) first occur at 1,720 ft (524 m) and extend downward to 3,500 ft (1,067 m). These strata consist of siltstone, claystone, and minor sandstone, and include abundant foraminifera, common tuffaceous interbeds, and rare macerated carbonaceous material. Upper Eocene to lower Oligocene Refugian Stage (fig. 2) foraminifera are present throughout the interval. Significant Refugian taxa are *Sigmomorphina schencki*, *Ceratobulimina washburnei*, and *Uvigerina cocoaensis* (Rau, 1981). Foraminifera suggest deposition under upper bathyal water depths in the upper part of the section; significant bathyal species are *Cassidulina galvinensis* and *Uvigerina cocoaensis* (Ingle, 1980). Water depths in the lower part of the section were most likely greater but probably did not exceed middle bathyal depths. Rocks of the Blakeley Formation are exposed about 14 mi (23 km) to the south of this well site (Yount and Gower, 1991) where they consist of sandstone, mudstone, and conglomerate deposited in submarine fan environments (McLean, 1976). Foraminifera from these outcrops are of the Refugian and Zemorrian Stages (fig. 2; Fulmer, 1975); thus, the upper (Zemorrian) part of the Blakeley Formation is not present in the well. Seismic reflection data (Johnson and others, 1994) support the interpretation that the upper part of the Blakeley Formation has been eroded from the Kingston arch.

Sandstone and siltstone are the dominant rock types penetrated between 3,500 and 4,800 ft (1,067 and 1,463 m) in the well, although claystone and tuffaceous interbeds are also present. Carbonaceous fragments and debris are locally abundant in a nonfossiliferous interval between about 4,640 and 4,800 ft (1,415 and 1,470 m). These strata are tentatively assigned to the Narizian Stage (fig. 2); however, foraminifera are rare and none present are restricted to the Narizian Stage. The presence of the Narizian *Cibicides natlandi* is in question. Two other taxa on the species list whose presence

is not unique to the Narizian(?) interval are *Valvulineria willapaensis* which is more often characteristic of the Refugian rocks, and *Cibicides haydoni*, which can also be found in younger strata. The consistent presence of species such as *Gyroidina orbicularis planata, Cassidulina galvinensis*, and *Uvigerina cocoaensis* in the Narizian(?) interval suggests deposition in upper bathyal water depths (table 25; Ingle, 1980). The nearest outcrops of Narizian Stage strata are about 18 mi (30 km) to the west in the Quilcene area where they were included in the Twin River Formation (Yount and Gower, 1991), and about 22 mi (35 km) to the northwest on the Quimper Peninsula where they were included in the Lyre Formation (fig. 4; Whetten and others, 1988). Correlative nonmarine to marginal marine rocks of the Puget Group (fig. 4) crop out approximately 25 mi (40 km) to the southeast in the Renton area (Yount and Gower, 1991).

The interval penetrated between 4,800 and 5,360 ft (1,463 and 1,634 m) consists primarily of siltstone and claystone, but includes several interbeds of tuff and very fine grained to granular sandstone. This interval contains foraminifera characteristic of the upper lower to lower middle Eocene Ulatisian Stage (fig. 2), such as *Vaginulinopsis mexicana vacavillensis, Cibicides* cf. *C. venezuelanus*, and *Bulimina corrugata* (Rau, 1981). This sparse Ulatisian fauna was deposited at bathyal water depths, as indicated by taxa such as *Praeglobobulimina* cf. *P. bradburyi, Karreriella elongata, Bulimina corrugata* and *Pleurostomella acuta* (table 25; Ingle, 1980, McDougall, 1980). These strata are assigned to the sandstone of Scow Bay (fig. 4; Armentrout and Berta, 1977; Armentrout and others, 1983), which crops out approximately 30 km to the north-northwest on Indian and Marrowstone Islands.

Strata between 5,360 and 7,200 ft (1,634 and 2,195 m) consist mainly of siltstone and lesser interbedded sandstone. Foraminifera from this interval are referred to the lower Eocene Penutian Stage (fig. 2) with key taxa including *Globorotalia* cf. *G. aragonensis*, *Globorotalia* cf. *G. cerroazulensis*, and *Anomalina dorri aragonensis* (Rau, 1981). Foraminifera such as *Pullenia* cf. *P. eocenica, Karreriella elongata*, and *Bulimina corrugata* suggest middle bathyal water depths (table 25; Ingle, 1980; McDougall, 1980). Furthermore, the presence of two species each of two planktonic genera (*Globigerina* and *Globorotalia*) indicates that perhaps the warmest water conditions observed in this well are from these strata. These shallow-water taxa may have been redeposited and therefore their paleobathymetric significance has been disregarded. These strata are also assigned to the nearby sandstone of Scow Bay (fig. 4), which includes turbidite sandstone that has been interpreted as a submarine fan deposit (J.M. Armentrout, written commun., 1982; Melim, 1984).

The lowest interval in the well, from 7,200 (2,195 m) to total depth at 8,648 ft 2,637 m), consists of basalt and minor interbeds of siltstone, tuff, and conglomerate. Foraminifera from sedimentary interbeds, particularly *Vaginulinopsis mexicana var.* B, *Cibicides* cf. *C. coalingensis*, and *Anomalina dorri aragonensis*, suggest a Penutian age (fig. 2; Rau, 1981). Although some taxa from this interval (e.g., *Discorbis* cf. *D. baintoni, Amphistegina spp.*, and *Quinqueloculina* cf. *Q. triangularis*) suggest deposition at neritic water depths (table 25; Ingle, 1980), bathyal foraminifera (such as *Anomalina dorri aragonensis, Cibicides* cf. *C. coalingensis*, and *Cibicides ouachitaensis alhambrensis*; table 25; Ingle, 1980) are also present, suggesting downslope redeposition of the shallow-water species. Strata in this lowest interval are included in the correlative basaltic Crescent Formation, which crops out 12.5 mi (20 km) to the west-northwest.

Strata in the Mobil Kingston well have also been examined for coccoliths (D. Bukry, written commun. to Parke Snavely, Jr., 1988). Reported zones include CP15 from 2,430 to 4,280 ft (741 to 1,305 m), CP14 or CP15 from 4,430 to 4,760 ft (1,351 to 1,451 m), CP11 or CP12 from 5,210 to 5,240 ft (1,588 to 1,598 m), and CP11 from 5,990 to 8,370 ft (1,826 to 2,552 m) (fig. 2). These age assignments agree reasonably well with those based on foraminifera (Almgren and others, 1988) described above.

7

STANDARD OIL COMPANY OF CALIFORNIA SOCAL-SCHROEDER NO. 1

The Standard Oil Company of California Socal-Schroeder No. 1 well was drilled in 1972 in southwestern Snohomish County, Washington (SW 1/4 sec. 26, T. 27 N., R. 4 E.). It is located in a structurally complex area on the eastern extension of the Kingston arch, a few kilometers south of the southeast extension of the southern Whidbey Island fault zone (fig, 3; Gower and others, 1985; Johnson and others, 1994, 1996). Total depth was 9,675 ft (2,949 m). The description below is based on analysis of mud logs and geophysical logs, and examination (by W.W. Rau; table 7) of 26 samples (from cuttings) for foraminifera between 680 and 5,660 ft (207 m and 1,725 m).

Unconsolidated Pleistocene sand, gravel, and clay were penetrated in the upper 680 ft (207 m) of the well. These deposits are primarily of nonmarine glacial and interglacial origin, however the presence of sparse shell fragments also indicates the presence of glaciomarine drift. These strata unconformably overlie a unit extending from 680 to 2,160 ft (207 to 658 m) that is comprised of siltstone, mudstone, and sandy siltstone and contains foraminifera typical of the Oligocene Zemorrian Stage (fig. 2). Key species are *Bolivina marginata adelaidana, Buliminella bassendorfensis, Valvulineria menloensis, Anomalina californiensis*, and *Buccella mansfieldi oregonensis* (Rau, 1981). Foraminiferal assemblages indicate deposition at upper bathyal water depths as suggested by the frequent occurrence of *Bolivina*

marginata adelaidana, Gyroidina orbicularis planata, and *Cassidulina galvinensis* (table 25; Ingle, 1980).

Strata penetrated in the well between 2,160 and 3,260 ft (658 to 994 m) consist of locally carbonaceous and concretionary siltstone, sandy siltstone, and sandstone that are barren of foraminifera. Foraminifera typical of the upper Eocene to lower Oligocene Refugian Stage (fig. 2) first occur at 3,260 ft (994 m), thus the boundary between Zemorrian and Refugian Stage strata is somewhere between the depths of 2,160 and 3,260 ft (658 to 994 m).

Strata containing Refugian Stage foraminifera extend from 3,260 to 5,660 ft (994 to 1,725 m). Typical Refugian species include *Melonis halkyardi, Valvulineria willapaensis, Ceratobulimina washburnei,* and *Eponides kleinpelli* (Rau, 1981). From 3,260 to 3,900 ft (994 to 1,189 m), strata are mainly sandy siltstone and siltstone. Sandstone and sandy siltstone are dominant between 3,900 and 4,600 ft (1,189 and 1,402 m). The interval between 4,600 and 4,750 ft (1,402 and 1,448 m) includes thick coal beds interbedded with siltstone and mudstone. The interval between 4,750 and 5,660 ft (1,448 and 1,725 m) consists primarily of sandstone and sandy siltstone.

Although rare, foraminifera recovered from 3,260 to 3,900 ft (994 to 1,189 m) suggest deposition at shallow-marine (neritic) water depths, with key taxa including *Valvulineria willapaensis* and *Eponides kleinpelli* (table 25; Ingle, 1980; McDougall, 1980). The presence of coal-bearing strata in this lower interval indicates fluctuating nonmarine and shallow-marine environments. The faunal and sedimentologic evidence suggests that water depths become progressively greater during the deposition of the Refugian and Zemorrian intervals.

We assign the Zemorrian and Refugian stage rocks in the Schroeder No. 1 well to the Blakeley Formation (fig. 4; Fulmer, 1975, McLean, 1976). However, it should be noted that the nonmarine to shallow-marine environments inferred for the Refugian rocks in the Schroeder well differ from the submarine-fan environments inferred for the Blakeley Formation at its type locality about 18.5 mi (30 km) to the south on the south flank of the Seattle basin, and with the upper bathyal water depths inferred for Refugian strata assigned to the Blakeley Formation in the Standard Oil Company of California Alderwood #1 well 8 km to the north. These contrasts may reflect local tectonics associated with the evolution of the Seattle fault and Seattle basin (Johnson and others, 1994) and the southern Whidbey Island fault (Johnson and others, 1996). The lower coal-bearing part of the Refugian section in the Standard Oil Company of California Schroeder No. 1 well is probably contiguous with the coal-bearing, upper middle to upper Eocene (fig. 2; equivalent to upper Narizian and lower Refugian stages) Renton Formation (fig. 4), which crops out in highlands on the south flank of the Seattle basin and is overlain by Refugian Stage strata (Yount and Gower, 1991). However, no marine fossils have been reported from the Renton Formation.

Strata penetrated in the Schroeder No. 1 well between 5,660 and 8,000 ft (1,725 and 2,438 m) consist of nonfossiliferous sandstone, siltstone, mudstone, and coal. These strata have an inferred nonmarine origin and are assigned to the Renton Formation. Andesitic volcanic rocks interbedded with carbonaceous mudstone and siltstone were encountered between depths of 8,000 and 8,850 ft (2,438 and 2,697 m). We assign these rocks to the lithologically similar middle and (or) upper Eocene volcanic rocks of Mount Persis (fig. 4), exposed about 9.5 mi (15 km) to the east (Tabor and others, 1993; here inferred to include the unnamed Tertiary volcanic rocks in Snohomish County of Yount and Gower, 1991). Both the volcanic rocks of Mount Persis and the unnamed Tertiary volcanic rocks are probably correlative with the middle to upper Eocene Tukwila Formation, exposed 19-25 mi (30-40 km) to the south on the south flank of the Seattle basin.

Strata penetrated in the Schroeder No. 1 well between 8,850 and 9,675 ft (2,697 and 2,949 m) consist of siltstone, mudstone, coal, and minor sandstone. We assign these rocks to an undifferentiated part of the Puget Group (Waldron, 1962; Vine, 1969). Based on lithology and stratigraphic position, they are probably correlative with the middle Eocene Tiger Mountain Formation, which underlies the Tukwila Formation in outcrops 19-25 mi (30-40 km) to the south on the south flank of the Seattle basin.

8

AMOCO PRODUCTION COMPANY NO. WC-83-14

The Amoco Production Company No. WC-83-14 well was drilled in 1984 in central King County, Washington (SE 1/4 sec. 14, T. 23 N., R. 7 E.). It is located in a structurally complex area on Taylor Mountain, on the south flank of the Seattle basin (fig. 3) and the east flank of the north-trending Raging River anticline (Vine, 1969). Total depth was 1,752 ft (534 m). The well was cored almost continuously from 151 ft (46 m) to total depth. Johnson and O'Connor (1994) present a detailed description of that core, including a graphic log plotted at a scale of 1 inch = 33.6 ft (1 cm = 4 m). The following discussion summarizes that comprehensive account.

The mean dip of beds encountered in the Amoco WC-83-14 well was about 50°. Thus, the amount of section penetrated by the well is about 1,126 ft (343 m). Of this section, the upper 358 ft (109 m) of section is considered part of the Tiger Mountain Formation and the lower 768 ft (243 m) of the section is considered part of the Raging River Formation. The contact between the Tiger Mountain Formation and the underlying Raging River Formation is within a gouge zone at a depth of about 538 ft (164 m) and is characterized

by a downward change from yellowish-gray, well-stratified, micaceous sandstone to light-to medium-gray, bioturbated, poorly stratified mudstone and minor lithic sandstone.

Core of the Tiger Mountain Formation consists of interbedded yellowish-gray sandstone and medium-gray to grayish-black silty mudstone. The sandstone to mudstone ratio is about 5-6:1. Sandstone is typically moderately sorted and fine to medium grained and forms beds several meters thick. Primary stratification is mainly parallel lamination; low-angle lamination and wave-ripple lamination are uncommon. An anomalous thin-bedded interval from 434.5-423.7 ft (132.5 to 129.2 m) consists of 10 graded beds that fine upward from massive coarse-grained or granular sandstone to commonly parallel laminated, fine-grained sandstone. Bioturbation is present in most sandstone beds. Silty and (or) carbonaceous mudstone commonly form thin layers within thick sandstone beds and ranges from parallel laminated and fissile to massive. On the basis of sedimentary structures and textures, Johnson and O'Connor (1994) inferred that this lowermost part of the Tiger Mountain Formation formed in a marine shelf environment, probably in a prodelta setting.

Core of the underlying upper part of the Raging River Formation consists mainly of medium- to dark-gray silty or sandy mudstone and light- to medium-gray, very fine to medium-grained sandstone. The sandstone to mudstone ratio is approximately 1:4. Mudstone is typically massive, but markedly fissile horizons are also present. Trace fossils are abundant in many siltstone and mudstone beds. Rare gastropod and pelecypod shells and unidentified shell fragments are also present in several horizons.

Sandstone beds in the Raging River Formation are most abundant at depths of 1,752-1,648, 1,535-1,504, 927-916, and 906-835 ft (534-502, 468-459, 283-279, and 276-254 m). Strata are typically fine to medium grained and well sorted. Beds are structureless, parallel laminated, cross laminated, or extensively burrowed and exhibit relict parallel lamination. Grading is rare, but a few thin (< 20 cm) beds fine upward. Chert-pebble conglomerate forms a 14-centimeter-thick interbed at a depth of 1,524 ft (465 m).

Foraminiferal faunas recovered from two intervals in the well are sparse, but reasonably diagnostic of an early Narizian age (fig. 2; table 8). Taxa recovered from the interval between 1,255 and 1,263 ft (383 and 385 m) include *Dentalina* spp., *Gyroidina* spp., *Quinqueloculina* cf. *Q. triangularis*, *Amphimorphina californica*, and *?Pseudoglandulina* spp. Rau (in Vine, 1969, p. 16) has previously reported a more extensive list of foraminifers from this part of the Raging River Formation. The combined species list, including particularly *Bulimina* cf. *B. jacksonensis*, *Gyroidina orbicularis planata*, and *Cibicides* cf. *C. coalingensis* suggest an upper to middle bathyal depositional setting (table 25; Ingle, 1980; McDougall, 1980), which is consistent with Johnson and O'Connor (1994), who suggested deposition in a marine slope environment.

A composite sample between 1,693 and 1,700 ft (516 and 518 m) has a sparse fauna that includes *Plectofrondicularia packardi packardi, Pseudoglandulina* cf. *P. pyrula*, and *Dentalina* spp. Although *Plectofrondicularia* has been inferred to indicate deposition at upper to middle bathyal depths (Ingle, 1980), McDougall (1980) and D. R. McKeel (paleontology consultant, oral commun., 1992), have suggested that it may be more characteristic of an outer neritic environment. This alternative interpretation is more consistent with the occurrence of hummocky stratification noted by Johnson and O'Connor (1994) from outcrops of this horizon.

Thus, lithofacies and (or) biofacies indicate that the depositional environments of strata in this core change upward from outer shelf to slope to prodelta shelf. The abruptness of these changes and their presence within only about 900 ft (274 m) of stratigraphic section suggests tectonic control on sedimentation (Johnson and O'Connor, 1994).

9

UNION OIL COMPANY OF CALIFORNIA WILSON CREEK NO. 1

The Union Oil Company of California Wilson Creek No. 1 well was drilled in 1962-1963 approximately 8 mi (12.9 km) east of Raymond and 0.5 miles (800 m) north of Wilson Creek in northern Pacific County, Washington (NE 1/4, sec. 20, T. 14 N., R. 7 W.) (McFarland, 1983). It is located in the southern part of the Grays Harbor basin (fig. 3) on the crest of a gentle anticline bounded to the northwest and south by normal faults (Wagner, 1967). Surface exposures at the well site have been assigned to the upper part of the Astoria (?) Formation. Total depth was 4,989 ft (1,521 m). The description below is based on analysis of geophysical logs and mud logs and samples collected from cuttings. Foraminifera were collected and identified (by W.W. Rau; table 9) in 41 samples.

Based on foraminiferal assemblages, the strata in this well can be divided into three biostratigraphic units. The upper two units are assigned to the lower and middle Miocene Astoria (?) Formation, and the lower unit is assigned to the Oligocene part of the upper Eocene to Oligocene Lincoln Creek Formation (fig. 4).

The upper biostratigraphic unit extends from the surface to a depth of about 2,990 ft (911 m). Rock types in this interval consist mainly of siltstone, sandy siltstone, and sandstone. Sandstone is most abundant at about 580 ft (177 m), 1,340 ft (408 m), 1,420 ft (433 m), 1,500 ft (457 m), 1,670 ft (509 m), 2,050 to 2,200 ft (625 to 671 m), 2,370 to 2,650 ft (722 to 808 m), and 2,720 ft (829 m). Tuffaceous and carbonaceous beds are between 2,000 and 2,900 ft (610 and 884 m). Foraminiferal assemblages recovered from this upper biostratigraphic unit typify the *Baggina washingtonensis* zone with key

species including *Baggina washingtonensis, Uvigerenella californica*, and *Florilus costiferum* (fig. 2; Rau, 1981). The upper part of this zone is referred to the middle Miocene Relizian Stage and the lower part of the zone is assigned to the lower to middle Miocene Saucesian Stage. The foraminiferal assemblage suggests deposition at upper bathyal water depths with key species including *Uvigerenella californica* and *Cassidulina translucens* (table 25). This biostratigraphic unit corresponds to the upper and middle units of the Astoria (?) Formation mapped in this area by Wagner (1967).

The middle biostratigraphic unit was penetrated between about 2,990 and 4,210 ft (911 to 1,283 m). It consists almost entirely of locally tuffaceous and (or) carbonaceous siltstone, sandy siltstone, and mudstone. Foraminiferal assemblages recovered from this unit characterize the western Washington *Siphogenerina kleinpelli* zone (fig. 2; Rau, 1981), with key species including *Siphogenerina kleinpelli, Valvulineria araucana, Epistominella parva*, and *Uvigerinella obesa impolita*. This zone is referred to the lower to lower middle Miocene Saucesian Stage (fig. 2). The foraminiferal assemblage suggests deposition at upper to upper middle bathyal water depths. Upper bathyal taxa include *Bolivina marginata adelaidana, Cassidulina* cf. *C. californica*, and *Valvulineria* cf. V. *williami*, and upper middle bathyal taxa include *Valvulineria araucana* and the genus *Siphogeneria* (table 25; Enbysk, 1960; Ingle, 1980; McDougall, 1980). This biostratigraphic unit corresponds to the lower unit of the Astoria (?) Formation mapped in this area by Wagner (1967).

The lowest biostratigraphic unit penetrated in this well extends from about 4,210 ft (1,283 m) to total depth of 4,989 ft (1,521 m). It consists of siltstone, sandy siltstone, and silty mudstone. Foraminiferal assemblages recovered from this fine-grained strata characterize the Oligocene Zemorrian Stage (fig. 2), with key species including *Cibicides elmaensis, Sphaeroidina bulloides, Lenticulina brevispinosus*, and *Cassidulina crassipunctata*. Strata in this lower biostratigraphic unit represent the upper part of the Lincoln Creek Formation as mapped in this area by Wagner (1967). These assemblages were probably deposited at lower to lower-middle bathyal water depths as suggested by the consistent occurrence of the lower bathyal *Gyroidina soldanii* (table 25; Ingle, 1980). Furthermore, *Globigerina* spp. occurrence is greatly decreased in this unit, supporting a deeper water interpretation. Thus, the cumulative section penetrated in this well indicates progressive upward shoaling from the Oligocene to the middle Miocene.

10

EL PASO PRODUCTS COMPANY MONTESANO NO. 1-X

The El Paso Products Company Montesano No. 1-X well was drilled in 1974 in the valley of the Chehalis River about 1.5 mi (2.4 km) southwest of Montesano in southeastern Grays Harbor County, Washington (NW 1/4, sec. 13, T. 17 N., R. 8 W.) (McFarland, 1983). It is in the central part of the Grays Harbor basin (fig. 3) along the buried (by Quaternary alluvium) crest of the Melbourne anticline as mapped by Gower and Pease (1965). Total depth was 6,928 ft (2,112 m). The description below is based on analysis of geophysical logs and mud logs, and samples collected from cuttings. Foraminifera were collected and identified (by W.W. Rau; table 10) in 63 samples.

The well was spudded in alluvium of the Chehalis River and well records begin at 240 ft (73 m). Four biostratigraphic units are recognized in the underlying strata. The uppermost unit extends from about 240 to 900 ft (73 to 274 m). Rock types include claystone, siltstone, sandy siltstone, and rare sandstone. Foraminiferal assemblages recovered from this unit typify the *Siphogenerina kleinpelli* zone of the lower to lower middle Miocene Saucesian Stage of western Washington (fig. 2; Rau, 1981). Key species include *Siphogenerina kleinpelli, Florilus costiferum, Epistominella parva*, and *Valvulineria araucana*. Faunas in this unit suggest deposition at upper to upper middle bathyal water depths with key species including *Buliminella subfusiformis, Cassidulina crassipunctata*, and *Uvigerinella californica* (table 25; Ingle, 1980; McDougall, 1980). These strata are assigned to the Miocene Astoria (?) Formation (fig. 4) which crops out about 0.6 mi (960 m) to the east (Gower and Pease, 1965).

Strata penetrated from 900 to 5,500 ft (274 to 1,676 m) form the second biostratigraphic unit. Claystone and less common siltstone and sandy siltstone characterize the section between 900 and 3,100 ft (274 and 945 m). The section between 3,100 and 5,500 ft (945 and 1,676 m) consists of claystone, siltstone, sandy siltstone, and rare sandstone. Strata throughout the unit are commonly tuffaceous. Foraminiferal assemblages characterize the Oligocene Zemorrian Stage (fig. 2), with key taxa including *Sphaeroidina bulloides, Cibicides elmaensis* var. *A., Anomalina californiensis, Dentalina quadrulata, Valvulineria menloensis, Siphogenerina nodifera*, and *Elphidiun* cf. *E. minutum* (Rau, 1981). Although formal zones have not been established in the Zemorrian Stage of western Washington, Rau (1981) recognized upper and lower parts of the stage. In this well, the Zemorrian Stage appears to be completely represented with both upper and lower parts present, separated by a gradational boundary. Fauna in this unit suggest deposition at upper to upper middle bathyal water depths with key species including *Uvigerinella obesa impolita, Uvigerina gallowayi*, and *Globobulimina* cf. *G. pacifica* (table 25; Enbysk, 1960; Ingle, 1980). These strata are assigned to the upper part of the upper Eocene to Oligocene Lincoln Creek Formation (fig. 4), which crops out about 1.2 mi (1,900 m) to the south along the axis of the Melbourne anticline (Gower and Pease, 1965).

Strata penetrated in the well between about 5,500 and 6,100 ft (1,676 and 1,859 m) form the third biostratigraphic

unit. This unit consists commonly of tuffaceous siltstone, sandy siltstone, and sandstone, with sandstone most abundant in the lower half of the unit. Foraminiferal assemblages characterize the upper Eocene and lower Oligocene Refugian Stage (fig. 2), with significant species including *Nonion halkyardi, Ceratobulimina wasburnei, Valvulineria willapaensis,* and *Gyroidina condoni* (fig. 2; Rau, 1981). Although these Refugian strata contain many significant taxa, none are diagnostic for zonal subdivision. Fauna in this unit suggest deposition at upper to upper middle bathyal water depths with key species including *Uvigerina cocoaensis* and *Cassidulina galvinensis* (table 25). These strata are assigned to the lower part of the upper Eocene to Oligocene Lincoln Creek Formation (fig. 4). The more sandstone-rich lower portion of the Lincoln Creek is correlative with the lower basaltic sandstone member of the Lincoln Creek that has been described at many localities in southwest Washington (for example, Snavely and others, 1958; Rau, 1966).

The lowest biostratigraphic unit penetrated in the well extends from 6,100 ft to total depth at 6,928 ft (1,859 to 2,112 m). This unit consists of siltstone, mudstone, and rare sandstone. Foraminiferal assemblages characterize the middle and upper Eocene Narizian Stage (fig. 2), with characteristic species including *Bulimina schencki, Amphimorphina californica, Angulogerina hannai, Bulimina corrugata,* and *Valvulineria tumeyensis*. Assemblages from 6,100 to 6,400 ft (1,859 to 1,951 m) characterize the *Bulimina schencki-Plectofrondicularia* cf. *P jenkinsi* zone of western Washington (fig. 2; Rau, 1981). Key species are *Cibicides mcmastersi, Valvulineria* aff. *V. willapaensis, Bulimina schencki,* and *Angulogerina hannai*. Below 6,400 ft (1,951 m), faunal elements of three underlying zones, the *Uvigerina* cf. *U. yazooensis* zone, the *Bulimina* cf. *B. jacksonensis* zone, and the *Vaginulinopsis vacavillensis* assemblage, are dispersed throughout the strata. Thus, this interval is regarded as "lower Narizian, undifferentiated."

Fauna in Narizian Stage strata suggest deposition at upper middle bathyal water depths with key species including *Bulimina microcostata* and *Stilostomella* spp.(table 25; Ingle, 1980; McDougall, 1980). These rocks are assigned to the middle and upper Eocene Humptulips Formation of Rau (fig. 4; 1984, 1986), which crops out about 18 mi (29 km) northwest of the well site.

11

OHIO OIL COMPANY BERRY-ROBINSON NO. 1

The Ohio Oil Company Berry Robinson No. 1 well was drilled in 1933 on the northeastern side of Grays Harbor about 1.25 mi (2 km) northwest of Aberdeen in southern Grays Harbor County, Washington (NW 1/4, sec. 5, T. 17 N., R. 9 W.) (McFarland, 1983). It is on the southwest flank of the northwest-trending Reservoir anticline (Rau, 1986) in the western part of the Grays Harbor basin (fig. 3). Total depth was 6,725 ft (2,050 m). The description below is based on analysis of mud logs and samples collected from cuttings and cores. No electric logs are available. Foraminifera were recovered and identified in 52 samples by W.W. Rau (table 11).

No samples were available for the upper 1,400 ft (427 m) of the well. Based on surface mapping (Rau, 1986), the well was spudded in the Miocene Astoria (?) Formation (Saucesian Stage; fig. 2). The uppermost core samples contain foraminifera diagnostic of the Oligocene Zemorrian Stage (fig. 2) representing the upper part of the Lincoln Creek Formation (fig. 4). Thus, the contact between the Astoria (?) and Lincoln Creek Formations is somewhere between 0 and 1,400 ft (427 m). We place the contact at 700 ft (213 m), consistent with cross section D-D' of Rau, based mainly on surface data (1986). In surface exposures near the well site, the Astoria (?) Formation consists of siltstone, claystone, and rare thin beds of sandstone (Rau, 1986).

Four biostratigraphic units are recognized in the interval that extends from 1,400 ft (427 m) to total depth. The uppermost unit extends from about 1,400 to 1,568 ft (213 to 478 m) and consists (based on borehole samples and nearby outcrops) mainly of tuffaceous siltstone, mudstone, and sandy siltstone with scattered concretions (Rau, 1986). As described above, these strata contain Zemorrian Stage (fig. 2) foraminifera and are assigned to the upper part of the Lincoln Creek Formation (fig. 4) which crops out about 1 mi (1.6 km) north-northwest of the well site. Diagnostic Zemorrian taxa include *Uvigerina gallowayi, Cassidulina crassipunctata,* and *Anomalina californiensis.*

The second biostratigraphic unit was penetrated between about 1,568 and 2,323 ft (478 and 708 m) and also consists mainly of tuffaceous siltstone, mudstone, and sandy siltstone. These rocks are locally calcareous, micaceous, and pyrite-bearing. These strata contain upper Eocene to lower Oligocene Refugian Stage (fig. 2) foraminifera and are assigned to the lower part of the Lincoln Creek Formation (fig. 4). Significant taxa include *Ceratobulimina washburnei, Cibicides hodgei, Cancris joaquinensis, Sigmomorphina schencki,* and *Uvigerina cocoaensis*. The fauna in both the Zemorrian and Refugian parts of the Lincoln Creek Formation suggest deposition at upper middle bathyal water depths. Diagnostic species include *Pullenia bulloides* and *Eponides duprei ciervoensis* (table 25; Ingle, 1980; McDougall, 1980). Strata of the overlying Astoria (?) Formation were probably also deposited at bathyal water depths based on similar lithology and faunas from nearby outcrops.

Strata of the third biostratigraphic unit were penetrated between about 2,323 and 5,250 ft (708 and 1,600 m). The lower contact of this unit is arbitrarily placed between samples containing different faunas collected at 4,498 ft (1,371 m) and 5,345 ft (1,629 m). Strata in this unit also

consist of siltstone, mudstone, and sandy siltstone and are locally calcareous, micaceous, and pyritic. Middle and upper Eocene Narizian Stage (fig. 2) foraminifera were recovered from the unit with key species including *Plectofrondicularia* cf. *P. jenkinsi, Lenticulina welchi, Valvulineria tumeyensis, Bulimina corrugata, Uvigerina* cf. *U. yazooensis*, and *Amphimorphina californica*. Foraminifera from this interval suggest deposition at lower middle bathyal water depths with key indicators including *Bulimina corrugata* and *Stilostomella spp.* (table 25; Ingle, 1980; McDougall, 1980). These strata are assigned to the middle and upper Eocene Humptulips Formation (fig. 4; Rau, 1984, 1986), which crops out about 10 mi (16 km) to the northwest.

The lowest units penetrated in the well consists of sedimentary rock (siltstone, mudstone, minor sandstone) penetrated from about 5,250 to 5,560 ft (1,600 to 1,695 m) and basaltic volcanic rock penetrated from about 5,560 ft (1,695 m) to total depth of 6,725 ft (2,050 m). Foraminifera recovered from two samples in the upper sedimentary part of the penetrated section typify the lower to middle Eocene Ulatisian Stage (fig. 2). Characteristic taxa include *Spiroplectammina directa, Uvigerina churchi, Pleurostomella* cf. *P. nuttalli*, and *Cibicides* cf. *C. venezuelanus*. Foraminifera from this interval suggest deposition at lower to lower middle bathyal water depths, with key indicators including *Cibicides alhambrensis ouachitaensis* and *Pleurostomella* cf. *P. nuttalli* (table 25; Ingle, 1980). Both the sedimentary and volcanic rocks in this unit are assigned to the lower and middle Eocene Crescent Formation, which crops out about 11 mi (18 km) northwest of the well site and forms the basement for southwest Washington. Snavely (1991) described a similar sedimentary unit on top of Crescent-equivalent volcanic rocks (Siletz River Volcanics) in the central Oregon Coast Range and assigned these strata to a new unit, the Salmon River Formation. Outcrop data indicate the contact between the Siletz River Volcanics and the Salmon River Formation is an unconformity.

12

AMOCO PRODUCTION COMPANY AMOCO-WEYERHAEUSER NO. 1-29

The Amoco Production Company Amoco-Weyerhaeuser No. 1-29 well was drilled in 1984 and 1985 about 1 mile (1.6 km) west of the Wynoochee River in east-central Grays Harbor County, Washington (SW 1/4, sec. 29, T. 19 N., R. 8 W.). It is near the northwest-trending axis of the Wynoochee River syncline on the north flank of the Grays Harbor basin (fig. 4; Rau, 1967). Total depth was 12,293 ft (3,747 m). The description below is based on analysis of geophysical logs and mudlogs and samples collected from cuttings. Foraminifera were recovered and identified in 44 samples by W.W. Rau (table 12). Five units were recognized based on samples and log interpretations.

The middle and upper Miocene Montesano Formation (fig. 4) extends downward from the surface to about 1,550 ft (472 m). The Montesano consists of locally carbonaceous and micaceous sandstone and siltstone. Foraminifera recovered from samples between 170 and 850 ft (52 and 259 m) characterize the middle Miocene to lower Pliocene Mohnian and Delmontian Stages (undifferentiated; fig. 2), with key species including *Epistominella pacifica, Virgulina californiensis ticensis, Bulimina curta*, and *Uvigerina modeloensis*. The most frequently occurring taxa in this interval, *Cassidulina laevigata, Epistominella pacifica*, and *Buliminella curta*, suggest water depths varying from outer neritic to upper middle bathyal (Ingle, 1980). Upper to upper middle bathyal water depths are therefore inferred.

Rocks assigned to the lower and middle Miocene Astoria (?) Formation are present from about 1,550 to 3,200 ft (472 to 975 m). These strata consist mainly of siltstone that is locally carbonaceous and micaceous, resembling outcrops of the Astoria (?) Formation about 1.2 mi (2 km) northeast of the well site (Rau, 1967). Foraminifera recovered from samples between 1,570 and 3,180 ft (479 and 969 m) characterize the lower and middle Miocene Relizian and Saucesian stages (fig. 2), with key species including *Uvigerinella californica ornata, Buccella mansfieldi oregonenesis, Siphogenerina kleinpelli, Valvulineria araucana, Bulimina inflata alligata*, and *Baggina washingtonensis*. Although some faunal elements of both the *Baggina washingtonensis* zone and the *Siphogenerina kleinpelli* zone are present, a zonal boundary is not clearly evident. We therefore refer this interval to those zones undifferentiated. An uppermost zone of the southwestern Washington Miocene section, the *Rotalia becki* zone, is clearly missing in this sequence. The absence of this zone is consistent with an unconformity between the Montesano and Astoria (?) Formations that has been recognized elsewhere in the region (Rau, 1967; Rau and Armentrout, 1983).

The fauna of the Astoria (?) Formation suggests a gradual shoaling of water from upper middle bathyal depths for the lower part of the interval, as indicated by *Siphogenerina kleinpelli* and *Valvulineria araucana*, to upper bathyal conditions for the upper part of the interval where *Cassidulina transluscens* and *Uvigerinella californica ornata* consistently are found (table 25; Enbysk, 1960; Ingle, 1980). The fauna and lithology described above typify the lower and middle parts of the Astoria (?) Formation.

Rocks assigned to the Oligocene Lincoln Creek Formation (fig. 4) are present from about 3,200 to 8,500 ft (975 to 2,591 m). These strata consist of tuffaceous, concretionary, fossiliferous claystone, siltstone, and less common sandstone, similar to outcrops of the Lincoln Creek Formation that are about 2 mi (3.2 km) north of the well site (Rau, 1967). Intervals that contain the highest proportion of sandstone are between 3,750 and 4,350 ft (1,143 and 1,326 m),

4,700 and 4,860 ft (1,433 and 1,481 m), and 5,780 and 6,000 ft (1,762 and 1,829 m). The contact between the Astoria (?) and Lincoln Creek Formations appears gradational and its position is tentative. The highest possible Oligocene Zemorrian Stage (fig. 2) indicator (*Guadryina alazanensis*) is at about 3,265 ft (995 m). From this depth to 4,120 ft (1,256 m), both Saucesian Stage foraminifera and species common to the Zemorrian Stage are present (fig. 2). The first occurrence of taxa restricted to Zemorrian and older strata (*Uvigerina gallowayi* and *Eponides duprei*) is at about 4,165 ft (1,269 m). Additional Zemorrian species are between 4,210 and 5,860 ft (1,283 and 1,786 m) include *Bulimina alsatica, Dentalina quadrulata, Gyroidina condoni*, and *Hoeglundina eocenica*. Foraminifera recovered in the Lincoln Creek Formation interval suggest deposition at upper to upper middle bathyal water depths with key species including *Globulimina* cf. *G. pacifica, Gyroidina orbicularis planata, Eponides duprei*, and *Uvigerina gallowayi* (table 25; Enbysk, 1960; Ingle, 1980).

Strata penetrated between 5,860 and 9,000 ft (1,786 and 2,743 m) produced no reliable foraminifera data. The contact at 8,500 ft (2,591 m) between the Lincoln Creek Formation and the underlying Humptulips Formation is based on analysis of cuttings and electric logs which suggest a downward decrease in grain size, and on regional stratigraphy and unit thicknesses. Rau's (1967) cross sections from the Wynoochee Valley and other data from the northern flank of the Grays Harbor basin (Rau, 1966; Beikman and others, 1967; Armentrout, 1973; Rau and Armentrout, 1983) suggest the Lincoln Creek Formation ranges in thickness from about 5,000 to 9,000 ft (1,500 to 2,750 m). Nearby outcrops of the Lincoln Creek Formation contain upper Eocene to lower Oligocene Refugian Stage (fig. 2) foraminifera, a time interval not represented in well samples. Thus, a considerable part of the unfossiliferous part of the section penetrated in the borehole most likely belongs to the Lincoln Creek Formation.

Siltstone, claystone, and minor sandstone that are assigned to the middle Eocene Humptulips Formation (fig. 4) were penetrated between about 8,500 and 11,500 ft (2,591 and 3,505 m). Intervals that contain the highest proportion of sandstone are between 10,320 and 10,520 ft (3,146 and 3,206) and 10,780 and 10,900 ft (3,286 and 3,322 m). Within this unit, a sparse Narizian Stage (fig. 2) foraminiferal assemblage was recovered from between 9,000 and 9,390 ft (2,743 and 2,862 m); otherwise, the unit is apparently barren of fossils. The thickness assigned to the Humptulips Formation in this well is similar to that reported in the nearby Ohio Oil Company Berry Robinson No. 1 well (this report) and in outcrops east and west of the well site on the north flank of the Grays Harbor basin (Rau, 1984). Key Narizian species include *Bulimina corrugata, Vaginulinopsis saundersi*, and *Cibicides natlandi*. Paleobathymetric indicators are sparse; the possible presence of *Bulimina corrugata* suggests lower-middle bathyal water depths (Ingle, 1980; McDougall, 1980).

Rocks penetrated in the well between 11,500 feet and total depth of 12,293 ft (3,505 and 3,747 m) are tentatively assigned to the lower to middle Eocene Crescent Formation. Within the Crescent Formation, the upper 660 ft (201 m) of the interval consists of siltstone, claystone, and minor sandstone and the lower 134 ft (41 m) consists of basalt. No fossils were recovered from these strata. The thickness we've assigned to the section of clastic rocks at the top of the mainly volcanic Crescent Formation (660 ft, 201 m) is similar to that reported for the Continental Oil Company City of Hoquiam No. 1 well (this report). On the northwest Olympic Peninsula and in the central Oregon Coast Range, Snavely and others (1993a, b) have defined a thin sedimentary sequence above the Crescent Formation as distinct stratigraphic unit. Information from a few wells, however, is insufficient to make a similar distinction in southwest Washington.

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CONTINENTAL OIL COMPANY CITY OF HOQUIAM NO. 1

The Continental Oil Company City of Hoquiam No. 1 well was drilled in 1954 in the northwest part of the Grays Harbor basin (fig. 3). The well was spudded in Quaternary deposits adjacent to the west fork of the Hoquiam River about 6 mi (10 km) north of Hoquiam in west-central Grays Harbor County, Washington (NW 1/4, sec. 3, T. 18 N., R. 10 W.) (McFarland, 1983). Total depth was 3,737 ft (1,139 m). The description below is based on analysis of geophysical logs and mudlogs and samples collected from cuttings and cores. Foraminifera were recovered and identified from 28 samples by W.W. Rau (table 13).

Logs and samples are lacking for the upper 260 ft (79 m) of the well, which penetrated Quaternary alluvium and possibly the upper Miocene Montesano Formation (fig. 4), which crops out about 3 mi (5 km) to the west along the east fork of the Hoquiam River (Rau, 1986). Four biostratigraphic units are recognized in strata below 260 ft (79 m). The uppermost unit extends from about 260 to 760 ft (79 to 232 m) and consists almost entirely of siltstone and claystone. Foraminifera recovered from this interval represent the middle Eocene Narizian Stage (fig. 2), with significant species including *Plectofrondicularia packardi, Anomalina* cf. *A. garzaensis, Alabamina wilcoxensis californica*, and *Uvigerina garzaensis* (Rau, 1981). Foraminifera from the sequence include species such as *Gyroidina soldanii octocamerata, Anomalina cf. A. garzaensis, Uvigerina garzaensis*, and *Globobulimina* cf. *G. pacifica* that are thought to have lived at upper to lower bathyal water depths (table 25; Enbysk, 1960; Ingle, 1980; McDougall, 1980), so deposition in the deeper part of this range is likely. These rocks are assigned to the Eocene Humptulips Formation (fig. 4), which crops out about 2.5 mi (4 km) to the northwest (Rau, 1986).

The second biostratigraphic unit was penetrated between 760 and 2,460 ft (232 and 750 m) and similarly consists of siltstone and claystone. Foraminifera recovered from this interval represent the *Bulimina* cf. *B. jacksonensis* zone of the lower to middle Eocene Ulatisian Stage (fig. 2; Rau, 1981), with significant species including *Cibicides venezuelanus, Cibicides* cf. *C. spiropunctatus, Asterigerina crassaformis*, and *Vaginulinopsis cf. V. Mexicana.* Foraminifera from this sequence include a mix of species (such as *Gyroidina soldanii octocamerata, Uvigerina garzaensis, Cibicides* cf. *C. spiropunctatus*, and *Cibicides* cf. *C. pachyderma*) that probably lived at variable bathyal depths (table 25; Ingle, 1980; McDougall, 1980), suggesting deposition in the deeper part of this range. These strata are tentatively assigned to the lower part of the Humptulips Formation (fig. 4) based on lithology. However, prior to this report, rocks of the Humptulips have been restricted to only the Narizian Stage (Rau, 1984, 1986). The underlying and mainly volcanic Crescent Formation is characterized by the older lower Ulatisian *Vaginulinopsis vacavillensis* assemblage and by pre-Ulatisian assemblages (fig. 4; Rau, 1981).

The third biostratigraphic unit was penetrated between about 2,460 and 2,960 ft (750 and 902 m) and also consists of mainly siltstone and claystone. Foraminifera recovered from this interval represent the *Vaginulinopsis Vacavillensis* zone of the lower Ulatisian Stage (fig. 2; Rau, 1981) with key taxa including *Amphistegina* spp., *Vaginulinopsis* cf. *V. vacavillensis*, and *Bulimina lirata.* Additional taxa in this lower Ulatisian sequence suggest general bathyal deposition, particularly *Bulimina microcostata* and *Plectofrondicularia* cf. *P. vaughani* (table 25; Ingle, 1980; McDougall, 1980). These rocks are assigned to the upper, clastic part of the mainly volcanic lower and middle Eocene Crescent Formation. The Crescent Formation crops out about 4 miles (6.5 km) northwest of the well site (Rau, 1986). On the northwest Olympic Peninsula and in the central Oregon Coast Range, Snavely and others (1993a, b) have defined a thin sedimentary sequence above the Crescent Formation as distinct stratigraphic units. Information from a few wells, however, is insufficient to make a similar distinction in southwest Washington.

The lowest biostratigraphic unit extends from 2,960 ft to total depth at 3,737 ft (902 to 1,139 m). The upper 140 ft (43 m) of this interval consists of siltstone and claystone. Below this clastic interval, rocks are predominantly basalt (based on a few samples and log interpretation). Foraminifera recovered from the upper clastic part of this biostratigraphic unit are of pre-Ulatisian early Eocene age (fig. 4), as indicated by the first occurrence of *Anomalina dorri aragonensis* (Rau, 1981). Limited paleobathymetric evidence suggests that these pre-Ulatisian rocks may also have been deposited at bathyal water depths. Rocks of this lowest biostratigraphic unit are also assigned to the lower and middle Eocene Crescent Formation.

14

UNION OIL COMPANY OF CALIFORNIA BANNSE NO. 1

The Union Oil Company Bannse No. 1 well was drilled in 1948 and 1949 in the valley of the Skookumchuck River, Thurston County, Washington (NW 1/4, sec. 22, T. 15 N., R. 2 W.), about 4 mi (6.4 km) northeast of Centralia. It is on the uplift north of the Chehalis basin (fig. 2) on the crest of an unnamed anticline mapped by Snavely and others (1958). Total depth was 4,330 ft (1,320 m). The description below is based on interpretation of geophysical logs and mud logs and analysis of samples (by W.W. Rau) collected from cores and cuttings. Foraminifera were collected and identified in 16 samples (table 14). Some of this information was included in Rau (1958).

Alluvial and glacial(?) sand and gravel of Pleistocene and Holocene age were encountered in the uppermost 200 ft (61 m) of this well. These unconsolidated deposits unconformably overlie an upper Eocene section of sedimentary and minor igneous bedrock that extends to total depth. Three units are recognized in this section based on lithologic and biostratigraphic information.

Strata penetrated between 200 and 860 ft (61 and 262 m) consist of interbedded sandstone and siltstone with common carbonaceous material, minor coal, and rare marine fossils. Sandstone is most abundant between 420 and 750 ft (128 and 229 m), with more fine-grained strata predominating above and below this interval. Foraminifera were recovered from one interval at 375 ft (114 m) and are characteristic of the *Bulimina schencki-Plectofrondicularia* cf. *P. jenkinsi* zone of the middle to upper Eocene Narizian Stage (fig. 2; Rau, 1981). The foraminiferal assemblage suggests an inner neritic depositional environment with key species including *Quinqueloculina minuta* and *Elphidium* spp.(table 25; Ingle, 1980). These rocks are assigned to the upper middle to upper Eocene Skookumchuck Formation (Snavely and others, 1958), which crops out just 600 ft (183 m) to the west on the west flank of the Skookumchuck River valley. Five mi (8 km) to the east in the Centralia mine, the upper part of the Skookumchuck Formation includes thick coal beds of coastal plain origin (Brownfield and others, 1994; Flores and Johnson, 1995). The interval penetrated in this well, however, correlates with the lower coal group of the Skookumchuck Formation (Snavely and others, 1958, p. 113), which includes only one significant coal bed.

The interval between 860 and 1,560 ft (262 and 476 m) penetrated in the well consists of tuffaceous sandstone and siltstone, and thin andesite flows. Rocks penetrated between 1,750 and 1,900 ft (533 and 579 m) consist mainly of tuffaceous sandstone. On the basis of lithology and stratigraphic position, these strata are assigned to the upper middle to upper Eocene Northcraft Formation (fig. 4). The Northcraft underlies and

interfingers with the Skookumchuck Formation, and overlies and interfingers with the middle Eocene McIntosh Formation. The Northcraft Formation crops out 7 mi (11.3 km) to the east of the well site (Snavely and others, 1958).

Intervals penetrated between 1,560 and 1,750 ft (476 and 579 m) and 1,900 ft to 4,156 ft (579 to 1,267 m) are assigned to the McIntosh Formation. The upper of these two intervals consists of a coarsening upward sandstone sequence that is probably correlative with a thick sandstone unit at the top of the McIntosh Formation exposed 6 mi (9.7 km) to the northeast of the well site at Tenino (Snavely and others, 1958). The lower interval consists of mudstone, siltstone, and minor sandstone that is locally fossiliferous or carbonaceous. Foraminifera recovered from samples between 2,110 and 3,149 ft (643 and 960 m) represent the *Uvigerina* cf. *U. yazooensis* zone of the Narizian Stage (fig. 2; Rau, 1981). A few key species include *U. yazooensis, Gyroidina simiensis, Valvulineria jacksonensis welcomensis*, and *V. tumeyensis*. Foraminifera recovered from samples between 3,364 and 3,826 ft (1,025 and 1,166 m) represent the *Bulimina* cf. *B. jacksonensis* zone of the Narizian Stage (fig. 2; Rau, 1981). Key species include *B. jacksonensis* and *Amphimorphina californica*. Foraminifera from both zones in the McIntosh Formation suggest deposition at middle to upper bathyal water depths, significantly deeper than those inferred for the Skookumchuck Formation. Species indicative of bathyal depths include *Bulimina corrugata, B. jacksonensis, Uvigerina* cf. *U. yazooensis*, and *Globobulimina pupoides* (table 25; Ingle, 1980; McDougall, 1980).

Igneous rocks, interpreted by Snavely and others (1958) as an Oligocene intrusion, were penetrated between 4,156 and 4,330 ft (1,267 and 1,320 m) at the base of the section.

15

EARL F. SILER AND J.W. TANNER KOSTICK NO. 1

The Earl F. Siler and J.W. Tanner Kostick No. 1 well was drilled in 1955 and 1956 in the valley of Coal Creek, Lewis County, Washington (SE 1/4, sec. 29, T. 14 N., R. 2 W.), about 0.5 mi (0.8 km) north of Chehalis. It is on the southwest flank of the Chehalis anticline, about 0.7 mi (1.1 km) north of the Chehalis-Doty fault zone on the north flank of the Chehalis basin (Snavely and others, 1958). Total depth was 9,455 ft (2,882 m). The description below is based on analysis of geophysical logs and mudlogs and samples collected from cuttings. Foraminifera were identified in 29 samples by R.E. Stewart (paleontological consultant, personal communication to W.W. Rau, 1956), and three biostratigraphic units were recognized (table 15). Stratigraphic control was also provided by a nearby proprietary seismic reflection profile (Stanley and others, 1994; Johnson and Stanley, 1995). Strata are assigned to the Eocene Skookumchuck and McIntosh Formations (Snavely and others, 1958).

Rocks penetrated in the upper 3,400 ft (1,036 m) of the well consist of sandstone, siltstone, mudstone, and coal, and are assigned to the middle to upper Eocene Skookumchuck Formation. The well was spudded at the approximate stratigraphic position of the Tono coal beds, and numerous coal beds are in the upper 1,400 ft (427 m). This interval is similar in thickness to (adjusted for a structural dip of 35°) and is correlated with the upper coal group of the Skookumchuck recognized by Snavely and others (1958). Flores and Johnson (1995) recently described the stratigraphy and sedimentology of most of this interval from exposures in the Centralia coal mine and suggested that these strata formed in tidal flat and channel, peat swamp, shoreface, and inner shelf depositional environments. Strata penetrated between 1,400 and 3,400 ft (427 and 1,280 m) contain fewer coal beds and represent the lower part of the Skookumchuck Formation. Foraminifera recovered between 130 and 1,870 ft (40 and 570 m) typify the upper Narizian Stage *Bulimina schencki-Plectofrondicularia* cf. *P. jenkinsi* zone of southwest Washington (fig. 2; Rau, 1981). Significant taxa (apart from those for which the zone is named) include *Cibicides natlandi, Florilus* cf. *F. inflatum*, and *Quinqueloculina weaveri*. The fauna suggest that environments of deposition shoaled upward from outer-neritic to littoral depths within this upper 1,870 ft (570 m), consistent with the sedimentologic interpretations of Flores and Johnson (1995). Key paleobathymetric indicators include *Florilus* cf. *F. inflatum* and *Elphidium cf. E. minutum*.

No fossils were recovered from the interval between 1,870 and 6,190 ft (570 and 1,887 m). We assign strata penetrated between 3,400 and 9,455 ft (1,036 and 2,882 m) to the middle Eocene McIntosh Formation (fig. 4). The Skookumchuck-McIntosh contact is placed at 3,400 ft (1,036 m) in order to be consistent with stratigraphic thicknesses inferred from detailed field observations (Snavely and others, 1958).

The upper part of the McIntosh Formation consists of sandstone and lesser amounts of siltstone and coal, and correlates with the thick sandstone-rich interval at the top of the McIntosh Formation exposed 14 mi (23 km) to the north near Tenino (Snavely and others, 1958). As in the Tenino outcrops (Johnson and Stanley, 1995), the upper part of the McIntosh Formation penetrated in the Kostick No. 1 well probably represents a range of delta plain environments. The middle part of this interval, from 4,300 to 6,100 feet (1,311 and 1,859 m), consists mainly of locally carbonaceous and tuffaceous siltstone and minor sandstone. This middle interval is unfossiliferous but its lithology and stratigraphic position suggest deposition at neritic and possibly upper bathyal water depths (see below).

Strata penetrated between 6,100 ft to 9,445 ft (1,859 and 2,879 m) belong to the lower part of the McIntosh Formation and consist of interbedded sedimentary rocks (siltstone,

mudstone, minor sandstone) and volcanic rocks (flows and volcaniclastics). Foraminiferal faunas described for samples between 6,190 and 6,330 ft (1,887 and 1,929 m) are characteristic of the middle Narizian Stage *Uvigerina* cf. *U. yazooensis* zone of southwest Washington (fig. 2; Rau, 1981), with typical taxa including *Valvulineria tumeyensis, Cibicides warreni*, and *Bolivina basisenta oregonensis*. Upper bathyal water depths were most likely based on the occurrence of *Uvigerina* cf. *U. yazooensis*, *Bolivina basisenta oregonensis* and *Valvulineria tumeyensis* (table 25; Ingle, 1980; McDougall, 1980). No fossil data are available for the interval between 6,330 and 7,730 ft (1,887 and 2,356 m). Foraminiferal faunas described for samples between 7,730 and 9,430 ft (2,356 and 2,874 m) typify the upper Ulatisian Stage to lower Narizian Stage *Bulimina* cf. *B. jacksonensis* zone of southwest Washington (fig. 2; Rau, 1981), with key taxa including *Vulvulineria jacksonensis welcomensis, Bulimina corrugata*, and *Amphimorphina californica*. This fauna suggests deposition at middle bathyal water depths, with key species including *Globobulimina pacifica*, *Bulimina* aff. *B. instabilis*, and *Bulimina corrugata* (table 25; Enbysk, 1960; Ingle, 1980; McDougall, 1980). Taken as a whole, the section penetrated by this well apparently represents fairly continuous upward shoaling.

The volcanic rocks interbedded with the McIntosh Formation in this well are somewhat enigmatic in that their stratigraphic position is lower than that generally assigned to the volcanic Northcraft Formation and higher than that assigned to the Crescent Formation. The middle to upper Eocene Northcraft Formation is exposed about 10 mi (16 km) to the east and in wells to the north (for example, the Union Oil Company of California Bannse No. 1, this report) and southeast (for example, the Selburn-Washington Oil Corporation Wulz No. 1, this report), is mainly subaerial, and is between the Skookumchuck and McIntosh Formations (Snavely and others, 1958). The lack of volcanic rocks between the Skookumchuck and McIntosh Formations at about 3,000 to 4,000 ft (914 to 1,219 m) in this well and the bathyal marine origin of volcanic strata in the McIntosh Formation at about 6,000 ft (1,829 m) strongly suggests that the Northcraft Formation pinches out east of the Kostick No. 1 well site. The lower to middle Eocene Crescent Formation is typically characterized by lower to middle Ulatisian Stage and older(?)*Vaginulinopsis vacavillensis* assemblage foraminifera and is older than the McIntosh Formation (figs. 2, 4). Proprietary seismic reflection data reveal that the top of the Crescent Formation, a high-amplitude discontinuous reflection that can be traced southward from the Black Hills (about 15 mi (24 km) to the north) to the Chehalis River Valley 1 mi (1,600 m) west of the Kostick No. 1 well site, should be within about 1,000 ft (300 m) below total depth of this borehole. Given this information, we think that the volcanic rocks within the lower part of the McIntosh Formation were derived from a small unrecognized marine volcanic center and are correlative with the Pe Ell volcanics member of the Cowlitz Formation of Henriksen (1956) which crops out 14 mi (23 km) to the west of the borehole or with the Grays River volcanics (Wells, 1981; Walsh and others, 1987), which crops out 17 mi (27 km) to the south. Comparable small volcanic centers slightly younger than the Crescent Formation have also been described from the perimeter of the Olympic Mountains (Snavely and others, 1993a).

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SELBURN-WASHINGTON OIL CORPORATION WULZ NO. 1

The Selburn-Washington Oil Corporation Wulz No. 1 well was drilled in 1952 in the north-central part of the Chehalis Basin (fig. 3), Lewis County, Washington (NE 1/4, sec. 29, T. 13 N., R. 1 W.), about 8 mi (13 km) southeast of Chehalis. Snavely and others (1958, cross section C-C') suggested the well was located on a gentle structural arch within the Chehalis basin. Proprietary seismic reflection data collected in 1983 reveals that the well was drilled about 0.3 mi (500 m) east of the crest of this arch. Total depth was 6,500 ft (1,981 m). The description below is based on analysis of geophysical logs and mudlogs, core descriptions, and samples collected from cuttings. Foraminifera were identified in 37 samples by Harold Billman and James Eke of Union Oil Company (written commun., 1954, to W.W. Rau; table 16).

The Wulz No. 1 well was spudded in deposits of Pleistocene(?) sand and gravel assigned to the Logan Hill Formation (Snavely and others, 1958). Between about 150 and 800 ft (46 and 244 m), the well penetrated nonmarine rocks of probable late middle and (or) late Miocene age. Analysis of cuttings indicates the lower part of this interval consists of siltstone, sandstone, and conglomerate. Snavely and others (1958) referred to these rocks as unnamed nonmarine sedimentary rocks, whereas Schasse (1987) mapped them as the Wilkes Formation (fig. 4). The nearest exposures of this unit are about 1.5 mi (2.4 km) northwest of the well site (Snavely and others, 1958).

Strata assigned to the Oligocene Lincoln Creek Formation (fig. 4) were penetrated between about 800 and 2,325 ft (244 and 709 m) in the well. The upper contact is revised upward from Rau (1958) and Snavely and others (1958) based on more detailed analysis of cuttings. Strata mainly consist of tuffaceous siltstone; sandstone is most abundant between 1,100 and 1,200 ft (335 and 366 m) and 2,225 and 2,325 ft (678 and 709 m). Foraminifera recovered from 1,370 and 2,060 ft (418 and 628 m) in this interval are typical of the *Sigmomorphina schencki* zone of the lower part of the Refugian Stage (fig. 2; Rau, 1981). A complete section of the Lincoln Creek Formation includes faunas of both the Refugian and younger Zemorrian stages (Beikman and others, 1967; Rau and others, 1983). Therefore, the rocks penetrated in this

well comprise only the lower part of the Lincoln Creek Formation, and the upper contact of this unit represents a significant unconformity. Characteristic foraminifera of the *Sigmomorphina schencki* zone found in this well include *Ceratobulimina washburnei, Cibicides natlandi, Sigmomorphina schencki*, and Valvulineria willapaensis (Rau, 1981). The combined presence of *Eponides kleinpelli* and *Globocassidulina globosa* suggest deposition at neritic water depths (table 25; Ingle, 1980; McDougall, 1980). The Lincoln Creek Formation crops out about 5 mi (8 km) to the north on the north flank of the Chehalis basin.

Strata penetrated between 2,325 and 6,500 ft (709 and 1,981 m) are assigned to the middle to upper Eocene Skookumchuck Formation (fig. 4), which crops out about 6.5 mi (10 km) to the north and northwest. Gabbroic intrusive rocks of Oligocene(?) age (Snavely and others, 1958) intrude the Skookumchuck Formation at several horizons between about 2,325 and 2,850 ft (709 and 869 m), 4,175 and 4,450 ft (1,273 and 1,356 m), and 4,950 and 5,000 ft (1,509 and 1,524 m). Skookumchuck Formation consists of interbedded sandstone, siltstone, mudstone, and coal. Coal beds are most abundant between about 3,000 and 4,100 ft (914 and 1,250 m), an interval that is of similar thickness to and considered correlative with the most coal-rich horizon (between the Mendota and Tono beds) in exposures of the Skookumchuck Formation to the north (Snavely and others, 1958). The interval between 5,200 and 6,000 ft (1,585 and 1,829 m) contains the highest proportion of fine-grained sedimentary rocks. Rau (1958) and Snavely and others (1958) previously assigned the interval between 6,000 and 6,500 ft (1,829 and 1,981 m) in this well to the middle Eocene McIntosh Formation, but that assignment is changed here based on additional analysis of Chehalis basin subsurface data.

Foraminifera recovered from the Skookumchuck Formation between 3,840 and 6,500 ft (1,170 and 1,981 m) are representative of the *Bulimina schencki-Plectofrondicularia* cf. *P. jenkinsi* zone, belonging to the upper part of the Narizian Stage (fig. 2; Rau, 1981). Significant species (other than those for which the zone is named) include *Quinqueloculina goodspeedi, Gyroidina condoni, Bolivina basisenta oregonensis*, and *Valvulineria* aff. *V. willapaensis*. Foraminiferal assemblages suggest deposition variously from inner to outer neritic water depths for the upper, coal-bearing part of the penetrated section (above about 5,000 ft (1,524 m)), and upper bathyal water depths for the lower part of the section. In the upper part of the Skookumchuck section, shallow marine facies apparently interfinger with coastal-plain facies as described by Flores and Johnson (1995) from the Centralia coal mine. Key species suggesting neritic deposition for the upper interval include *Eponides yeguaensis* and *Quinqueloculina* spp. Key species supporting bathyal deposition for the lower interval include *Plectofrondicularia searsi, Uvigerina garzaensis*, and *Bolivina basisenta oregonensis* (table 25; Ingle, 1980; McDougall, 1980).

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PLEASANT VALLEY GAS AND OIL COMPANY GUENTHER NO. 1

The Pleasant Valley Gas and Oil Company Guenther No. 1 well was drilled in 1958 at Jackson Prairie in the central part of the Chehalis Basin (fig. 3), Lewis County, Washington (S 1/2, sec. 8, T. 12 N., R. 1 W.), about 11 mi (18 km) southeast of Chehalis. Mapping by Schasse (1987) suggests the well was located near the axis of a north-northwest trending syncline, the subsurface northern extension of a fold mapped in uplifted Tertiary rocks on the southeast margin of the Chehalis basin (Phillips, 1987a; Walsh and others, 1987). A proprietary seismic reflection profile across the trend of this syncline about 2.5 mi (4 km) north of the well site reveals very gentle dips on the syncline flanks. Total depth was 8,015 ft (2,443 m). The well penetrated numerous high-porosity sandstone bodies in the Eocene Skookumchuck Formation (fig. 4; see below). These sandstone bodies were recognized as suitable gas-storage reservoirs, and the area near the Guenther No. 1 well was developed as the site of the Jackson Prairie Gas Storage project operated by Washington Natural Gas (Wurden and Ford, 1976). Since the Guenther No. 1 well was drilled, more than 75 gas-storage wells have been drilled in the 3,000 acre (12 km2) gas storage project area (McFarland, 1983). The description below is based on analysis of geophysical logs and mudlogs, core descriptions, and samples collected from cuttings. Foraminifera were identified in 25 samples by W.W. Rau (table 17).

From 0 to 400 ft (0 to 122 m), the Guenther No. 1 well penetrated deposits of Pleistocene(?) sand and gravel that Schasse (1987) assigned to the Logan Hill Formation. From about 400 to 750 ft (122 to 229 m), the well penetrated mainly carbonaceous siltstone and mudstone of probable late middle and (or) late Miocene age. Snavely and others (1958) referred to these strata as unnamed nonmarine sedimentary rocks, whereas Schasse (1987) assigned them to the Wilkes Formation (fig. 4). The nearest exposures of the Wilkes Formation are about 3.5 mi (5.5 km) northwest of the well site (Snavely and others, 1958; Schasse, 1987).

Strata assigned to the Oligocene Lincoln Creek Formation (fig. 4) were penetrated between about 750 and 1,600 ft (229 and 488 m) in the well and consist mainly of tuffaceous siltstone. Basaltic sandstone and locally carbonaceous mudstone are less common lithofacies. Foraminifera recovered from 1,000 to 1,600 ft (305 and 488 m) in this interval are typical of the Refugian Stage, particularly the *Sigmomorphina schencki* zone which represents the lower part of the stage (Rau, 1981; fig. 2). A complete section of the Lincoln Creek Formation in southwest Washington includes faunas of both the Refugian and overlying Zemorrian stages (Beikman and others, 1967; Rau and others, 1983). Therefore, the rocks penetrated in the Guenther No. 1 well comprise only

the lower part of the Lincoln Creek Formation, and the upper contact of the Lincoln Creek in this well represents a significant unconformity. Characteristic foraminifera of the *Sigmomorphina schencki* zone found in this well include *Uvigerina cocoaensis, Uvigerina atwilli, Ceratobulimina washburnei,* and *Valvulineria willapaensis* (Rau, 1981). The occurrence of taxa such as *Elphidium californicum* and possibly *Valvulineria willapaensis* in the lower 150 ft (45.7 m) of this Refugian sequence, suggests that deposition took place at neritic depths (table 25; Ingle, 1980; McDougall, 1980). The occurrence of deeper water taxa (such as *Uvigerina cocoaensis* and *Gyroidina orbicularis planata*) suggests bathyal water depths for the remaining upper part of the sequence (table 25; Ingle, 1980; McDougall, 1980). The Lincoln Creek Formation crops out about 9 mi (14 km) to the north on the north flank of the Chehalis basin.

Strata penetrated between 1,600 and 8,015 ft (488 and 2,443 m) are assigned to the middle to upper Eocene Skookumchuck Formation (fig. 4), which crops out about 10 miles (16 km) to the north. These strata consist of interbedded sandstone, siltstone, mudstone, and coal. Coal beds are most abundant between about 2,600 and 4,400 ft (793 and 1,341 m), an interval that is roughly correlative with the most coal-rich horizon (between the Mendota and Tono beds) in exposures of the Skookumchuck Formation to the north (Snavely and others, 1958). The interval between 6,800 and 8,015 ft (1,829 and 2,443 m) contains the highest proportion of fine-grained sedimentary rocks. Gabbroic intrusive rocks of Oligocene(?) age (Snavely and others, 1958) intrude the Skookumchuck Formation between about 1,900 and 2,500 ft (579 and 762 m).

Foraminifera recovered from the Skookumchuck Formation between 1,620 and 1,700 ft (494 and 518 m) and between 3,460 and 6,500 ft (1,055 and 1,981 m) are representative of the *Bulimina schencki-Plectofrondicularia* cf. *P. jenkinsi* zone, belonging to the upper part of the Narizian Stage (fig. 2; Rau, 1981). Significant species include *Bulimina schencki, Valvulineria* aff. *V. willapaensis, Cibicides natlandi, Quinqueloculina weaveri,* and *Bolivina basisenta oregonensis.*

The preponderance of neritic taxa, including *Cibicides natlandi, Cibicides mcmastersi, Pullenia* cf. *P. salisburyi, Eponides yeguaensis,* and *Florilus* cf. *F. inflatum* within the coal-bearing interval between 1,620 and 3,800 ft (494 and 1,158), suggest deposition of the upper Skookumchuck Formation fluctuated between nonmarine and inner to possibly outer neritic environments (table 25; Ingle, 1980; McDougall, 1980). Lower in the section between 5,860 and 6,520 ft (1,786 and 1,987 m), the presence of bathyal taxa including *Bolivina basisenta oregonensis, Uvigerina* cf. *U. garzaensis,* and *Plectofrondicularia* spp. indicate that deposition was at times in water at least as deep as upper bathyal (McDougall, 1980).

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HUMBLE OIL AND REFINING COMPANY ROSCOE B. PERRY ET UX NO. 1

The Humble Oil and Refining Company Roscoe B. Perry et ux No. 1 well was drilled in 1962 in the central part of the Chehalis Basin (fig. 3), Lewis County, Washington (SW 1/4, sec. 12, T. 12 N., R. 1 W.), about 12 mi (20 km) southeast of Chehalis. The structural setting of the well site is unknown but a grid of three proprietary seismic profiles that are less than 6 mi (10 km) to the west, north, and southeast within the Chehalis basin suggest that structural dips at the well site should be relatively gentle. Total depth was 10,708 ft (3,264 m). The description below is based on analysis of geophysical logs and mudlogs and samples collected from cuttings. Foraminifera were identified in 9 samples by W.W. Rau (table 18).

The Perry No. 1 well penetrated Pleistocene(?) sand, gravel, and minor clay assigned to the Logan Hill Formation (Snavely and others, 1958) between the surface and 500 ft (152 m). Between 500 and 1,210 ft (152 and 369 m), the well encountered tuffaceous siltstone and minor sandstone assigned to the Oligocene Lincoln Creek Formation (fig. 4). Foraminifera recovered from 650 to 1,210 ft (198 to 369 m) in this interval are typical of the *Sigmomorphina schencki* zone of the lower part of the Refugian Stage (fig. 2; Rau, 1981). A complete section of the Lincoln Creek Formation in southwest Washington includes faunas of both the Refugian and overlying Zemorrian stages (Beikman and others, 1967, Rau and others, 1983). Therefore, the rocks penetrated in this well comprise only the lower part of the Lincoln Creek, and the upper contact of this unit is a significant unconformity. Key species of the *Sigmomorphina schencki* zone found in this well include *Valvulineria willapaensis, Cibicides haydoni, Sigmomorphina schencki,* and *Ceratobulimina washburnei.* The fossil assemblage indicates deposition at neritic water depths, with key species including *Florilus* cf. *inflatum, Eponides kleinpelli, Cibicides kleinpelli,* and *Cibicides lobatulus* (table 25; Enbysk, 1960; Ingle, 1980; McDougall, 1980). The Lincoln Creek Formation crops out about 9 mi (14 km) to the north on the north flank of the Chehalis basin (Snavely and others, 1958). Correlative rocks of the Toutle Formation crop out 9 mi (14 km) to the southeast on the southeast flank of the Chehalis basin (Phillips, 1987a).

Strata penetrated between 1,210 ft and 6,250 ft (369 to 1,905 m) are assigned to the middle to upper Eocene Skookumchuck Formation (fig. 4), which also crops out about 9 mi (14 km) to the north and northwest. These rocks consist of interbedded sandstone, siltstone, mudstone, and coal. Igneous rocks were penetrated between about 2,800 and 4,250 ft (853 and 1,295 m). These rocks could be associated with gabbroic intrusive rocks of Oligocene(?) age discussed by Snavely and others (1958). Alternatively, they could represent

part of a small upper Eocene volcanic complex (P.D. Snavely, written commun., 1996). The Skookumchuck sequence above these igneous rocks contains more sandstone and is coarser grained than the Skookumchuck sequence underlying the intrusions. Coal beds are most abundant between about 1,400 and 1,600 ft (427 and 488 m) and between about 4,700 and 4,850 ft (1,433 and 1,478 m).

Foraminifera recovered from two widely scattered intervals in the Skookumchuck are typical of the upper part of the Narizian Stage and are referred to the *Bulimina schencki-Plectofrondicularia* cf. *P. jenkinsi* zone of southwest Washington (fig. 2; Rau, 1981). Key species present are *Cibicides natlandi, Quinqueloculina goodspeedi*, and *Bolivina basisenta oregonensis*. The faunal assemblages suggest deposition at neritic water depths for the sequence above the thick intrusions, with key species including *Florilus* cf. *F. inflatum, Cassidulina* cf. *C. subglobosa*, and *Quinqueloculina imperialis* (table 25; Enbysk, 1960; Ingle, 1980; McDougall, 1980). This interpretation is consistent with Flores and Johnson (1995), who showed that in the Centralia coal mine to the north, shallow-marine and coastal-plain facies interfinger in the upper part of the Skookumchuck. Foraminifera in the sequence below the intrusive rocks suggest deposition at upper bathyal to outer neritic water depths, indicating upward shoaling. Key bathyal indicators include *Uvigerina* spp, *Bolivina cf. B. basisenta*, and *Bulimina ovata cowlitzensis* (table 25; Ingle, 1980).

The Perry No. 1 well penetrated volcanic flows and tuff beds between 6,250 and 10,708 ft (1,905 and 3,264 m). Based on their stratigraphic position, these rocks are assigned to the middle to upper Eocene Northcraft Formation, which crops out about 11 mi (18 km) to the north where it underlies the Skookumchuck Formation (Snavely and others, 1958). Alternatively, these rocks could have been derived from small volcanic centers and be correlative with the Pe Ell volcanic rocks of the Cowlitz Formation (Henriksen, 1956) and possibly correlative rocks described in the Earl F. Siler and J.W. Tanner Kostick No. 1 well (this report).

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SHELL OIL COMPANY THOMPSON NO. 1

The Shell Oil Company Thompson No. 1 well was drilled in 1959 in the south-central part of the Chehalis Basin (fig. 3), Lewis County, Washington (SW 1/4, sec. 34, T. 12 N., R. 1 W.), about 14 mi (22 km) southeast of Chehalis. Mapping by Roberts (1962) suggests the well is located along the axis of the Napavine syncline; proprietary seismic reflection data show that the well penetrated a relatively flat-lying part (structural dip less than 5°) of the Chehalis basin fill (Stanley and others, 1994). Total depth was 10,820 ft (3,298 m). The description below is based on analysis of geophysical logs and mudlogs and samples collected from cores and cuttings. Foraminifera were identified in 39 samples by W.W. Rau (table 19).

The Thompson No. 1 well penetrated lower Pleistocene(?) sand and gravel assigned to the Wingate Hill drift and Logan Hill Formation (Phillips, 1987a) between the surface and about 150 ft (46 m). Between about 150 and 550 ft (46 and 168 m), the well penetrated mainly carbonaceous claystone and siltstone of probable late middle and (or) late Miocene age assigned to the Wilkes Formation (fig. 4; Roberts, 1962, Phillips, 1987a). The nearest exposures of the Wilkes Formation are about 2 mi (3 km) south of the well site (Roberts, 1962; Phillips, 1987a). The Wilkes Formation is correlative with unnamed nonmarine rocks mapped by Snavely and others (1958) to the north in the Chehalis basin.

From a depth of about 550 to 2,100 ft (168 to 640 m), the well encountered strata assigned on the basis of lithology to the upper Eocene to Oligocene Toutle Formation (fig. 4). No paleontologic data are available from this interval. The upper part of this section, from about 550 to 1,200 ft (168 to 366 m), consists of tuffaceous sandstone, siltstone, and minor lignitic coal. The lower part of this section, from about 1,200 to 2,100 ft (366 to 640 m), is more fine-grained and consists primarily of tuffaceous siltstone and claystone. The Toutle Formation crops out about 5.5 mi (9 km) to the south on the southeast flank of the Chehalis basin. The Toutle Formation is correlative with and grades into the Lincoln Creek Formation, which crops out on the north flank of the Chehalis basin and was penetrated in the Perry No. 1, Guenther No. 1, Wulz No. 1, and Kostick No. 1 wells (this report). Roberts (1962) suggests the Toutle Formation is of mixed nonmarine and marine origin. The distribution of rock types penetrated by the Thompson No. 1 well suggests shoaling-upward depositional environments.

Strata penetrated between about 2,100 ft and 6,800 ft (640 and 2,703 m) are assigned to the middle to upper Eocene Skookumchuck Formation (fig. 4). Strata consist of interbedded sandstone, siltstone, mudstone, and coal. The proportion of sandstone increases upward in the section. Coal beds are most abundant between about 2,100 and 2,800 ft (640 and 853 m) and between about 4,000 and 5,000 ft (1,219 and 1,524 m). Foraminifera recovered from the Skookumchuck are typical of the upper part of the Narizian Stage and are referred to the *Bulimina schencki-Plectofrondicularia* cf. *P. jenkinsi* zone of southwest Washington (fig. 2). Foraminifera in this sequence suggest deposition at neritic water depths with key species including *Eponides yeguaensis, Elphidium* cf. *E. minutum*, and *Florilus inflatum* (table 25; Ingle, 1980). This interpretation is consistent with Flores and Johnson (1995), who showed that in the Centralia coal mine to the north, shallow-marine and coastal-plain facies interfinger in the upper part of the Skookumchuck Formation.

The Skookumchuck Formation crops out about 12 mi (19 km) to the north on the north flank of the Chehalis basin. It is correlative with and grades into the middle to upper

Eocene Cowlitz Formation, which crops out about 6 mi (10 km) to the southwest on the southeast and west flanks of the Chehalis basin. We follow Snavely and others (1958) in using Skookumchuck nomenclature for these rocks because they are underlain by rocks tentatively assigned to the Northcraft Formation (fig. 4; see below).

The Thompson No. 1 well penetrated volcanic flows, tuff beds, and interbedded sedimentary rocks between 6,800 and 10,820 ft (2,073 and 3,298 m). In available mud logs and lithologic logs, the volcanic rocks are referred to as basalt, andesite, and basaltic andesite. Sedimentary rocks are most abundant between about 6,800 and 7,600 ft (2,073 and 2,316 m) and about 10,400 and 10,700 ft (3,170 and 3,261 m), reflecting interfingering with and transition to the overlying Skookumchuck Formation and the underlying McIntosh Formation (fig. 4). Foraminifera in the sedimentary interbeds in the uppermost part of this mainly volcanic unit indicate an age and depositional environment similar to the overlying Skookumchuck Formation. Based on their stratigraphic position, the rocks in this interval are assigned to the middle to upper Eocene Northcraft Formation, which consists of a mix of basaltic andesite, andesite, basalt, and volcaniclastic rocks, and which crops out about 12 mi (19 km) to the north where it underlies the Skookumchuck Formation (Snavely and others, 1958; Hagen, 1987). It should be pointed out, however, that correlative basalts of the middle to upper Eocene Grays River volcanics (informal name; Duncan, 1982) underlie and interfinger with the Cowlitz Formation about 7.5 mi (12 km) to the southwest (Wells, 1981; Walsh and others, 1987). It is possible that volcanic rocks derived from both Northcraft and Grays River eruptive centers interfinger in the lower, volcanic-dominated section penetrated in the Thompson No. 1 well.

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SHELL OIL COMPANY STURDEVANT NO. 1

The Shell Oil Company Sturdevant No. 1 well was drilled in 1959 on the gently-dipping western flank of the Chehalis Basin (fig. 3), Lewis County, Washington (NW 1/4, sec. 27, T. 12 N., R. 2 W.), about 10.5 mi (17 km) south of Chehalis and 1 mi (1.6 km) northeast of Winlock. Total depth was 8,446 ft (2,574 m). The description below is based on analysis of geophysical logs and mudlogs and samples collected from cores and cuttings. Foraminifera were identified in 28 samples by W.W. Rau (table 20).

The Sturdevant No. 1 well penetrated lower Pleistocene(?) sand and gravel assigned to the Logan Hill Formation (Schasse, 1987) between the surface and about 225 ft (69 m). From 225 to 1,400 ft (69 to 426m), the well penetrated a sequence of tuffaceous, locally glauconitic siltstone and sandy siltstone assigned to the upper Eocene to Oligocene Lincoln Creek Formation (fig. 4). Foraminifera recovered from below 660 ft (201 m) are referred to the Refugian Stage and typify the *Sigmomorphina schencki* zone of southwest Washington (fig. 2; Rau, 1981). Key species present are *Elphidium smithi, Valvulineria willapaensis, Nonion halkyardi*, and *Ceratobulimina washburnei*. A complete section of the Lincoln Creek Formation, in southwest Washington includes faunas of both the Refugian and overlying Zemorrian stages (Beikman and others, 1967; Rau and others, 1983). Therefore, the rocks penetrated in this well comprise only the lower part of the Lincoln Creek Formation, and the upper contact of this unit is a significant unconformity. Foraminifera indicate deposition at neritic water depths, with key species including *Eponides kleinpelli, Elphidium smithi*, and *Valvulineria willapaensis* (table 25; Ingle, 1980; McDougall, 1980). The Lincoln Creek Formation crops out in the bed of Olequa Creek within 1 mi (1.5 km) of the well site (Henriksen, 1956; Phillips, 1987a). Correlative rocks of the Toutle Formation were penetrated in the Thompson No. 1 well (this report) and crop out 7.5 mi (12 km) to the southeast on the southeast flank of the Chehalis basin (Phillips, 1987a).

Strata penetrated between about 1,400 ft and 7,340 ft (426 to 2,237 m) are assigned to the middle to upper Eocene Cowlitz Formation (fig. 4), which crops out in the bed of Olequa Creek about 2 mi (3 km) to the south (Henriksen, 1956; Phillips, 1987a). Strata consist of interbedded sandstone, siltstone, mudstone, and coal. Sandstone is most common between 4,100 and 4,400 ft (1,250 and 1,341 m), 5,000 and 5,200 ft (1,524 and 1,585 m), and 6,200 and 6,800 ft (1,890 and 2,073 m). Coal is most common between about 2,400 and 2,600 ft (732 and 793 m), about 3,200 and 3,350 ft (975 and 1,021 m), and about 6,200 and 6,400 ft (1,890 and 1,951 m). Foraminifera recovered from numerous intervals in the Cowlitz Formation are typical of the upper part of the Narizian Stage and are referred to the *Bulimina schencki-Plectofrondicularia* cf. *P. jenkinsi* zone of southwest Washington (fig. 2; Rau, 1981). Key species present are *Bulimina schencki, Cibicides natlandi*, and *Valvulineria* aff. *V. willapaensis*. Neritic water depths for the marine (non coal-bearing) parts of the section are suggested by the common occurrence of *Eponides yeguaensis* and *Cibicides natlandi* (table 25; Ingle, 1980; McDougall, 1980). The Cowlitz Formation is correlative with and lithologically similar to the Skookumchuck Formation, which was penetrated in the other Chehalis basin wells (Wulz No. 1, Guenther No. 1, Roscoe Perry et ux No. 1, and Thompson No. 1) discussed in this report. We follow Henriksen (1956) and Wells and Rau (1983) in using Cowlitz nomenclature for these rocks because they are underlain by sedimentary rocks (see below) and not the volcanic Northcraft Formation.

Strata penetrated between about 7,340 and 8,446 ft (2,237 and 2,574 m) consist almost entirely of mudstone and siltstone and are assigned to the middle Eocene McIntosh Formation (fig. 4). Fine-grained rocks of the McIntosh

Formation are gradational with the interbedded rock types of the Cowlitz Formation. Thus, placement of the Cowlitz-McIntosh contact is somewhat arbitrary; we have placed the contact at the approximate location of a biostratigraphic boundary. Foraminifera from the McIntosh Formation are typical of the middle part of the Narizian Stage and are referred to the *Uvigerina* cf. *U. yazooensis* zone of southwest Washington (fig. 2; Rau, 1981). Key species are *Uvigerina* cf. *U. yazooensis*, *Valvulineria tumeyensis*, and *Bulimina corrugata*. Parke Snavely (written commun., 1996) reports that D. Bukry found CP14a stage coccoliths (fig. 2) from the McIntosh Formation, which is consistent with the foraminifera data. The foraminiferal assemblage suggests deposition at bathyal water depths, with key species including *Uvigerina* cf. *U. yazooensis*, *Valvulineria tumeyensis*, and *Bulimina corrugata* (table 25; Ingle, 1980; McDougall, 1980).

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THE TEXAS COMPANY BENSON CLATSKANIE NO. 1

The Texas Company Benson Clatskanie No. 1 well was completed in 1945 about 7.5 mi (12 km) northeast of Mist in northern Columbia County, Oregon (NE 1/4, sec. 36, T. 7 N., R. 4 W.). The well was drilled on the postulated axis of an unnamed, broad northwest-trending anticline (Newton and Van Atta, 1976). This postulated anticline is superimposed on the Nehalem Arch (fig. 3), a structural uplift that separates the Willamette and Astoria basins. Total depth was 5,660 ft (1,725 m). The description below is based on analysis of geophysical logs and mudlogs, samples collected from cuttings, and an interpretive log of the well by Newton and Van Atta (1976). Foraminifera were recovered and identified in 31 samples by W.W. Rau (table 21). Five stratigraphic units were recognized.

The well was spudded in the upper Eocene to Oligocene Keasey Formation (Newton and Van Atta, 1976), which extends from the surface down to a depth of about 730 ft (223 m). The Keasey Formation consists of siltstone and sandstone that is locally tuffaceous, carbonaceous, and fossiliferous.

Between about 730 and 2,350 ft (223 and 716 m), the well penetrated a sequence of interbedded sedimentary rocks assigned to the Cowlitz Formation and volcanic rocks that are tentatively assigned to the Grays River volcanics (informal name of Duncan, 1982). Sedimentary rocks between about 1,190 and 1,730 ft (363 and 527 m) consist mainly of siltstone and claystone and are inferred to correlate with the upper mudstone member of the Cowlitz Formation (Bruer, 1980; Niem and others, 1990, 1992). This fine-grained unit forms the seal for gas reservoirs in the nearby Mist gas field. Sedimentary rocks between 2,061 and 2,350 ft (628 and 716 m) consist of three 20-70-ft (6-21-m) thick sandstone-rich horizons interbedded with more fine-grained strata. This interval probably correlates with the Clark and Wilson sandstone, which forms the lower part of the Cowlitz Formation and the gas reservoir in the Mist field (Bruer and others, 1984; Niem and others, 1994). Basaltic volcanic flows, breccia, conglomerate, and possibly intrusive rocks are between 730 and 1,190 ft (223 and 363 m) and between 1,730 and 2,061 ft (527 and 628 m). Because the Cowlitz Formation is interbedded with volcanic rocks now assigned to the Grays River volcanics in southwestern Washington (Henriksen, 1956; Walsh and others, 1987) and in the nearby Exxon GPE Federal Community No. 1 well (Niem and others, 1992; this report) in south-central Columbia County, the volcanic rocks in this well are also assigned to the Grays River volcanics.

Between 2,350 and 5,560 ft (716 and 1,695 m), the Benson Clatskanie No. 1 well also penetrated interbedded sedimentary and volcanic rocks. Sedimentary rocks are between about 2,350 and 2,800 ft (716 and 853 m), 3,150 and 3,380 ft (960 and 1,030 m), 3,465 and 4,490 ft (1,056 and 1,369 m), and 5,115 and 5,560 ft (1,559 and 1,695 m). The upper three sedimentary intervals consist almost entirely of siltstone, sandy siltstone, and shale; the lowest interval is coarser grained and includes a significant proportion of sandstone. These sedimentary rocks are assigned to the Hamlet formation (informal name of Niem and Niem, 1985), based on their relatively fine grain size and their stratigraphic position below rocks assigned to the Cowlitz Formation. Volcanic rocks are between about 2,800 and 3,150 ft (853 and 960 m), 3,380 and 3,465 ft (1,030 and 1,056 m), and 4,490 and 5,115 ft (1,369 and 1,559 m), and consist mainly of basaltic breccia and agglomerate. These rocks are assigned to the middle Eocene Tillamook volcanics, which crop out about 24 mi (39 km) to the southwest in the Tillamook highlands and interfinger with the Hamlet formation in the nearby Mist gas field (Niem and others, 1990, 1992).

The highest foraminiferal assemblage recovered from well samples came from a depth of 628 ft (191 m) in the Keasey Formation, and is assigned a late Narizian age (fig. 2) based mostly on the occurrence of *Bulimina schencki*. Foraminifera recovered from all lower depths and stratigraphic units in the well also suggest a Narizian age, with additional significant species including *Cibicides natlandi*, *Lenticulina welchi*, *Quinqueloculina welchi*, and *Gyroidina condoni*.

Foraminifera from the upper 3,400 ft (1,036 m) in this well suggest deposition at neritic depths. Taxa that support this conclusion and are mostly restricted to this stratigraphic interval include *Eponides yeguaensis*, *Nonion planatum*, *Nonion* cf. *N. applini*, and several species of *Quinqueloculina* (table 25; Ingle, 1980). Strata penetrated from 5,149 ft to total depth at 5,650 ft (1,569 to 1,722 m) contain the bathyal *Plectofrondicularia searsi* and several taxa characteristic of neritic water depths. The sequence therefore appears to shoal upwards.

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THE TEXAS COMPANY CLARK AND WILSON NO. 6-1

The Texas Company Clark and Wilson No. 6-1 well was drilled in 1947 about 2 mi (3 km) east of Mist and the Mist gas field in western Columbia County, Oregon (NE 1/4, sec. 19, T. 6 N., R. 4 W.). The Clark and Wilson No. 6-1 well and the Mist gas field are on the Nehalem Arch (fig. 3), a structural uplift that separates the Willamette and Astoria basins (Armentrout and Suek, 1985; Niem and others, 1994). Total depth was 8,501 ft (2,591 m). The description below is based on analysis of geophysical logs and mudlogs, samples collected from cuttings, and an interpretive log of the well by Newton and Van Atta (1976). Foraminifera were recovered and identified from 33 samples by W.W. Rau (table 22). Four stratigraphic units were recognized.

The well was spudded in a thin section of Quaternary alluvium, which overlies locally tuffaceous and fossiliferous siltstone and sandy siltstone of the upper Eocene to Oligocene Keasey Formation (fig. 4). Although no foraminifera were recovered from the Keasey Formation in this well, these strata are considered upper Narizian and lower Refugian (fig. 2) elsewhere in northwest Oregon (McDougall, 1975; Niem and Niem, 1985). The Keasey Formation overlies siltstone of the Cowlitz Formation and there is no obvious representation of the contact on electric logs. Lira (1990) reported that siltstone beds of the Keasey and the Cowlitz Formations have different trace-element geochemistries based on their different provenance (mainly volcanic rocks for the Keasey and mainly crystalline rocks for the Cowlitz) and showed that this geochemical contrast could be used to identify the Keasey-Cowlitz contact on gamma logs. Using these criteria, H.J. Meyer (Oregon Natural Gas, oral commun., 1995) placed the Keasey-Cowlitz contact in the Clark and Wilson No. 6-1 well at a depth of about 700 ft (213 m).

The upper Eocene Cowlitz Formation extends from about 700 to 3,620 ft (213 to 1,103 m). Strata consist mainly of siltstone, sandy siltstone, and sandstone that is typically micaceous and locally fossiliferous. Sandstone is concentrated in two zones, extending from 2,075 to 2,150 ft (633 to 655 m) and from about 3,030 to 3,620 ft (924 to 1,103 m). The upper zone has not been named (H.J. Meyer, Oregon Natural Gas, oral commun., 1995) but the lower zone represents the Clark and Wilson sandstone, which forms the gas reservoir in the nearby Mist field. Foraminifera recovered from the Cowlitz Formation are characteristic of the upper part of the Narizian Stage (fig. 2), with key species including *Cibicides natlandi*, *Bulimina schencki*, *Lenticulina welchi*, *Angulogerina* cf. *A. hannai*, and *Eponides yeguaensis*. Upper Narizian foraminifera within this unit suggest deposition at neritic water depths, with key taxa including *Globocassidulina globosa*, *Cibicides natlandi*, *Nonion* spp., *Quinqueloculina* spp., and *Eponides yeguaensis* (table 25; Ingle, 1980; McDougall, 1980). It should be noted that the thickness (2,980 ft; 908 m) of the Cowlitz Formation in this well is significantly greater than that in the Mist field (about 1,100 to 2,600 ft; 305 to 793 m) just 2 mi (3 km) to the west (Niem and others, 1990, 1992, 1994). This thickness contrast is related to a period of differential tectonism and erosion after deposition of the Cowlitz Formation and before deposition of the overlying Keasey Formation (Bruer and others, 1984).

From about 3,620 ft to total depth of 8,501 ft (1,103 to 2,591 m), the Clark and Wilson No. 6-1 well penetrated a section of interbedded sedimentary rocks assigned to the "Hamlet" formation and volcanic rocks assigned to the Tillamook Volcanics. The sedimentary rocks consist of micaceous siltstone, mudstone, and minor sandstone. Volcanic rocks consist of basalt and basaltic andesite flows, mudflow breccia, basalt conglomerate, tuff, and possibly intrusive rocks (Newton and Van Atta, 1976; Niem and others, 1994). Thicknesses of primarily volcanic interbeds range from about 50 to 500 ft (15 to 152 m). The regional cross section of Niem and others (1992) shows that interbedding of the "Hamlet" formation and Tillamook Volcanics extends east-west for about 6 mi (10 km) in the area of the Mist gas field. Foraminifera from the "Hamlet"-Tillamook section are referred to the upper part of the Narizian Stage from about 3,620 to 6,400 ft (1,103 to 1,951 m) and to the lower part of the Narizian Stage (fig. 2) from about 6,400 to 8,501 ft (1,951 to 2,591 m). Upper Narizian faunas from the upper interval are similar to those reported from the overlying Cowlitz Formation and suggest deposition at similar neritic water depths. Significant taxa include *Globocassidulina globosa*, *Eponides yeguaensis*, *Cibicides hodgei*, *Cibicides natlandi*, *Nonion* cf. N. *applini*, and *Elphidium* spp. (McDougall). Key species of the lower Narizian assemblage found in the lower interval include *Bulimina* cf. B. jacksonensis, *Valvulineria jacksonensis welcomensis*, and *Bulimina corrugata*. Water depths during deposition of the lowest Narizian strata of this well were at least as deep as middle bathyal, indicated by the presence of *Bulimina corrugata*, *Bulimina* cf. *B. jacksonensis*, and Valvulineria jacksonensis welcomensis (table 25; Ingle, 1980; McDougall, 1980). The overall section penetrated in the Clark and Wilson No. 1 well thus records a shoaling-upward sequence.

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EXXON CORPORATION GPE FEDERAL COMMUNITY NO. 1

The Exxon Corporation GPE Federal Community No. 1 well was drilled in 1985 about 7 mi (11 km) east of Vernonia in south-central Washington County, Oregon (SW 1/4, sec. 3, T. 4 N., R. 3 W.). The well is on the north flank of the Willamette basin about 1,300 ft (400 m) northeast of

a northwest-trending oblique-slip fault (Niem and others, 1992). Total depth was 11,270 ft (3,435 m). The description below is based on analysis of geophysical logs and mud-logs, and samples collected from cuttings. Foraminifera were recovered and identified in more than 100 samples by W.W. Rau (table 23). Six stratigraphic units were recognized based on samples, log analysis, and the interpretations of Niem and others (1992) who included the well on a regional offshore-onshore cross section. Warren and Norbisrath (1946), Newton and Van Atta (1976), and Niem and others (1994) also provide useful maps and reviews of the geology of this region.

From the surface to a depth of 210 ft (64 m), the well penetrated the middle Miocene Grande Ronde Basalt of the Columbia River Basalt Group (fig. 4). This basalt represents the distal end of extensive flood basalts that flowed westward from eastern Oregon and Washington through a low area in the Cascade Range (Niem and others, 1992).

Between about 210 and 810 ft (64 and 247 m), the well penetrated a sequence of sandstone, siltstone, and less common mudstone and conglomerate assigned to the Oligocene Pittsburg Bluff Formation (fig. 4). A diagnostic debris-flow deposit of the Scaponia member of the Pittsburg Bluff Formation was intersected at a depth of about 600 ft (183 m). The well also penetrated the Divide and East Fork members of the formation (Niem and others, 1994; McKnight and others, 1995). Sanidine- and biotite-bearing ash-fall tuff that overlies the debris flow in nearby outcrop has yielded an isotopic date of 29.83 + 0.3 Ma (McKnight and others, 1995). The limited foraminiferal assemblage recovered from above 400 ft (122 m) in the upper part of the Pittsburg Bluff Formation is referred to the Zemorrian Stage (fig. 2), with *Buccella mansfieldi oregonensis* a key species. The lower part of the unit was barren of foraminifera. Elsewhere, upper Refugian Stage foraminifera have been reported from the lower Pittsburg Bluff Formation (for example, Niem and Niem, 1985; Niem and others, 1994). The foraminiferal assemblage in the well samples suggests deposition at neritic water depths; key paleobathymetric indicators include *Buccella mansfieldi oregonensis* and *Quinqueloculina* spp. (table 25; Ingle, 1980).

The Federal Community No. 1 well penetrated an interval of tuffaceous siltstone, claystone, and minor sandstone from about 810 to 3,160 ft (247 to 963 m). Sandstone is most prevalent in the lower 500 ft (152 m) of the interval. These rocks are assigned to the upper Eocene to Oligocene Keasey Formation (fig. 4). Foraminifera recovered from the upper part of the Keasey Formation, between 1,000 and 1,180 ft (305 and 360 m) in this well, are in both the Zemorrian and Refugian Stage (fig. 2). Given evidence from elsewhere in northwest Oregon that the Keasey Formation has a late Narizian to early Refugian age (for example, McDougall, 1975; Niem and Niem, 1985; Niem and others, 1994), we interpret these upper Keasey strata to be of Refugian age. Foraminiferal assemblages that are clearly Refugian in age were recovered from depths of 1,210 to 2,830 ft (369 to 863 m). Key species include *Uvigerina cocoaensis*, *Melonis halkyardi*, *Ceratobulimina washburnei*, *Eponides kleinpelli*, and *Valvulineria willapaensis*. Foraminifera from the Keasey Formation above a depth of 1,200 ft (366 m) suggest deposition at neritic water depths, with *Florilus* cf. *F. incisum*, *Quinqueloculina* spp., and *Elphidium* spp. as key taxa (table 25; Ingle, 1980). From a depth of about 1,200 to 2,500 ft (366 to 762 m), the foraminiferal assemblage suggests deposition at upper bathyal water depths with key species including *Uvigerina cocoaensis*, *Praeglobobulimina* cf. *P. pupoides*, and *Globobulimina pacifica* (table 25; Enbysk, 1960; Ingle, 1980; McDougall, 1980). Below 2,500 ft (762 m) in the lowest part of the Keasey Formation, the presence of *Elphidium californicum* suggests shallow-marine deposition. The Keasey Formation in this well thus appears to record a transgression followed by a regression.

Between depths of 3,160 and 7,180 ft (963 and 2,188 m) and 7,810 and 8,410 ft (2,380 and 2,563 m), the Federal Community No. 1 well penetrated intervals of interbedded volcanic rocks and commonly tuffaceous sandstone, siltstone, and claystone. Niem and others (1992) described the volcanic rocks as low-TiO_2 basalt and basaltic andesite, and correlated them on the basis of their geochemistry and stratigraphic position with the upper Eocene Goble Volcanics (fig. 4). The type locality of the Goble Volcanics crops out about 19 mi (30 km) to the northeast along the Columbia River (Wilkinson and others, 1946). Phillips (1987a, b) mapped and described extensive Goble Volcanics east of the Columbia River in southwestern Washington and suggested a thickness greater than about 5,000 ft (1,500 m) for the unit. Using information from seismic-reflection profiles and nearby boreholes, Niem and others (1992) showed that the interbedded volcanic and sedimentary rocks assigned to the Goble Volcanics pinch out just 5 mi (8 km) to the west of the Federal Community No. 1 well, and therefore interpreted the rocks in the well as the distal deposits of the Goble volcanic center(s). Borehole samples recovered from between 3,160 and 8,410 ft (963 and 2,563 ft) are essentially barren of foraminifera. However, the interval is overlain by Refugian Stage strata, and foraminifera from the lowest part of the lower Goble interval are referred to the upper Narizian Stage. Thus the age of the unit is constrained to the upper Narizian and (or) lower Refugian by its stratigraphic position.

The interval between the two wedges of Goble Volcanics, from 7,180 ft to 8,030 ft (2,188 to 2,448 m), consists of siltstone, claystone, and minor sandstone. Given its late Narizian or early Refugian age (based on stratigraphic position) and its fine-grained lithology, this unit is here considered a tongue of the Keasey Formation. Niem and others (1992) also considered this possibility but preferred to

assign these rocks to an unnamed unit based on stratigraphic relationships interpreted from a nearby seismic reflection profile.

From 8,370 to 9,720 ft (2,551 to 2,963 m), the Federal Community No. 1 well penetrated a sequence of sandstone, siltstone, and claystone assigned to the middle to upper Eocene Cowlitz Formation (fig. 4). Sandstone is most abundant between 8,510 and 8,660 ft (2,594 and 2,640 m), 8,770 and 8,820 ft (2,673 and 2,688 m), 9,060 and 9,130 ft (2,761 and 2,783 m), 9,310 and 9,370 ft (2,838 and 2,856 m), 9,440 and 9,490 ft (2,877 and 2,893 m), and 9,590 and 9,710 ft (2,923 and 2,960 m). Farther west in northwest Oregon, the Cowlitz Formation has been divided (for example, Niem and others, 1992) into an upper unit of mainly mudstone and a lower unit (Clark and Wilson sandstone), typically about 300 ft (100 m) thick, consisting mainly of micaceous, arkosic sandstone. This latter unit forms the gas reservoir in the Mist gas field, about 17 mi (27 km) northwest of the well site (Newton, 1979; Alger, 1985; Niem and others, 1994). Based on analysis of mudlogs and geophysical logs, that Cowlitz subdivision may be less useful in areas to the east (including the Federal Community No. 1 well site) where the Cowlitz strata may include more sandstone in its upper part. Upper Narizian Stage foraminifera were recovered from the interval between 8,370 and 9,690 ft (2,551 and 2,954 m). Diagnostic species include *Bulimina schencki*, *Quinqueloculina* cf. *Q. minuta*, *Globocassidulina globosa*, and *Cibicides natlandi*. The foraminiferal assemblage suggests deposition at neritic to littoral depths, with key species including *Eponides yeguaensis*, *Quinqueloculina* spp., *Elphidium californicum*, and *Cibicides natlandi*.

Volcanic rocks were penetrated in the well between 9,720 and 10,140 ft (2,963 and 3,091 m) and are most abundant in the upper 220 ft (67 m) of this interval. Niem and others (1992) suggested that these rocks could either represent sills or dikes of Goble Volcanics (Cole Mountain basalts of Niem and Niem, 1985; Berkman, 1990), or flows of the slightly older Tillamook Volcanics. In southwestern Washington, flows of the Grays River volcanics are interbedded with shallow marine strata of the Cowlitz Formation (Wells, 1981).

Sedimentary rocks that are interbedded with the volcanic rocks between 9,720 and 10,140 ft (2,963 and 3,091 m) and extend to a total depth of 11,270 ft (3,435 m) in the Federal Community No. 1 well are assigned to the upper Eocene Hamlet formation (fig. 4; informal name of Niem and Niem, 1985; Niem and others, 1992). Strata consist of siltstone, claystone, and sandstone. Claystone and siltstone dominate between 10,140 and 10,780 ft (3,091 and 3,286 m). The highest proportion of sandstone is between depths of 10,880 and 11,150 ft (3,316 and 3,399 m), an interval which Niem and others (1992) referred to the Sunset Highway member of the Hamlet formation (informal names). Foraminifera recovered from the Hamlet formation in well cuttings are extremely rare and nondiagnostic as to age. Nevertheless, no foraminifera from this interval indicate an age older than late Narizian. The paucity of foraminiferal data precludes assigning a firm paleobathymetric range to these strata. However, to the west of the Federal Community No. 1 well (seaward in paleogeographic reconstructions), Niem and others (1992, 1994) used sedimentologic and paleontologic data from surface exposures and well data to suggest that Hamlet formation mudstone beds were deposited at bathyal depths, and that the Sunset Highway member is a shallow-marine facies.

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