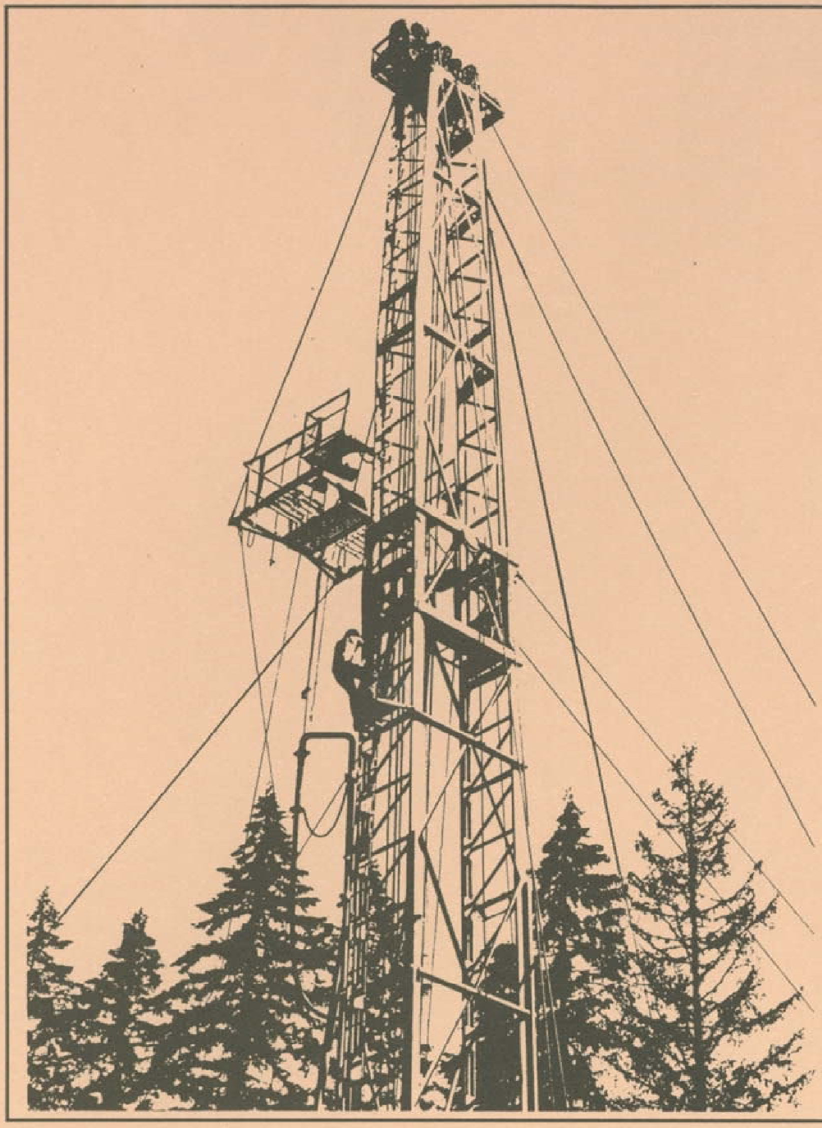
OIL AND GAS INVESTIGATION 17



ONSHORE-OFFSHORE GEOLOGIC CROSS SECTION FROM THE MIST GAS FIELD, NORTHERN OREGON COAST RANGE, TO THE NORTHWEST OREGON CONTINENTAL SHELF

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NOTICE

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Onshore-Offshore Geologic Cross Section from the Mist Gas Field, Northern Oregon Coast Range, to the Northwest Oregon Continental Shelf and Slope: Discussion

by

Alan R. Niem, Parke D. Snavely, Jr., and Wendy A. Niem

INTRODUCTION

In order to understand better the stratigraphic and tectonic framework and to evaluate the oil and gas potential of the Oregon continental margin, a number of offshore-onshore geologic cross sections are being constructed in a cooperative effort among the U.S. Geological Survey, Oregon State University, oil companies, geologic consultants, and the Oregon Department of Geology and Mineral Industries (DOGAMI) with funding from the Minerals Management Service (MMS). This onshore-offshore cross section will be followed by a second DOGAMI-sponsored cross section approximately 20 km to the north. Similar cross sections across the central coast of Oregon and across the southwestern and northwestern Washington coast have been published by the U.S. Geological Survey (Snavely and others, 1987; Snavely and Wagner, 1981, 1982; Snavely, Wagner, and Lander, 1980, 1985).

The onshore part of this cross section and geologic strip map and the interpretation are mainly from Niem and Niem (1985), from theses for areas in Clatsop County by A. Niem's graduate students (Neel, 1976; Rarey, 1986; Mumford, 1988; Nelson, 1985; Olbinski, 1983) at Oregon State University and in Columbia County by R. O. Van Atta's and G. T. Benson's graduate students (Ketrenos, 1986; Kadri, 1982) at Portland State University, and from unpublished mapping of the Mist Gas Field done in 1989 by Alan Niem. These surface data are further supported by electric logs, lithology logs, and microfossil age data from several deep exploration wells provided by ARCO Oil and Gas Company (Dan Fortier and Bob Jackson), Diamond Shamrock (now

Maxus Energy Corp.), and Northwest Natural Gas Company (Jack Meyer), by a correlation section from Bruer and others (1984), and by seismic-reflection profiles provided by ARCO Oil and Gas Company (Dave Huggins) and Diamond Shamrock Corporation (Alan Seeling).

Parke D. Snavely, Jr. interpreted the U.S. Geological Survey 24-channel seismic-reflection profile WO 76-7. Parts of single-channel seismic-reflection profiles SP-106 and SP-107 by Oregon State University (OSU) College of Oceanography are reproduced here. The entire OSU profiles were initially interpreted by L.D. Kulm. We are indebted to these individuals for their assistance in acquiring and interpreting these data. A preliminary interpretation of the offshore seismic-reflection profile WO 76-7 was published as a U.S. Geological Survey open-file report (87-612) by Snavely and McClellan (1987); much of that interpretation is retained in this report.

Explanation of the offshore cross section is based upon interpretation of these seismic-reflection profiles and the accompanying magnetic and gravity (free air and Bouguer) profiles which were drawn from maps by the U.S. Geological Survey (1984), Finn and others (1984), and Dehlinger and others (1967). Acoustical units were correlated with subsurface units which were encountered in deep exploratory test wells (P-072 and P-075) drilled by Shell Oil Company on the outer continental shelf in the mid-1960's (Fig. 1 on Plate 1; Braislin and others, 1971; Snavely, Pearl, and Lander, 1977; Kulm and others, 1984; Peterson and others, 1984; Cooper, 1981; unpublished data). Dredge samples recovered along this line of cross section provided additional information on the age of strata that crop out on the sea floor on Nehalem Bank (Kulm and Fowler, 1974; Peterson and others, 1986).

LOCATION OF CROSS SECTION

Multi-channel seismic-reflection profile WO 76-7 and a concurrent single-channel high resolution profile (UNIBOOM) were collected in 1976 aboard the S.P. Lee, a U.S. Geological Survey research vessel. The line begins approximately 20 km west of Tillamook Head and extends 58 km westward across the continental shelf, Nehalem Bank, and the upper and lower continental slope near latitude 45 50′ (Fig. 1).

Single-channel seismic-reflection profiles (SP 106 and SP 107) obtained in 1969 onboard the R/V Yaquina, an Oregon State University research ship, subparallel line WO 76-7 (2 to 3 km to the north) and provide additional geologic control. The parts of the OSU profiles reproduced on Plate 1 extend approximately 20 km east and northeast beyond the end of line WO 76-7 to within 3 km of Tillamook Rock. The rock is a sea stack of a middle Miocene basalt sill that is 2.5 km offshore from Tillamook Head where the same sill crops out. Some horizontal adjustments were made to resolve the navigational differences between the USGS and OSU profiles in order to correlate north-south structures on the two profiles. Only those parts of the OSU lines that extend beyond the east end of the USGS line are shown on our cross section. Note the changes in the time axis along the OSU profiles.

The onshore cross section extends eastward from Tillamook Head through the Diamond Shamrock Crown Zellerbach 11-28 well, across the northern flank of the Tillamook highlands (Fig. 1), then northward to the Quintana Watzek 30-1 well in order to depict the oldest rocks (Tillamook Volcanics) exposed in the area. From the Watzek well, the line continues eastward across the Clatsop County-Columbia County boundary into the Mist Gas Field near the town of Mist. The line turns north and terminates in the northern part of the field. The locations of wells drilled in the Mist field, as of 1989, are shown on the inset map above the geologic strip map on Plate 1. Stratigraphic and structural control on rock units was maintained by projecting several wells into the line of section; these wells are ARCO Oregon 34-25-66, DY Neverstill 33-30, Tenneco Columbia County 24-38-65, ARCO Columbia County 31-27-65, Oregon Natural Gas Development Corp. IW32-10 (originally Columbia County 32-10; the deepest well), and Reichhold Energy Corp. Adams 32-34.

Synthetic seismograms generated from sonic logs for some of these wells and for the offshore (by U.S. Geological Survey) allowed transformation of two-way travel time to depth for the cross section. Note that the horizontal scale of the onshore seismic-reflection profiles from industry is as much as 2.3 times larger than the scale of the cross section in order to show more clearly the structural and stratigraphic features that are not resolvable at the cross section scale (1:100,000). The U.S. Geological Survey's offshore seismic-reflection profile is shown at approximately 1:100,000, about the same scale as the cross section.

SEISMIC DATA COLLECTION AND PROCESSING

Seismic data for line WO 76-7 (line A-A') were collected using an energy source of five airguns with a combined volume of 1326 cubic inches of air compressed to approximately 1900 PSI; the airguns were fired at a 50-meter shot interval. The recording system included a 24-array streamer 2400 meters long, with a uniform 100-meter group interval, and a GUS (Global Universal Science) Model 4200 magnetic-tape recorder. Records were sampled in the field at a 2-millisecond rate, and later desampled to 4 milliseconds during the demultiplexing process. Navigational control was by a Marconi integrated satellite-doppler sonar navigational system.

The seismic processing sequence included editing-demultiplexing, automatic gain control, deconvolution filtering, velocity analysis and normal-moveout correction, trace balancing, and bandpass filtering. In areas of shallow sea floor, the early arrivals on far-channel traces were muted to remove refracted energy. In areas of deeper water, the near-channel traces were muted at and below approximately twice the water-bottom time, to suppress the amplitude of water-bottom multiples in the stacked traces. The 24-fold data were then stacked with a normalizing stacking program. The stacked data were migrated using a finite-difference time-migration routine, with a migration velocity model prepared from constant-velocity migration analyses. Processing was done at the USGS Pacific Marine Geology Multichannel Processing Center in Menlo Park, California.

Industry seismic lines (C-C′, D-D′′′, E-E′, and F-F") were collected using either vibroseis (in Clatsop County) or dynamite (in Columbia County) energy sources and varying arrays of digital recorders. Seismic processing included deconvolution, CDP stacking, and migration. Some lines follow winding logging roads that subparallel the geologic cross section (see dotted seismic lines versus solid lines of cross section on geologic strip map). Other lines are along straight cut trails that follow the geologic cross section. Middle Miocene basalt sills, 200 to 300 m thick, that lie close to the surface in Clatsop County attenuated resolution (e.g., line C-C′). A synthetic seismogram for the Quintana Watzek 30-1 well (no. 3) provided by Diamond Shamrock (now Maxus Exploration), chemical analyses of basalt cuttings (Olbinski, 1983; Nelson, 1985), and electric logs allowed correlation to deeply buried middle Miocene Grande Ronde sills that show up as the strongest reflectors in seismic profiles in Clatsop County (see lines D-D′, E-E′, and C-C′).

STRATIGRAPHY

Discussion of the stratigraphy along the offshore cross section following seismic-reflection profile line WO 76-7 is presented in a chrono-stratigraphic sense because onshore formations that crop out in the northern part of the Coast Range generally cannot be correlated directly with offshore acoustical units. Also, many shallow-water sandstone-dominated units onshore (Niem and Niem, 1985) lose their characteristic lithologies seaward due to facies changes to deeper-water mudstones (Cooper, 1981). However, provisional correlations have been made between offshore acoustic units and onshore formations in the northern Oregon Coast Range (see Time-Rock Chart on Plate 1). Onshore units are projected several km offshore beneath lines SP-106 and SP-107. The closest deep subsurface control to line WO76-7 is Shell Oil Company's P-072 well drilled 18 km north of the profile to a depth of 8219 feet (2505 m)(Fig. 1 on Plate 1). The ages of the strata penetrated in this well were determined from a study of foraminifers by W. W. Rau (written communication to Snavely, 1976; Cooper, 1981).

The offshore stratigraphic units distinguished in the seismic-reflection profile (A-A′) were originally divided into three tectono-stratigraphic terranes by Snavely and McClellan (1987). The terranes are: (1) the deep marginal Astoria basin, consisting of a 3,000 to 4,000 m thick sequence of Tertiary sedimentary, volcanic, and intrusive rocks (units Ttv, Toe, Tmlm, Tb, Tmu, and Tp) beneath the continental shelf (correlative units crop out in the northern Oregon Coast Range in the onshore Astoria basin; Niem and Niem, 1985); (2) the upper(?) Oligocene to middle Miocene accretionary complex (unit Tmo) and overlying slope basin units (units Tmu, Tp, Qp, and Qh) beneath the upper continental slope; and (3) thrust faulted and folded Pleistocene and Pliocene abyssal plain, slope, and submarine fan sediments west of fault A (units Qp and Tp).

The onshore stratigraphic units include the middle and upper Eocene Tillamook Volcanics overlain by a 2,500-m thick forearc sequence of upper Eocene to middle Miocene marine mudstone, sandstone, and minor conglomerate which is intruded by Eocene and middle Miocene basalts. The onshore forearc sequence in the Astoria basin can be generally correlated, particularly the thick sills and volcanic basement, to the offshore marginal sequence of the Astoria basin beneath the inner continental shelf. The thick deep-marine basinal fill of upper Miocene (unit Tmu), Pliocene (unit Tp), and Quaternary (units Qh and Qp) sediment beneath the continental shelf, however, has no correlative onshore units other than minor Quaternary alluvium and beach sand (unit Qal). This may be because during the late Miocene, Pliocene, and Quaternary much of the northern Oregon Coast Range was uplifted and was shedding sediment into the adjacent subsiding marginal basin on the continental shelf (Snavely and Wagner, 1963).

Astoria Basin Sequence

Middle and Upper Eocene Volcanic and Intrusive Rocks. Underlying the sedimentary sequence both onshore and on the continental shelf are the >3,000 m thick Tillamook Volcanics (unit Ttv)(Snavely and Wells, 1984). The top of this unit in the offshore area may be represented by a few high-amplitude reflections near the east end of section A-A′ and near faults E and D. Onshore along this transect, this unit appears as the lowest strong, high-amplitude continuous reflectors (e.g., sections D"-D‴, E-E′, and F-F"). The volcanic basement was penetrated in the Crown Zellerbach 11-28 well (no. 1)(Rarey, 1986), Columbia County 31-27-65 well (no. 7), IW32-10 well (no. 8), and Adams 32-34 well (no. 9). The unit crops out to form the rugged Tillamook Highlands (see Fig. 1 on Plate 1). The Tillamook Volcanics consists chiefly of subaerial high titanium plagioclase- and augite-phyric to aphyric basalt and basaltic andesite flows (Wells and others, 1983; Niem and Niem, 1985; Rarey, 1986; Mumford, 1988). Some andesite and dacite flows, basaltic dikes and sills, and weathered debris flows occur with minor interbeds of fluvial basaltic sandstone and conglomerate and multicolored paleosoils and terrestrial red mudstones in the upper subaerial part of the unit in Clatsop and Columbia counties (Safley, 1989; Olbinski, 1983; Berkman, 1990). The subaerial part of the volcanic sequence is developed on a thick submarine pillow breccia, tuff breccia, and lapilli tuff that forms the lower part of the Tillamook Volcanics to the south in Tillamook County (Wells and others, 1983). Snavely and McClellan (1987) suggested that the subaerial Tillamook basalts of Clatsop County may grade westward (offshore) into submarine basalt breccias, basalt dikes, pillow lavas, and minor basaltic sandstone and siltstone. Similar lateral volcanic facies change to the southwest was noted onshore in Tillamook County by Wells and others (1983) and Snavely (1990) where basaltic sandstone and minor pillow lava and mudflow breccia, correlative with the Tillamook Volcanics, interfinger with deep-marine upper middle Eocene siltstone of the Yamhill Formation (Bukry and Snavely, 1988).

Niem and Niem (1985) reported that McElwee of Oregon State University determined K/Ar and Ar40/Ar38 ages of 37.1 +/- 0.4 Ma to 42.4 +/- 0.5 Ma for flows near the top of the volcanic sequence in Clatsop County. Magill and others (1981) reported K/Ar ages of 43.2 to 46.0 +/- 0.9 Ma (av. 44.3 +/- 0.6 Ma) for samples from near the base of the thick pillow breccia and pillow flow sequence in Tillamook County. Magill and others

(1981) and Nelson (1985) also reported from paleomagnetic studies that the unit has been rotated on land approximately 45 degrees clockwise since the late Eocene. The thick volcanic unit on land forms a gravity high (Bromery and Snavely, 1964; Nehalem Arch of Armentrout and Suek, 1985) that trends north/northeast beneath the Mist Gas Field (Fig. 2 on Plate 1). The broad positive Bouguer and free-air gravity anomalies on the gravity profiles on Plate 1 occur where the Tillamook Volcanics crop out or lie just below the surface. The unit includes both normal and reverse polarized flows (Rarey, 1986; Mumford, 1988; Safley, 1989) and therefore does not create a distinctive magnetic anomaly on the aeromagnetic maps of Finn and others (1984). The positive anomaly on the magnetic profile over the outcrop area of Tillamook Volcanics appears to be partly attributable to the thick basaltic to gabbroic sills of the younger Cole Mountain basalt (unit Tcm) which have normal remanent magnetic polarity (Rarey, 1986; Nelson, 1985; Mumford, 1988).

Wells and others (1984), Rarey (1986), and Mumford (1988) interpreted the Tillamook basalts as an oceanic island(s) formed as several coalescing stratovolcanoes in a forearc setting after accretion of the lower to middle Eocene Siletz River Volcanics. McElwee and Duncan (1982) and Duncan and Kulm (1989) pictured the Tillamook Volcanics as the surface track of Yellowstone hot spot activity in this part of the Coast Range as the hot spot was overridden by the western margin of North America. Alternatively, these and other upper Eocene volcanics may be products of mantle-derived eruptions in an oblique dextral rifted continental margin during periods of extension (Snavely and MacLeod, 1974; Snavely, 1987).

This thick basalt sequence is widespread across Clatsop and western Columbia counties and has been penetrated in many deep exploration wells

(Bruer and others, 1984; Niem and Niem, 1985). It most likely was penetrated at depths of 9750 ft (2972 m) to the total depth of 10,160 ft (3,097 m) by Shell Oil Company's P-075 well 30 km north of cross section A-A' on the inner continental shelf, where similar palagonitic basalt breccia, baked shale, and intrusive basaltic rock were recovered (Snavely and McClellan, 1987; Peterson and others, 1984; Shell Oil Company lithologic and electric logs, 1966)(Fig. 1 on Plate 1). Petrographically, a sample from 9750 ft looks like the altered microgabbro that is typical of the upper Eocene Cole Mountain basalt intrusives that overlie the Tillamook Volcanics in Clatsop County. The Tillamook Volcanics in the subsurface north of the Mist Gas Field may be petrologically correlative to the Grays River Volcanics recognized by Wolfe and McKee (1972), Wells (1981), and Phillips and others (1989) in southwestern Washington.

These volcanics are considered the economic basement onshore although older lower to middle Eocene sedimentary and volcanic units (e.g., mudstone of the Yamhill Formation, turbidite sandstone and mudstone of the Tyee Formation, thick lower Eocene gabbroic sills, Siletz River Volcanics, Hembre Ridge Volcanics) underlie this 3,000-m thick unit in Tillamook County to the south (Wells and others, 1983; Wells, 1990, personal communication).

In Clatsop County and western Columbia County plagioclase- and clinopyroxene-phyric basalt sills (up to 100 m thick) with some dikes and pillow flows locally intrude the Hamlet and Cowlitz formations (units Th and Tc, respectively) along the contact of these units with the overlying Keasey Formation (unit Tk). These porphyritic basalts are informally called the Cole Mountain basalt (unit Tcm)(Niem and Niem, 1985; Rarey, 1986; Mumford, 1988; Farr, 1989; Berkman, 1990). They are commonly vesicular and deuterically altered. These calcalkaline basalts are geochemically similar to the Cascade arc-derived Goble Volcanics of southwestern Washington (Rarey, 1986; Mumford, 1988; Phillips and others, 1989). The Cole Mountain basalt has yielded a total fusion Ar40/Ar38 age of 34.3 +/- 2.1 Ma and an overlapping isochron age of 36.0 +/- 1.7 Ma (Kris McElwee in Niem and Niem, 1985). Some sills (unit Tb) noted as distinctive reflectors in unit Toe in the marginal basin sequence beneath the continental shelf may be Cole Mountain basalt although these are more likely middle Miocene Grande Ronde (unit Tgi) or Frenchman Springs basalt (unit Tfi). Cole Mountain basalt sills have normal polarity; and, therefore, where Cole Mountain and Grande Ronde basalt sills are thick and close to the surface, they produce a positive magnetic anomaly (e.g., see magnetic profile).

Oligocene and Upper Eocene Strata. These offshore marginal basin strata (unit Toe) on the continental shelf east of fault D are correlative to the deep-marine upper Eocene (upper Narizian) Hamlet formation (unit Th), Cowlitz Formation (unit Tc), Keasey Formation (unit Tk; Narizian to Refugian), and lower part of the Smuggler Cove formation (unit Tsc) along the onshore part of this transect in western Clatsop County (see Time-Rock Chart on Plate 1). The base of this 2,500-m thick sequence consists of local cobble to boulder basalt conglomerate (Roy Creek member of Hamlet formation, unit Thr) that rests unconformably on Tillamook Volcanics from which it was derived (Olbinski, 1983; Nelson, 1985; Rarey, 1986; Mumford, 1988; Safley, 1989). Overlying the conglomerate are massive to thin beds of shallow-marine basaltic sandstone of the Roy Creek member (unit Thr) which grade upward into a few hundred meters of micaceous laminated bathyal mudstone of the upper Hamlet formation (unit Th), thick glauconitic to tuffaceous bioturbated slope mudstone of the Keasey Formation, and massive tuffaceous siltstone and glauconitic sandstone of the lower Smuggler Cove formation (Rarey, 1986; Mumford, 1988; Niem and Niem, 1985). Units Th, Tk, and Tsc are projected from onshore and queried on the inner continental shelf east of fault G. The Shell Oil Company P-072 well (Fig. 1 on Plate 1) encountered similar deep-marine tuffaceous mudstone of late Eocene and Oligocene age below a depth of about 1829 m. In that well, this sequence is cut by numerous shear zones and apparently extends to a depth of at least 2095 m. No age diagnostic microfossils were recovered from samples below that depth.

In the subsurface of western Columbia County in the southern part of the Mist Gas Field, the Tillamook Volcanics appears to interfinger with arkosic and basaltic sandstone of the overlying Sunset Highway (unit Ths) and Roy Creek (unit Thr) members of the Hamlet formation (section F′-F") (Bruer and others, 1984). These sedimentary units are, however, cut out by an unconformity at the base of the upper Eocene Cowlitz Formation (unit Tc); and the Cowlitz Formation onlaps a "Tillamook" volcanic high in the northern part of the Mist Gas Field (cross section F′-F").

The gas reservoir in the Mist Gas Field is the 100-m thick upper Eocene (upper Narizian) C & W sandstone member of the Cowlitz Formation (Alger, 1985; Newton, 1979). It is a shallow-marine to deltaic, coal-bearing micaceous arkosic sandstone. This sandstone reservoir pinches out in eastern Clatsop County to the bathyal mudstone facies of the Hamlet formation and upper mudstone member of the Cowlitz Formation (Rarey, 1986; Niem and Niem, 1985; Bruer and others, 1984; Nelson, 1985; Berkman, 1990). The upper mudstone and C & W sandstone members of the Cowlitz Formation are locally cut out by an unconformity at the base of the Keasey Formation (Bruer and others, 1984). This regional unconformity may reflect a late

Eocene underthrust event on the outer continental shelf (Snavely and Wells, 1984; Snavely, 1987). Field mapping and seismic profile F′-F" show that the bathyal turbidite arkosic sandstone and mudstone of the Sager Creek formation (unit Ts), which is a possible canyon head deposit (Olbinski, 1983; Nelson, 1985), are channeled into the upper Keasey Formation between wells no. 7 and 8 (on Plate 1) in the Nehalem graben. Overlying the Sager Creek unit are thick-bedded shallow-marine tuffaceous bioturbated sandy siltstone and deltaic sandstone of the Pittsburg Bluff Formation (unit Tpb) which is the principal bedrock unit that crops out in the Mist Gas Field (Kadri, 1982; Ketrenos, 1986; see geologic strip map near the town of Mist). In western Clatsop County, the Sager Creek and Pittsburg Bluff formations pinch out into tuffaceous siltstone and mudstone of the Smuggler Cove formation (Cressy, 1974; Nelson, 1985; Niem and Niem, 1985).

Lower Miocene Strata. Unit Tmlm unconformably overlies an acoustical unit (unit Tml?) that Snavely and McClellan (1987) inferred to be equivalent to the lower Miocene Nye Mudstone of the central Coast Range of Oregon. This unit (Tml?) is probably equivalent in part to the upper Smuggler Cove formation (unit Tsc; Niem and Niem, 1985; Oswald West mudstone of Cressy, 1974 and Niem and Van Atta, 1973) which includes lower Miocene (Saucesian) tuffaceous bathyal mudstone along the onshore part of this transect. Unit Tml? is present in the eastern part of offshore section A-A′ but is absent farther west, probably due to the unconformity at the base of the lower and middle Miocene unit (Tmlm). Along the coast, shallow-marine to deltaic Angora Peak sandstone of the Astoria Formation (a correlative of unit Tmlm) also unconformably overlies deep-marine (bathyal) lower Miocene Smuggler Cove mudstone as at Oswald West State Park (Cressy, 1974; Niem and Van Atta, 1973; Niem and Niem, 1985).

Lower and Middle Miocene Strata. Strata correlative to the lower and middle Miocene Astoria Formation (Pillarian to Newportian; Saucesian; unit Ta) onshore are widespread in the offshore part of this transect (see unit Tmlm on geologic strip map on Plate 1). The 300-m thick Cannon Beach member of the Astoria Formation consists of two units: a lower sequence of thin-bedded micaceous and carbonaceous sandstone turbidites and mudstone and a thicker upper sequence of bathyal, foraminifer-bearing, laminated carbonaceous mudstone (Silver Point member of Cooper, 1981 and Neel, 1976; Niem and Niem, 1985). The unit has been correlated offshore by Cooper (1981) to the Shell Oil Company P-072 well where it is 240 m thick but still contains lithologically similar feldspathic micaceous sandstone turbidite beds and laminated micaceous mudstone. Gas shows were noted in these highly carbonaceous thin-bedded turbidite sandstones in this offshore well (Cooper, 1981).

The 300-m thick lower and middle Miocene coal-bearing, deltaic Angora Peak sandstone member of the Astoria Formation underlies the Cannon Beach member onshore. In an onshore-offshore fence diagram of the Astoria Formation, Cooper (1981) projected the Angora Peak member several kilometers offshore south of this cross section. Lithofacies analysis shows that this unit was deposited in a wave-dominated deltaic setting (Niem, 1976). The largely shallow-marine micaceous lithic arkosic sandstone contains extrabasinal sedimentary quartzite and granitic pebbles and boulders in minor fluvial volcaniclastic conglomerates which suggest the delta formed at the mouth of the ancestral (Miocene) Columbia River (Smith, 1975; Cressy, 1973; Cooper, 1981). This friable member represents a potential reservoir target for offshore exploration south of this transect (Cooper, 1981; Niem and Niem, 1985). The overlying Cannon Beach carbonaceous mudstone member could act as a seal and as a possible gas-prone source rock if matured offshore (Niem and Niem, 1985). Unfortunately, the reservoir-quality deltaic and shallow-marine shelf arkosic sandstones of the Angora Peak member apparently thin and change facies to the deep-marine Cannon Beach mudstone and thin feldspathic turbidite sandstone beds northward onland and northwestward offshore from its type area near the coastline. Therefore, Angora Peak sandstone is not recognized in this onshore-offshore transect or in the Shell Oil Company P-072 well (Cooper, 1981).

Twenty-five kilometers north of this transect near the city of Astoria, the 200-m thick Youngs Bay member of the Astoria Formation (Niem and Niem, 1985) crops out over a 20 km long belt. The Youngs Bay member consists of thick, channelized, clean, friable arkosic micaceous sandstone of excellent reservoir quality. The sandstone was formed by high concentration turbidity currents, grain flows, and fluidized flows in a channel as much as 10 km wide that is enclosed in bathyal foraminifer-bearing, organic-rich mudstone (Nelson, 1978; Coryell, 1978). This unit appears to have been deposited in a submarine canyon head of an ancestral (middle Miocene) Astoria canyon at the former mouth of the Columbia River. The canyon trends southwestward offshore toward this transect line (Coryell, 1978; Nelson, 1978; Niem and Niem, 1985). This sandy canyon head deposit may have fed an ancestral middle Miocene Astoria submarine fan offshore. If so, a potential reservoir target may be preserved within offshore unit Tmlm and/or may have been partially subducted and accreted in unit Tmo west of fault C. The modern Astoria fan (Pleistocene and Holocene) is presently being subducted, obducted, and accreted to the lower continental slope (i.e., unit Qp)(Kulm and Fowler, 1974; Peterson and others, 1986; Carlson and Nelson, 1987; Duncan and Kulm, 1989).

Middle Miocene Basalts. Middle Miocene basalt sills and dikes (shown by strings of small x's and/or labeled Tb) intrude unit Tmlm from the eastern end of cross section A-A' westward to fault C. Acoustically, these basalt bodies display strong, high-amplitude multiple reflections and show cross-cutting relationships to older strata (see seismic profile B-B' on Plate 1). The intrusive basalts are offshore equivalents of the middle Miocene sills, dikes, and submarine breccias that are extensive throughout Clatsop County (Niem and Niem, 1985; see geologic strip map on Plate 1). Onshore, they intrude middle Miocene to upper Eocene sedimentary strata. They do not intrude any younger units (e.g., unit Tmu) offshore and, thereby, help define the top of unit Tmlm. These intrusive rocks and their extrusive counterparts are widespread on the northern and central Oregon continental shelf and coastal margin (Snavely and others, 1973; Tolson, 1976; Snavely and Wells, 1984; Niem and Niem, 1985). Most prominent is the 300-m thick middle Miocene sill of low MgO Grande Ronde Basalt (unit Tgi) which forms Tillamook Head (a rugged headland) and Tillamook Rock (a 40-m high sea stack 2.5 km offshore). A K/Ar age of 15.9 +/- 0.4 Ma (middle Miocene) has been obtained for the sea cliff exposures of the basalt sill at Tillamook Head (Niem and Cressy, 1973; Turner, 1970). The topography of the sill forms a large positive anomaly on the magnetic profile across Tillamook Head onshore and above Tillamook Rock offshore. Several km farther offshore the sill forms a second positive anomaly. The Tillamook Head sill also can be traced as a near surface prominent, irregular reflector beneath onlapping units Qh and Qp along OSU's seismic-reflection profile SP-106 to line WO 76-7 for 20 km. It steps downward to the west into lower and middle Miocene (unit Tmlm) to Oligocene (unit Toe) synclinal strata for another 15 km on the U.S.G.S. seismic profile WO 76-7.

The thick Tillamook Head sill can be traced inland for 15 km both by geologic mapping and seismically (line C-C′) as a strong reflector to the Diamond Shamrock Crown Zellerbach 11-28 well which penetrated a 60-m thick sill with low MgO Grande Ronde chemistry at a depth of 2,000 ft (610 m; Rarey, 1986). Between the coastline and the well, the thick sill which crops out discontinuously has attenuated most acoustical reflections, resulting in a "noisy" seismic record (line C-C′). Thus, the Tillamook Head sill can be traced tentatively both onshore and offshore for over 50 km.

The origin of the middle Miocene sills and dikes has been a subject of some discussion. Snavely and others (1973) believed these intrusions originated locally from magma bodies at depth which produced thick submarine breccias, pillow lavas, and associated radial and ring dikes as at Cape Foulweather and Depoe Bay in the Newport embayment 130 km south of this transect. They were the first to recognize that these submarine basalts and intrusions exposed along the coast (which they formally named Depoe Bay Basalt, Cape Foulweather Basalt, and Basalt at Pack Sack Lookout) are age, petrographic, and chemical correlatives of the Yakima, Late Yakima, and Pomona basalts (now Grande Ronde, Wanapum, and Pomona basalts; Swanson and others, 1979) of the Columbia River Basalt Group of eastern Washington-Oregon and Idaho.

Beeson and others (1979) proposed an alternative hypothesis that these sills, dikes, and submarine pillow lavas and breccias are seaward invasive extensions of subaerial Columbia River Basalt flows. These flows were erupted on the Columbia Plateau of eastern Oregon-Washington and Idaho and flowed down an ancestral Columbia River valley to marine embayments along the Miocene coast. The subaerial flows encountered the shoreline in eastern Clatsop County where the dense hot fluid basalt interacted with seawater to form thick pillow palagonite lavas and breccias (Murphy and Niem, 1982; Rarey and others, 1984). Beeson and others hypothesized that these 20- to 50-m thick flows invaded and injected downward into the less dense, water-saturated poorly consolidated Miocene and older Tertiary sedimentary strata. Studies of paleomagnetism (Wells and Coe, 1985; Sheriff, 1984; Magill and others, 1981; Choiniere and Swanson, 1979; Kienle, 1971), major and minor/trace element geochemistry, and gravity and magnetic polarity (Hill, 1975; Pfaff, 1981; Peterson, 1984; Nelson, 1985; Rarey, 1986; Reidel and others, 1989; Goalen, 1988; Pfaff and Beeson, 1989; Tolan and others, 1989), and field mapping (Niem and Niem, 1985; Goalen, 1988; Coryell, 1978; Olbinski, 1983; Mumford, 1988; Wells and Niem, 1987) in Clatsop County and southwestern Washington strongly support this invasive hypothesis. Eighteen to twenty individual plateau-derived Grande Ronde, Frenchman Springs, and Pomona subaerial flows can be correlated to adjacent Miocene sills and dikes by geochemistry, petrography, and paleomagnetic signature (Wells and others, 1989). Invasive relations of Columbia River Basalts on the Columbia Plateau into thin sequences of fluvial and lacustrine (diatomaceous) sediment have been well documented (Schmincke, 1964, 1967; Byerly and Swanson, 1978, 1987; Swanson and Wright, 1978, 1981; Stoffel, 1984; Ross, 1989). The scale and depth (> 2,000 m) of invasion of fluid lava into Astoria basin strata (upper Eocene to middle Miocene) are impressive as seen by the scale of the Tillamook Head sill. The mechanics of such an invasive process are still being debated, particularly in light of recent mapping in the central part of the Oregon Coast Range by Snavely and others (1990) who found a Depoe Bay (Grande Ronde correlative) basalt sill apparently intruding pillow lava and breccia of the lower Eocene Siletz River Volcanics and Depoe Bay Basalt dikes intruding the upper Eocene Basalts of Cascade Head.

Grande Ronde sills can be traced over 14 km as three prominent reflectors in seismic records (e.g., D"-D‴ and E-E′) in eastern Clatsop County. These reflectors parallel and cut across upper Eocene strata (units Ts and Tk). The sills were correlated to the Watzek well on the basis of a synthetic seismogram (see also explanatory sketch between seismic lines D‴ and E on Plate 1). Three sills (10- to 76-m thick) were penetrated by the Quintana Watzek 30-1 well (no. 3 on Plate 1) at depths of 2810 ft (856 m), 3510 ft (1070 m), and 4510 ft (1375 m)(Olbinski, 1983). The invasive sills fed or were fed by a prominent set of three widely spaced 10- to 30-km long subparallel northeast-trending dikes (possibly fault- or joint-controlled) in eastern Clatsop County (Olbinski, 1983; Nelson, 1985; Niem and Niem, 1985; Goalen, 1988). The uppermost sill in the Watzek well has the same major element geochemistry as and may have fed (or was fed by) the prominent northeast-trending 10-km long basalt dike that crops out adjacent to the Watzek well (see geologic strip map on Plate 1). Similarly, the chemistry of the other two dikes in the set of three can be related to these subsurface sills.

Pfaff and Beeson (1989) and Pfaff (1981) showed that these northeast-trending dikes are chemically related to subaerial Columbia River Basalt flows. They also modelled gravity anomalies associated with two of these northeast-trending dikes and suggested that these two dikes extend only 107 meters or less below the surface, implying a shallow invasive origin. However, this interpretation depends on the densities selected for the basalt and for the host rocks and is not an unique solution. The seismic-reflection records presented here and the geochemistry of these invasive sills and dikes penetrated in the Watzek 30-1 and Crown Zellerbach 11-28 wells (Olbinski, 1983; Nelson, 1985; Niem and Niem, 1985; Rarey, 1986) show that these intrusions extend to much greater depths (i.e., 856 m to >1300 m) than predicted by Pfaff and Beeson.

Plateau-derived subaerial flows, pillow flows, and shallow invasive sills of Grande Ronde Basalt and Frenchman Springs Member of the Wanapum Basalt also crop out at the eastern end of this cross section and geologic strip map in the northern part of the Mist Gas Field. These flows are interbedded with weathered fluvial basalt gravels (derived from Columbia River Basalt flows), cross-bedded loose micaceous arkosic sands, and local lacustrine muds. These sedimentary interbeds have been reassigned to the middle Miocene Scappoose Formation (unit Tsp) of Ketrenos (1986) and Van Atta and Kelty (1985). Middle Miocene sills and flows with Pomona and Frenchman Springs chemistry (units Tfi and Tfe) occur near the coastline (Rarey and others, 1984; Niem and Niem, 1985) and could form some of the other middle Miocene(?) basalt sill reflectors offshore (unit Tb).

Although thin intrusions (i.e., <30 m thick) show little heating effect upon the host strata, thick basaltic to gabbroic sills (>100 m) have extensively baked the enclosing sedimentary strata for several hundred meters. Such thermally matured strata underlie over 1300 sq km of Clatsop County. Niem and Niem (1985) showed that a 146-m thick Grande Ronde gabbroic sill penetrated in a deep exploration hole (Diamond Shamrock Crown Zellerbach 31-17) had increased the vitrinite reflectance of the thermally immature host mudstone from 0.4 to 2.4 over a 300-m interval, thereby creating a source of thermogenic gas. Thermogenic gas shows were noted in gas chromatographs of this well whereas the same strata without sills in wells a few miles away were thermally immature and had only methane shows (Niem and Niem, 1985). The seismic records presented here show that thick sills can be traced over broad areas (tens of sq km) both onshore and offshore. If these thick widespread sills (like the Tillamook Head sill) have thermally matured the host strata over many square kilometers as has been demonstrated onshore (Niem and Niem, 1985) and offshore (Snavely and Wells, 1984), these sedimentary host rocks may represent a thermally mature source of thermogenic natural gas for future offshore exploration.

Upper Miocene Strata. On the inner continental shelf, a well defined acoustical sequence (unit Tmu) shows an eastward depositional downlap (between Nehalem Bank and A'). This sequence unconformably overlies unit Tmlm (Astoria Formation correlative). The absence of high-amplitude reflectors, interpreted as middle Miocene basalt intrusions, in unit Tmu helps to define the base of this upper Miocene acoustical unit. The unit has a maximum thickness of about 550 m in the axial part of the deep marginal basin. It thins both to the east and west away from the basin axis. The eastward downlap of these inferred upper Miocene strata indicates a western sediment source, most likely Nehalem bank.

Strata of late Miocene age are missing from the eastern end of cross section A-A', and no strata of late Miocene age crop out in northwestern Oregon (Niem and Niem, 1985). The late middle Miocene was a period of rapid underthrusting of the Juan de Fuca plate beneath the North American plate resulting in accretion of unit Tmo on the upper continental slope. Concurrently, uplift and erosion of the Coast Range and shelf was followed by basinal subsidence of the inner continental shelf (Kulm and Fowler, 1974; Snavely and Wells, 1984; Snavely, 1987; Duncan and Kulm, 1989; Niem and others, in press).

Although the thickness of upper Miocene strata is estimated to be about 550 m along the line of transect in the offshore area, only 70 m of upper Miocene bathyal siltstone was penetrated in Shell Oil Company well P-072 (18 km north of the line)(Cooper, 1981). This pronounced thickness difference is probably due to stratigraphic thinning of the upper Miocene strata onto an older structural high of Oligocene-middle Miocene melange penetrated in the Shell well. The Shell Oil Company P-075 well, 17 km northeast of the P-072 well, encountered 300 m of upper Miocene claystone (Cooper, 1981).

Strata of Pliocene Age. Acoustical unit Tp is present across the entire shelf but is of variable thickness. Variation in thickness is attributed to episodic periods of vertical and lateral tectonic movement during deposition and, in places, to erosion along the unconformity at the base of the Pleistocene sequence (Snavely and McClellan, 1987; Kulm and Fowler, 1974; Duncan and Kulm, 1989). In the nearby Shell Oil Company P-072 and P-075 wells, the Pliocene section is at least 763 m and >1400 m thick, respectively, and consists of olive-gray bathyal claystone and siltstone (Cooper, 1981). DSDP core hole 176 encountered fissile siltstone of Pliocene age at a depth of 41 m (Kulm and others, 1973; Kulm and Fowler, 1974).

On the shelf in cross section A-A′, Pliocene strata are thickest near the axis of the deep marginal basin beneath the continental shelf where strata assigned to the Pliocene are more than 800 m in maximum thickness. The Pliocene strata thin landward and do not crop out in northwestern Oregon (Niem and Niem, 1985) which was an uplifted highland during the Pliocene, supplying sediment to the continental shelf basins (Niem and Niem, 1984; Snavely and Wagner, 1963).

Pleistocene and Holocene Deposits. A thick sequence of Quaternary sediments (units Qh and Qp) is widespread on the continental shelf. These deposits are thickest in three broad synclines formed by gentle folding of Pliocene and older Tertiary strata and are separated by narrow highly faulted anticlinal folds cut by dextral(?) faults that have surface bathymetric expression (e.g., Nehalem Bank; Kulm and Fowler, 1974). Ages of these two youngest acoustical units on the cross section were interpreted chiefly from superposition and relation to unconformities. Pleistocene and Holocene sediments dredged and dated by Oregon State University along line SP-106 (Kulm and Fowler, 1974) that parallels line A-A′ 2.5 km to the north provide additional age control for these acoustical units. Also, DSDP core hole 176, drilled 6 km north of the USGS line, penetrated 41 m of Pleistocene glauconitic clayey silt resting unconformably on Pliocene(?) fissile siltstone (Kulm and others, 1973).

Accretionary Complex beneath the Continental Slope

The complex structure on the upper continental slope along cross section A-A′ reflects periods of compressive deformation resulting from oblique subduction of the Juan de Fuca plate beneath the North American continental margin. As interpreted by Snavely and McClellan (1987) from the 24-channel seismic-reflection profile (line WO 76-7), the structure consists of a landward-dipping thrust fault (i.e., fault C) and a younger set of seaward-dipping thrust faults (e.g., fault A). Between these zones of thrust faults are two west-dipping normal (growth or oblique-slip) faults bounding narrow basins that contain thick sequences of more gently deformed Miocene-Oligocene (unit Tmo), upper Miocene (unit Tmu), and Pliocene (unit Tp) strata (e.g., west of fault B).

Upper Oligocene to Middle Miocene Melange and Broken Formation. Snavely and McClellan (1987) had no direct evidence on which to determine the composition of this offshore acoustical unit (unit Tmo), but Shell Oil Company well P-072, 18 km north of this line, penetrated possibly correlative sheared, well-cemented, quartzose arkosic sandstone and indurated siltstone of middle Miocene to late Oligocene age that are cut by zeolite veins at depths of 1555 m to 2505 m (W. W. Rau, written commun. to Snavely, 1976; Cooper, 1981). Although this unit is not clearly correlative to any unit along the onshore part of this transect, it does appear to be equivalent to the tectonically complex middle Miocene to upper Oligocene Hoh assemblage that crops out along the west side of the Olympic Peninsula and offshore southwestern Washington (Rau, 1975; Snavely and Wagner, 1982; Snavely, 1987; Snavely and Kvenvolden, 1987; Niem and others, in press). Unit Tmo is unconformably overlapped in places by upper Miocene strata. If this stratigraphic correlation is valid, fault C on cross section A-A′ would have to strike northeastward in order to lie east of Shell Oil Company well P-072. This subducted upper Oligocene to middle Miocene melange and broken formation could include the seaward facies of the ancestral lower to middle Miocene Astoria submarine fan. Onshore the Miocene Astoria Formation contains deltaic and shallow marine deposits and slope and canyon head facies of the ancestral Columbia River and associated Astoria Canyon that projects offshore to a postulated Miocene Astoria fan deposit (Cooper, 1981). Alternatively, these postulated fan(?) deposits may have been transported northward along transcurrent faults D and E to southwestern Washington.

Pliocene and Pleistocene Sequence. A sequence of abyssal claystone, siltstone, and very fine-grained turbidite sandstone (units Qp and Tp) has been uplifted and obducted along seaward-dipping thrust faults and associated folds (fault A and west). Study of sediments from DSDP core hole 175 indicate that these units, in part, represent accreted Astoria fan sediment and hemipelagic muds (Kulm and Fowler, 1974; Peterson and others, 1986; Duncan and Kulm, 1989). Along this transect, this sequence appears to be thrust over the accretionary wedge of upper Oligocene to middle Miocene strata (unit Tmo) which may have acted as a gently sloping backstop during subduction of the Juan de Fuca plate beneath the lower continental slope (Snavely, 1987). Obducted strata and seaward verging thrust faults have formed a distinctive valley and ridge bathymetry with many north-south-trending elongate ridges and troughs on the lower continental slope off northwestern Oregon (Kulm and Fowler, 1974). Thick deposits of upper Miocene and Pliocene fine-grained sandstone, siltstone, and claystone fill upper slope basins created by two prominent normal, transpressional, or growth faults (i.e., fault B and west-dipping fault west of fault B). The Pliocene deposits are up to 800 m thick. Upper Pleistocene(?) and Holocene deposits (units Qp and Qh) of hemipelagic clay and terrigenous silt and very fine sand (semi-consolidated) blanket the older strata in most places on the continental slope.

TECTONIC FRAMEWORK

Interpretation of the stratigraphy and structure of the cross section across the northern Oregon continental shelf and upper slope is speculative because the multi-channel seismic profiles vary in quality and critical subsurface data are absent. Despite these limiting factors, the cross section clearly indicates that the continental margin has been subjected to compression, extension, wrench tectonics, and growth faulting during the Cenozoic. Varying rates of oblique convergence and clockwise rotation between Pacific oceanic plates (Farallon and Juan de Fuca) and the North American plate have resulted in episodic periods of underthrusting, dextral transcurrent faulting, and extension during the middle late Eocene, late Eocene, late middle Miocene, Pliocene, and Pleistocene (Snavely, Wagner, and Lander, 1980; Snavely, 1987). The structure on the onshore-offshore transect reflects the total of these episodic effects.

Two major faults, D and E, offset Tertiary strata on the outer continental shelf and appear to extend up through Pleistocene and Holocene sediments to the sea floor. Fault D displays a positive flower structure indicating transpressional strike-slip (dextral?) movement (Harding, 1985). The thickness difference of middle Miocene (unit Tmlm), upper Miocene (unit Tmu), Pliocene (unit Tp), and Pleistocene (unit Qp) strata east and west of fault D also supports strike-slip movement along this fault. Fault E also is most likely a strike-slip fault with a major component of vertical displacement (up on the east), as the thickness of middle Miocene strata (unit Tmlm) is twice as much east of the fault as to the west; also the sequence is offset across the fault with an apparent vertical separation of about 800 m. On a high-resolution profile (UNIBOOM), fault E appears to be overlapped by Quaternary sediments which, in turn, onlap the uplifted middle Miocene strata that form this part of Nehalem Bank (an outer continental shelf bathymetric ridge consisting of a highly faulted breached anticline). Farther east (this study) and north (2.5 km) uplifted Pliocene strata are exposed on the sea floor (Kulm and Fowler, 1974). A major north-trending dextral fault, the Fulmar fault (Snavely, 1980), has been mapped on the southern Oregon shelf. Although its trace north of latitude 45 degrees is unclear, this fault may be related to fault D.

In the eastern part of section A-A′, a set of recently active listric faults (e.g., fault F) offsets Holocene strata but not the sea floor (see high resolution profile of fault F on Plate 1). This westward-dipping thrust fault flattens at depth and appears to be a bedding plane fault on the multichannel record that lies immediately above the resistant middle Miocene Tillamook Head sill (Grande Ronde basalt) and truncates folds in unit Tmlm (Astoria Formation). The abrupt down-stepping across strata of this sill in the marginal basin immediately west of this bedding plane fault may have been the result of mechanics of intrusion. Similar abrupt down-stepping of middle Miocene sills across strata has been noted in cliff exposures onshore (Cressy, 1974; Mumford, 1988) and in onshore seismic-reflection profiles D′′ to D′′′and E to E′.

The listric thrust fault (fault F) indicates that compressional forces have been active on the inner continental shelf during Holocene time. Some normal faults that truncate upper Miocene and Pliocene strata (units Tmu and Tp) may have formed as result of late Tertiary basin extension. There are, however, more numerous normal and vertical faults and a few thrust faults offsetting the older upper Oligocene and middle Eocene strata (unit Toe) and lower to middle Miocene strata (unit Tmlm) in the deep

Astoria marginal basin beneath the inner continental shelf. Most of these faults do not extend above the unconformity at the base of upper Miocene strata (unit Tmu). Similarly, in the onshore part of this basin, there are numerous high-angle (60 to 85 degrees) conjugate northwest- and northeast-trending normal and vertical faults, many with oblique slip, and a few small east-west thrust and reverse faults in the Eocene through middle Miocene sedimentary and volcanic units (see geologic strip map on Plate 1). This onshore fault pattern is based on detailed geologic mapping (scale 1:24,000), many industry seismic lines (including lines C-C′, D-D′′′, E-E′, and F-F"), and well correlations (Niem and Niem, 1985; Rarey, 1986; Nelson, 1985; Olbinski, 1983).

Postulated high-angle faults G, H, and I on the inner continental shelf west of Tillamook Rock are based on steep magnetic gradients on the aeromagnetic map of this area published by the U.S. Geological Survey in 1984 and on the apparent offset of a large positive magnetic anomaly (presumed to be the Tillamook Head sill) west of Tillamook Head and Tillamook Rock. The aeromagnetic map and magnetic profile (Plate 1) indicate a northwest-trending trough, or graben, between the positive topographic anomaly over Tillamook Head and the positive anomaly offshore. Alternatively, the offshore magnetic anomaly may be due to changes in thickness or depth of the sill, and the sill is not faulted. Therefore, faults G, H, and I are queried on Plate 1 because there is no seismic coverage or only old single-channel seismic coverage where the faults are drawn.

Oblique-slip conjugate normal and vertical faults onshore tend to step the Eocene Tillamook volcanic basement down in "synclinal" basins and narrow northwest-trending pull-apart grabens and step-up the basalt basement into broad "anticlinal" fault-bounded horst-like blocks (e.g., Tillamook highlands and Green Mountain outlier; Fig. 1 and geologic strip map on Plate 1). Uplifted blocks of Tillamook Volcanics produce a broad positive anomaly on the gravity profiles. The continuation of this gravity high over the Tillamook Volcanics is the buried Nehalem Arch of Armentrout and Suek (1985; see Fig. 2 on Plate 1) which is recognizable as a small positive anomaly on the Bouguer gravity profile near the Clatsop-Columbia county line and as upthrown Tillamook Volcanics (unit Ttv) between wells 3 and 8 on the geologic cross section on Plate 1.

Seismic records and well data show that the amount of offset or throw on the normal faults, both onshore and offshore, tends to be greater in the older Eocene strata (e.g., units Thr, Ths, and Tc) and basement volcanic rocks (unit Ttv; prominent continuous lowest reflectors on seismic records) than offsets in the upper Eocene and Oligocene strata (units Tsc, Tk, Tpb, and Ts) and middle Miocene strata (unit Ta) and intrusions (units Tgi and Tfi). Motion on these high-angle normal faults was predominantly dip-slip during a period of late Eocene extension (post-Cowlitz but pre-Keasey)(Snavely, 1987; Wells and Snavely, 1989). Some faults terminate at the unconformity at the base of the Keasey (Niem and Niem, 1985).

Many exposed fault planes have abundant subhorizontal slickensides (Olbinski, 1983; Nelson, 1985; Rarey, 1986; Mumford, 1988), showing oblique slip. These faults offset middle Miocene Grande Ronde dikes by tens to hundreds of meters (e.g., dike near the Watzek well, no. 3). Older normal faults were reactivated in the late middle Miocene, but the motion was primarily horizontal to oblique slip formed in a wrench tectonic setting (Nelson, 1985; Niem and Niem, 1985; Rarey, 1986; Safley, 1989). Northwest-trending faults show predominantly right-lateral motion; northeast-trending faults display left-lateral offset (Olbinski, 1983; Nelson, 1985; Rarey, 1986; Mumford, 1988). Some east-west thrust faults also have been recognized.

This wrench tectonic setting created small northwest-trending pull-apart basins or grabens that cut obliquely across the gravity high of Tillamook Volcanics (e.g., along the Sunset Highway [US 26] and the Nehalem graben in the Mist Gas Field). The Nehalem River parallels the Nehalem or "Boomer" (oil company term) pull-apart graben. Scappoose strata (unit Tsp) are downstepped on mapped faults and on faults identified seismically (profile F′-F"; Dave Huggins, ARCO Oil and Gas Company, personal communication, 1990). A graben is consistent with interpretation of offset of older units in wells (Dan Fortier, ARCO Oil and Gas Company, personal communication, 1990). The Nehalem graben is bounded on the south by the large oblique-slip northwest-southeast trending fault J or "Boomer" fault, which has a throw of about 250 m. A sequence of smaller antithetic oblique-slip northwest-southeast to east-west trending faults (Dave Huggins, ARCO, personal communication, 1990) on the north side of the graben steps up the Tillamook Volcanics basement (seismic profile F′-F").

The Mist Gas Field consists of many small fault blocks within and adjacent to the Nehalem graben in Columbia County (see well locations inset map and geologic strip map on Plate 1). Thermogenic gas (largely methane, Armentrout and Suek, 1985) has accumulated in complexly tilted fault blocks. Structural traps are generally in the drag-folded upper Eocene Cowlitz strata (C & W sandstone reservoir) on the upthrown blocks. The C & W unit is an arkosic micaceous sandstone, as much as 200 m thick, which was deposited in a wave-dominated shelf-deltaic environment (Berkman, 1990). The sandstone is overlain by upper bathyal Cowlitz mudstone and tuffaceous Keasey mudstone which act as seals (Newton, 1979; Alger, 1985). Due to the small scale of the map and cross section, not all the northeast-trending faults that bound individual fault blocks are shown.

Faults mapped at the surface in northwestern Oregon appear to be more steeply dipping (many 80 to 90 degrees) than the faults in seismic-reflection records (most 50 to 60 degrees; e.g., in line F′-F"). On industry seismic records (e.g., Mist Gas Field), normal faults with more gentle dips show the greatest displacement of units. Faults with steeper dips at the surface and with oblique-slip motion appear to be reactivated normal faults and may not show up as well on seismic records because the displacement was predominantly horizontal rather than vertical. Kadri (1982) related the complex of fault blocks to primarily vertical basement uplift; however, with the preponderance of field evidence of oblique-slip (i.e., offset dikes, subhorizontal slickensides), a wrench tectonic setting is more likely (Olbinski, 1983; Peterson, 1984; Nelson, 1985; Niem and Niem, 1985; Rarey, 1986; Mumford, 1988; Safley, 1989).

Wells and Coe (1985), Nelson (1985), and Wells and others (1984) documented 15 to 30 degrees of clockwise paleomagnetic rotation in the middle Miocene Columbia River basalt flows and intrusions in southwestern Washington and northwestern Oregon. These writers have related the rotation to small block rotations between oblique-slip faults and to Miocene opening of the Basin and Range Province. They suggested that the northwest- and northeast-trending conjugate faults may have been formed by a north-south shear couple produced in the late middle Miocene by oblique subduction of the Juan de Fuca plate beneath the North American plate. Perhaps strike-slip faults E and D on the inner continental shelf reflect major tears between the obliquely subducting Juan de Fuca plate with accreted imbricate thrusted wedges of melanged Tmo strata (west of fault C) and the North American plate. Possibly this north-south shearing or wrenching stress was propagated across the inner continental shelf into the Oregon Coast Range by smaller subsidiary northwest-, northeast-, and east-west-trending normal and vertical faults with oblique right- and left-lateral slip and some east-west thrust faults during this late middle Miocene subduction and accretion episode.

The offshore sequence records that a major episode of underthrusting occurred in late middle Miocene time (Snavely, Wagner, and Lander, 1980; Snavely, 1987). This episode is interpreted to have resulted in subduction and formation of the Oligocene and Miocene melange (unit Tmo) west of fault C beneath the upper continental slope. This melange most likely is correlative with the Hoh melange of the western Olympic Mountains of Washington (Snavely and others, 1980; Snavely, 1987; Duncan and Kulm, 1989). Fault C represents the major underthrust boundary. The thick sequence of Paleogene strata (unit Toe) and Tillamook volcanic basement (unit Ttv) on the shelf east of fault D and onshore may have acted as a steep backstop and caused the underplating and accretion of the Miocene and Oligocene melange (unit Tmo) to the upper continental slope (Snavely, 1987). The imbricate thrusts in the western part of this marginal basin sequence (i.e., west of fault D) also show the effect of this underplating. The underplating event may have been initiated as early as early Miocene in as much as some thrusts and other faults appear to be truncated by the unconformity at the base of unit Tmlm. This early Miocene unconformity appears at the base of the shallow-marine sandstone of the lower and middle Miocene Astoria Formation that abruptly overlies deep-marine slope mudstone of the upper Eocene to lower Miocene Smuggler Cove formation (Cressy, 1974; Niem and Niem, 1985).

A more profound, widespread angular unconformity at the base of upper Miocene strata on the Oregon and Washington continental shelf records regional uplift of both the shelf and Oregon Coast Range that occurred in response to this major late middle Miocene episode of plate convergence and transpression (e.g., along faults E and D). Middle Miocene (unit Tmlm) and older Tertiary strata (unit Toe) were uplifted and folded on the shelf. They were later truncated by erosion before subsidence and deposition of upper Miocene and Pliocene marine strata (Snavely, Wagner, and Lander, 1980). Subsequent mountain building, erosion, and river entrenchment in middle Eocene to middle Miocene volcanics and sedimentary strata in the gently upwarped northern Oregon Coast Range, together with extrabasinal continental sources in the Columbia River drainage system, contributed large volumes of sand, silt, and clay to the subsiding late middle Miocene and Pliocene marginal basin on the inner continental shelf (Snavely and Wagner, 1963; Kulm and Fowler, 1974). A similar major unconformity between upper Miocene and older Tertiary strata has been recorded in many basins throughout the Circum-Pacific margin at this time and may be related to eustatic sea level changes. This unconformity correlates with the major 10.2 Ma sequence boundary between supercycles TB2 and TB3 as defined by Haq, Hardenbol, and Vail (1987).

Near the west end of the cross section, fault A thrusts a folded obducted sequence of Pliocene (unit Tp) and Pleistocene (unit Qp) abyssal strata and Astoria fan sediments over upper Oligocene and middle Miocene melange (unit Tmo). West of fault A, and probably extending to the base of the slope west of this cross section, imbricate, west-dipping and east-dipping low-angle thrust faults and fault propagation anticlinal folds (thrust-folds) have uplifted off-scraped abyssal plain and Astoria fan-trench sediments as much as 1000 m above their original site of deposition

(Kulm and Fowler, 1974; Snavely, Wagner, and Lander, 1980; Duncan and Kulm, 1989). These obducted deep-sea strata have created the ridge and trough bathymetry that characterizes the lower continental slope off northern Oregon (Kulm and Fowler, 1974; note bathymetric contours on geologic strip map). Similar obducted ridge bathymetry has been reported forming along the lower continental slope of Washington by Silver (1972) and Snavely (1987). This compressive deformation is inferred to occur in upper-plate strata that lie above a major decollement near the late Miocene-Pliocene boundary. Below this decollement, near latitude 45 degrees north, upper Miocene and Pliocene abyssal plain and hemipelagic-pelagic strata and upper Miocene oceanic basalts of the Juan de Fuca plate are being subducted and underplated and accreted (Snavely and others, 1987).

Although the quality of the seismic profile below 4 seconds is poor, discontinuous strong sub-horizontal reflectors are evident below the structurally complex Pliocene to Eocene strata along the entire offshore cross section. These reflectors could represent underplated strata above the upper Miocene oceanic basalt of the subducting Juan de Fuca plate.

Recent SeaMARC-1A sidescan sonar and deep dives by the ALVIN off Pacific City, Oregon (between 44 degrees 32´N and 45 degrees 12´N latitude) approximately 60 to 80 km south of this cross section indicate possible active strike-slip faults at the toe of the continental slope and on the abyssal seafloor (Goldfinger and others, 1989). In addition, at the toe of the continental slope are 800-m high anticlinal marginal ridges with backthrusts. Associated with the fault scarps are carbonate crusts and slabs formed by leakage of methane and carbon dioxide-charged fluids up backthrust fault planes (Appelgate and others, 1989; Kulm and others, 1989). Large-scale submarine landslides and slumps up to ten kilometers in length occur along the deformation front (Kulm, 1990, personal communication). Von Huene and others (1989) described similar great earthquake-generated landslides with detached slump blocks with back-tilted strata and debris flows against a gravity fault along the lower continental slope in the active convergent thrust fault margin off northern Peru. Similar gravity slides in the Oregon convergent margin could possibly be earthquake-generated. Recent smaller gravity slides related to earthquake events have been recognized by Field (1984) in the northern California convergent margin as well.

Normal fault B and the adjacent normal fault between faults A and B on the upper continental slope may have been similarly formed as a result of mega-collapse of the upper continental margin, either gravity-driven slumping generated by seismic activity or by a period of tectonic extension and normal faulting associated with the subducted sediment and decollement. Alternatively, these normal faults or half grabens may represent extension-related dextral faulting in an overall transpressional tectonic regime. The wedge-shaped thickening of units Tp and Tmu toward the faults in the fault-bounded basins also suggests growth faulting. Possibly, the high sedimentation rates off the mouth of the Columbia River could create growth faults on the upper continental slope in this convergent plate tectonic setting, as formed off the Mississippi and Niger deltas in a passive margin setting (Paine and Meyerhoff, 1970; Short and Stauble, 1967). Note the abrupt thickening of the sedimentary section across the fault B and the fault west of fault B on the downthrown block typical of many growth faults (Short and Stauble, 1967). Whether these are associated rollover anticlines and down-to-basin faults has yet to be determined. However, such rollover traps above underthrusted "Hoh melange" source rocks (unit Tmo)(Snavely and Kvenvolden, 1989) could be potential targets for further exploration for hydrocarbons in the future because they produce extensively off the Mississippi and Niger deltas and the Texas Gulf Coast (Fisher and McGowan, 1969).

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REFERENCES CITED

Alger, M. P., 1985, Geology; *in* Olmstead, D. L., Mist Gas Field: exploration and development, 1979-1984: Oregon Department of Geology and Mineral Industries Oil and Gas Investigation 10, p. 6-9.

Appelgate, T. B., Kulm, L. D., Embley, R. W., and Fox, C. G., 1989, Surficial structure of the central Oregon convergent margin: results from a SeaMARC-1A sidescan sonar survey: EOS (American Geophysical Union, Transactions), v. 70, p. 1345.

Armentrout, J. M. and Suek, D. H., 1985, Hydrocarbon exploration in western Oregon and Washington: American Association of Petroleum Geologists Bulletin, v. 69, no. 4, p. 627-643.

Armentrout, J. M., Hull, D. A., Beaulieu, J. D., and Rau, W. W., 1983, Correlation of Cenozoic stratigraphic units of western Oregon and Washington: Oregon Dept. of Geology and Mineral Industries Oil and Gas Investigation 7, 90 p.

Beeson, M. H., Perttu, R., and Perttu, J., 1979, The origin of the Miocene basalts of coastal Oregon and Washington: Oregon Department of Geology and Mineral Industries, Oregon Geology, v. 41, no. 10, p. 159-166.

Berkman, T. A ., 1990, Surface-subsurface geology of the middle to upper Eocene sedimentary and volcanic rock units, western Columbia County, northwest Oregon: Corvallis, Oreg., Oregon State University, master's thesis, 410 p.

Braislin, D. B., Hastings, D. D., and Snavely, P. D., Jr., 1971, Petroleum potential of western Oregon and Washington; *in* Cram, I. A., ed., Possible future petroleum provinces of North America: American Association of Petroleum Geologists Memoir 15, p. 229-238.

Bromery, R. W. and Snavely, P. D., Jr., 1964, Geologic interpretation of reconnaissance gravity and aeromagnetic surveys in northwestern Oregon: U.S. Geological Survey Bulletin 1181-N, 13 p.

Bruer, W. G., Alger, M. P., Deacon, R. J., Meyer, J. J., Portwood, B. B., and Seeling, A. F., 1984, Northwest Oregon: Correlation Section 24, Pacific Section, American Association of Petroleum Geologists, 1 sheet.

Byerly, G. R. and Swanson, D. A., 1978, Invasive Columbia River Basalt flows along the northwestern margin of the Columbia Plateau, north-central Washington: Geological Society of America Abstracts with Programs, v. 10, p. 98.

Byerly, G. R. and Swanson, D. A., 1987, The transition from subaerial to invasive lava flows, Grande Ronde Basalt, northwestern Columbia Plateau: Geological Society of America Abstracts with Programs, v. 19, p. 363.

Carlson, P. R. and Nelson, C. H., 1987, Marine geology and resource potential of Cascadia basin; in Scholl, D. W., Grantz, Arthur, and Vedder, J. G., eds., Geology and resource potential of the continental margin of western North America and adjacent ocean basins--Beaufort Sea to Baja California: Circum-Pacific Council for Energy and Mineral Resources Earth Science Series, v. 6, p. 523-535.

Choiniere, S. R. and Swanson, D. A., 1979, Magnetostratigraphy and correlation of Miocene basalts of the northern Oregon coast and Columbia Plateau, southeast Washington: American Journal of Science, v. 279, p. 755-777.

Cooper, D. M., 1981, Sedimentation, stratigraphy, and facies variation of the lower to middle Miocene Astoria Formation in Oregon: Corvallis, Oreg., Oregon State University, Ph.D. dissertation, 524 p.

Coryell, G. F., 1978, Stratigraphy, sedimentation, and petrology of the Tertiary rocks in the Bear Creek-Wickiup Mountain-Big Creek area, Clatsop County, Oregon: Corvallis, Oreg., Oregon State University, master's thesis, 178 p.

Cressy, F. B., Jr., 1974, Stratigraphy and sedimentation of the Neahkahnie Mountain-Angora Peak area, Tillamook and Clatsop counties, Oregon: Corvallis, Oreg., Oregon State University, master's thesis, 148 p.

Dehlinger, P., Rinehart, R. W., Couch, R. W., and Gemperle, M., 1967, Free-air gravity anomaly map of Oregon and Free-air gravity anomaly map west of Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series, maps GMS 4b and 4c, scale 1:500,000.

Duncan, R. A. and Kulm, L. D., 1989, Plate tectonic evolution of the Cascades arc-subduction complex; in Winterer, E. L., Hussong, D. M., and Decker, R. W., eds., The Eastern Pacific Ocean and Hawaii: Geological Society of America, The Geology of North America, v. N, p. 413-438.

Farr, L. C., Jr., 1989, Stratigraphy, diagenesis, and depositional environments of the Cowlitz Formation (Eocene), northwest Oregon: Portland, Oreg., Portland State University, master's thesis, 169 p.

Field, M. E., 1984, The submarine landslide of 1980 off northern California; in Clarke, S. H., ed., Highlights in Marine Research: U.S. Geological Survey Circular 938, p. 65-72.

Finn, Carol, Phillips, W. M., and Williams, D. L., 1984, Gravity maps of the State of Washington and adjacent areas: U.S. Geological Survey Open-File Report 84-416, scale 1:250,000.

Fisher, W. L. and McGowen, J. H., 1969, Depositional systems in Wilcox Group (Eocene) of Texas and their relation to occurrence of oil and gas: American Association of Petroleum Geologists Bulletin, v. 53, no. 1, p. 30-54.

Goalen, J. S., 1988, Geology of the Elk Mountain-Porter Ridge area, Clatsop County, northwestern Oregon: Corvallis, Oreg., Oregon State University, master's thesis, 356 p.

Goldfinger, Chris, Appelgate, T. B., Kulm, L. D., and Yeats, R. S., 1989, Sidescan sonar imaging of probable active faults on the Juan de Fuca plate adjacent to the central Oregon continental margin: EOS (American Geophysical Union, Transactions), v. 70, p. 1329.

Haq, Bilal, Hardenbol, Jan, and Vail, P. R., 1987, Chronology of fluctuating sea levels since the Triassic: Science, v. 235, p. 1156-1167.

Harding, T. P., 1985, Seismic characteristics and identification of negative flower structures, positive flower structures, and positive structural inversion: American Association of Petroleum Geologists Bulletin, v. 69, no. 4, p. 582-600.

Hill, D. W., 1975, Chemical composition of Oregon and Washington coastal basalts: Corvallis, Oreg., Oregon State University, master's thesis, 99 p.

Kadri, M.M., 1982, Structure and influence of the Tillamook uplift on the stratigraphy of the Mist area, Oregon: Portland, Oreg., Portland State University, master's thesis, 105 p.

Ketrenos, N. T., 1986, The stratigraphy of the Scappoose Formation, the Astoria Formation, and the Columbia River Basalt Group in northwestern Columbia County, Oregon: Portland, Oreg., Portland State University, master's thesis, 78p.

Kienle, C. F., Jr., 1971, The Yakima Basalt in western Oregon and Washington: Santa Barbara, Calif., University of California, Santa Barbara, Ph.D. dissertation, 171 p.

Kulm, L. D. and Fowler, G. A., 1974, Oregon continental margin model; in Burk, C. A. and Drake, C. L., eds., The geology of continental margins: New York, Springer-Verlag, . 261-283.

Kulm, L. D. and others, 1973, Site 176, Initial Reports of the Deep Sea Drilling Project: Washington, U.S. Government Printing Office, v. 18, p. 213-231.

Kulm, L. D., Appelgate, T. B., and Fox, C. G., 1989, Sidescan survey of structures and fluid vent sites on the central Oregon margin and subducting Juan de Fuca plate: EOS (American Geophysical Union, Transactions), v. 70, p. 1345.

Kulm, L. D., Loubere, P. W., and Peper, J. S., 1984, Geology of the continental margin and Cascadia basin; in Kulm, L. D. and others, eds., Western North American continental margin and adjacent ocean floor off Oregon and Washington, Atlas I: Ocean Margin Drilling Program, Regional Atlas Series, Marine Science International, Woods Hole, Massachusetts, sheet 29.

Magill, J. R., Cox, A. V., and Duncan, R. A., 1981, Tillamook Volcanic Series: Further evidence for tectonic rotation of the Oregon Coast Range: Journal of Geophysical Research, v. 86, no. 4, p. 2953-2970.

McElwee, K. R. and Duncan, R. A., 1982, Volcanic episodicity and Tertiary absolute motion in the Pacific Northwest: EOS (American Geophysical Union Transactions), v. 63, p. 1103-1104.

Mumford, D. F., 1988, Geology of the Nehalem River-Elsie area, south-central Clatsop and northern Tillamook counties, northwestern Oregon: Corvallis, Oreg., Oregon State University, master's thesis, 392 p.

Murphy, T. M. and Niem, A. R., 1982, Tectonic and paleoenvironmental significance and magnetic-geochemical stratigraphy of the Columbia River Basalt at the middle Miocene shoreline, northwestern Oregon Coast Range: EOS (American Geophysical Union Transactions), v. 63, no. 8, p. 173.

Neel, R. H., 1976, Geology of the Tillamook Head-Necanicum Junction area, Clatsop County, northwest Oregon: Corvallis, Oreg., Oregon State University, master's thesis, 204 p.

Nelson, D. E., 1985, Geology of the Fishhawk Falls-Jewell area, Clatsop County, northwestern Oregon: Corvallis, Oreg., Oregon State University, master's thesis, 370 p.

Nelson, M. P., 1978, Tertiary stratigraphy and sedimentation in the Lewis and Clark River-Youngs River area, Clatsop County, northwestern Oregon: Corvallis, Oreg., Oregon State University, master's thesis, 242 p.

Newton, V. C., Jr., 1979, Oregon's first gas wells completed: Oregon Department of Geology and Mineral Industries, Oregon Geology, v. 41, no. 6, p. 87-90.

Newton, V. C., Jr. and Van Atta, R. O., 1976, Prospects for natural gas production and underground storage of pipeline gas in the upper Nehalem River basin, Columbia-Clatsop counties, Oregon: Oregon Department of Geology and Mineral Industries Oil and Gas Investigation 5, 56 p.

Niem, A. R., 1976, Tertiary volcaniclastic deltas in an arc-trench gap, Oregon Coast Range: Geological Society of America Abstracts with Programs, v. 8, no. 3, p. 400.

Niem, A. R. and Cressy, F. B., Jr., 1973, K-Ar dates for sills from the Neahkahnie Mountain and Tillamook Head areas of the northwestern Oregon coast: Isochron/West, no. 7, p. 13-15.

Niem, A. R. and Niem, W. A., 1984, Cenozoic geology and geologic history of western Oregon; in Kulm, L. D. and others, eds., Western North American continental margin and adjacent ocean floor off Oregon and Washington, Atlas I: Ocean Margin Drilling Program, Regional Atlas Series, Marine Science International, Woods Hole, Massachusetts, sheet 17.

Niem, A. R. and Niem, W. A., 1985, Oil and gas investigation of the Astoria basin, Clatsop and northernmost Tillamook counties, northwest Oregon: Oregon Department of Geology and Mineral Industries, Oil and Gas Investigation No. 14.

Niem, A. R. and Van Atta, R. O., 1973, Cenozoic stratigraphy of northwestern Oregon and adjacent southwestern Washington, in Beaulieu, J. D., ed., Geologic field trips in northern Oregon and southern Washington: Oregon Department of Geology and Mineral Industries Bulletin 77, p. 75-132.

Niem, A. R., Snavely, P. D., Jr., and Niem, W. A., in press, Collision and emplacement of accretionary coastal terranes -- Olympic Mountains core rocks, in Christiansen, R. and Yeats, R. S., eds., DNAG (Decade of North American Geology) volume.

Niem, W. A., Niem, A. R., and Snavely, P. D., Jr., in press, Late Cenozoic continental margin of the Pacific Northwest -- Sedimentary embayments of the Oregon-Washington coast, in Christiansen, R. and Yeats, R. S., eds., DNAG (Decade of North American Geology) volume.

Olbinski, J. S., 1983, Geology of the Buster Creek-Nehalem Valley area, Clatsop County, Oregon: Corvallis, Oreg., Oregon State University, master's thesis, 204 p.

Paine, W. R. and Meyerhoff, A. A., 1970, Gulf of Mexico basin, interactions among tectonics, sedimentation, and hydrocarbon accumulation; in Exploration concepts for the Seventies: Gulf Coast Association of Geological Societies Transactions, v. 20, p. 5-44.

Peterson, C. P., 1984, Geology of the Green Mountain-Youngs River area, Clatsop County, northwest Oregon: Corvallis, Oreg., Oregon State University, master's thesis, 215 p.

Peterson, C. P., Kulm, L. D., and Gray, J. J., 1986, Geologic map of the ocean floor off Oregon and the adjacent continental margin: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-42, scale 1:500,000.

Peterson, C. P., Loubere, P. W., Kulm, L. D., and Peper, J. S., 1984, Stratigraphy of continental shelf and coastal region; in Kulm, L. D. and others, eds., Western North American continental margin and adjacent ocean floor off Oregon and Washington, Atlas I: Ocean Margin Drilling Program, Regional Atlas Series, Marine Science International, Woods Hole, Massachusetts, sheet 30.

Pfaff, V. J., 1981, Geophysical and geochemical analyses of selected Miocene coastal basalt features, Clatsop County, Oregon: Portland, Oreg., Portland State University, master's thesis, 151 p.

Pfaff, V. J. and Beeson, M. H., 1989, Miocene basalt near Astoria, Oregon; geophysical evidence for Columbia Plateau origin; in Reidel, S. P. and Hooper, P. R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 143-156.

Phillips, W. M., Walsh, T. J., and Hagen, R. A., 1989, Eocene transition from oceanic to arc volcanism, southwest Washington; in Muffler, L.J.P., Weaver, C. S., and Blackwell, D. D., eds., Geological, geophysical, and tectonic setting of the Cascade Range, Workshop XLIV: U.S. Geological Survey Open-File Report 89-178, p. 199-256.

Rarey, P. J., 1986, Geology of the Hamlet-North Fork of the Nehalem River area, southern Clatsop and northern Tillamook counties, Oregon: Corvallis, Oreg., Oregon State University, master's thesis, 488 p.

Rarey, P. J., Niem, A. R., and Murphy, T. M., 1984, Middle Miocene Pomona flow and intrusives in northwest Oregon Coast Range: Oregon Academy of Science Proceedings, v. 20, p. 51.

Rau, W. W., 1975, Geological map of the Destruction Island and Taholah quadrangles, Washington: Washington Division of Geology and Earth Resources, Geologic Map GM-13, scale 1:62,500.

Reidel, S. P., Tolan, T. L., Hooper, P. R., Beeson, M. H., Fecht, K. R., Bentley, R. D., and Anderson, J. L., 1989, The Grande Ronde Basalt, Columbia River Basalt Group; stratigraphic descriptions and correlations in Washington, Oregon, and Idaho; in Reidel, S. P. and Hooper, P. R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 21-53.

Ross, M. E., 1989, Stratigraphic relationships of subaerial, invasive and intracanyon flows of Saddle Mountains Basalt in the Troy basin, Oregon and Washington; in Reidel, S. P. and Hooper, P. R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 131-142.

Safley, L. E., 1989, Geology of the Rock Creek-Green Mountain area, southeastern Clatsop County, northwestern Oregon: Corvallis, Oreg., Oregon State University, master's thesis, 245 p.

Schmincke, H.-U., 1964, Petrology, paleocurrents, and stratigraphy of the Ellensburg Formation and interbedded Yakima basalt flows, south-central Washington: Ph.D. dissertation, Johns Hopkins University, Baltimore, Maryland, 426 p.

Schmincke, H.-U., 1967, Fused tuff and peperites in south-central Washington: Geological Society of America Bulletin, v. 78, no. 3, p. 319-330.

Sheriff, S. D., 1984, Paleomagnetic evidence for spatially distributed post-Miocene rotation of western Washington and Oregon: Tectonics, v. 3, no. 3, p. 397-408.

Short, K. C. and Stauble, A. J., 1967, Outline of geology of Niger delta: American Association of Petroleum Geologists Bulletin, v. 51, no. 5, p. 761-779.

Silver, E. A., 1972, Pleistocene tectonic accretion of the continental slope off Washington: Marine Geology, v. 13, p. 239-249.

Smith, T. N., 1976, Stratigraphy and sedimentation of the Onion Peak area, Clatsop County, Oregon: Corvallis, Oreg., Oregon State University, master's thesis, 190 p.

Snavely, P. D., Jr., 1980, Geophysical data collected on Oregon shelf along Line 5, Cruise LEE 3-76: U.S. Geological Survey Open-File Report 80-816, 1 p., 1 plate.

Snavely, P. D., Jr., 1987, Tertiary geologic framework, neotectonics, and petroleum potential of the Oregon-Washington continental margin; in Scholl, D. W., Grantz, Arthur, and Vedder, J. G., eds., Geology and resource potential of the continental margin of western North America and adjacent ocean basins--Beaufort Sea to Baja California: Circum-Pacific Council for Energy and Mineral Resources, Earth Science Series, v. 6, p. 305-335.

Snavely, P. D., Jr. and Kvenvolden, K. A., 1989, Geology and hydrocarbon potential; in Preliminary evaluation of the petroleum potential of the Tertiary accretionary terrane, west side of the Olympic Peninsula, Washington: U.S. Geological Survey Bulletin 1892, p. 1-17.

Snavely, P. D., Jr. and MacLeod, N. S., 1974, Yachats Basalt--an upper Eocene differentiated volcanic sequence in the Oregon Coast Range: U.S. Geological Survey Journal of Research, v. 2, no. 4, p. 395-403.

Snavely, P. D., Jr., MacLeod, N. S., and Minasian, D. L., 1990, Preliminary geologic map of the Neskowin quadrangle, Lincoln and Tillamook counties, Oregon: U.S. Geological Survey Open-File Report, scale 1:24,000.

Snavely, P. D., Jr., MacLeod, N. S., and Wagner, H. C., 1973, Miocene tholeiitic basalts of coastal Oregon and Washington and their relations to coeval basalts of the Columbia Plateau: Geological Society of America Bulletin, v. 85, p. 387-424.

Snavely, P. D., Jr. and McClellan, P. H., 1987, Preliminary geologic interpretation of USGS S. P. LEE seismic-reflection profile WO 76-7 on the continental shelf and upper slope, northwestern Oregon: U.S. Geological Survey Open-File Report 87-612, 12 p.

Snavely, P. D., Jr., Miller, J., von Huene, Roland, and Mann, D. M., 1987, The central Oregon margin Line WO 76-5; in von Huene, R., ed., Seismic images of convergent margin tectonic structure: American Association of Petroleum Geologists tudies in Geology No. 26, p. 28-29.

Snavely, P. D., Jr., Pearl, J. E., and Lander, D. L., 1977, Interim report on petroleum resources potential and geologic hazards in the outer continental shelf--Oregon and Washington Tertiary province: U.S. Geological Survey Open-File Report 77-282, 64 p.

Snavely, P. D., Jr. and Wagner, H. C., 1963, Tertiary geologic history of western Oregon and Washington: Washington Division of Mines and Geology Report of Investigations 22, 25 p.

Snavely, P. D., Jr. and Wagner, H. C., 1981, Geologic cross section across the continental margin off Cape Flattery, Washington, and Vancouver Island, British Columbia: U.S. Geological Survey Open-File Report 81-0978, 6 p.

Snavely, P. D., Jr. and Wagner, H. C., 1982, Geologic cross section across the continental margin of southwestern Washington: U.S. Geological Survey Open-File Report 82-459, 10 p.

Snavely, P. D., Jr., Wagner, H. C., and Lander, D. L., 1980, Geological cross section of the central Oregon continental margin: Geological Society of America Map and Chart Series MC-28J, scale 1:250,000.

Snavely, P. D., Jr., Wagner, H. C., and Lander, D. L., 1985, Land-sea geologic cross section of the southern Oregon continental margin: U.S. Geological Survey, Miscellaneous Investigation Series Map 1463.

Snavely, P. D., Jr. and Wells, R. E., 1984, Tertiary volcanic and intrusive rocks on the Oregon and Washington continental shelf: U.S. Geological Survey Open-File Report 84-282, 17 p.

Stoffel, K. L., 1984, Geology of the Grande Ronde lignite field, Asotin County, Washington: Washington Division of Geology and Earth Resources Report of Investigations 27, 79 p.

Swanson, D. A. and Wright, T. L., 1978, Bedrock geology of the northern Columbia Plateau and adjacent areas; in Baker, V. R. and Nummedal, D., eds., The channeled scabland; a guide to the geomorphology of the Columbia Basin, Washington: National Aeronautics and Space Administration, p. 37-57.

Swanson, D. A. and Wright, T. L., 1981, Guide to geologic field trip between Lewiston, Idaho, and Kimberly, Oregon, emphasizing the Columbia River Basalt Group; in Johnston, D. A. and Donnelly-Nolan, J., Guides to some volcanic terranes in Washington, Idaho, Oregon, and northern California: U.S. Geological Survey Circular 838, p. 1-28.

Swanson, D. A., Wright, T. L., Hooper, P. R., and Bentley, R. D., 1979, Revisions in stratigraphic nomenclature of the Columbia River Basalt Group: U.S. Geological Survey Bulletin 1457-G, 59 p.

Tolan, T. L., Reidel, S. P., Beeson, M. H., Anderson, J. L., Fecht, K. R., and Swanson, D. A., 1989, Revisions of the estimates of the areal extent and volume of the Columbia River Basalt Group; in Reidel, S. P. and Hooper, P. R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 1-20.

Tolson, P. M., 1976, Geology of the Seaside-Youngs River Falls area, Clatsop County, Oregon: Corvallis, Oreg., Oregon State University, master's thesis, 191 p.

Turner, D. L., 1970, Potassium-argon dating of Pacific Coast Miocene foraminiferal stages, in Bandy, O. L., ed., Radiometric dating and paleontological zonation: Geological Society of America Special Paper 124, p. 91-129.

U.S. Geological Survey, 1984, Aeromagnetic map of southwest Washington and northwest Oregon: U.S. Geological Survey Open-File Report 84-205, 1 sheet.

Van Atta, R. O. and Kelty, K. B., 1985, Scappoose Formation, Columbia County, Oregon: New evidence of age and relation to Columbia River Basalt Group: American Association of Petroleum Geologists Bulletin, v. 69, no. 5, p. 688-698.

Von Huene, Roland, Bourgois, Jacques, Miller, John, and Pautot, Guy, 1989, A large tsunamogenic landslide and debris flow along the Peru Trench: Journal of Geophysical Research, v. 94, no. B2, p. 1703-1714.

Wells, R. E., 1981, Geologic map of the eastern Willapa Hills, Cowlitz, Lewis, Pacific, and Wahkiakum counties, Washington: U. S. Geological Survey Open-File Map 81-674, scale 1:62,500.

Wells, R. E. and Coe, R. S., 1985, Paleomagnetism and geology of Eocene volcanic rocks of southwest Washington, implications for mechanisms of tectonic rotation: Journal of Geophysical Research v. 90, p. 1925-1947.

Wells, R. E., Engebretson, D. C., Snavely, P. D., Jr., and Coe, R. S., 1984, Cenozoic plate motions and the volcano-tectonic evolution of western Oregon and Washington: Tectonics, v. 3, no. 2, p. 275-294.

Wells, R. E. and Niem, A. R., 1987, Geology of the Columbia River Basalt Group in the Astoria basin, Oregon and Washington: Evidence for invasive flows: Geological Society of America Abstracts with Programs, v. 19, no. 6, p. 462-463.

Wells, R. E., Niem, A. R., MacLeod, N. S., Snavely, P. D., Jr., and Niem, W. A., 1983, Preliminary geologic map of the west half of the Vancouver (Washington-Oregon) 1 degree x 2 degree quadrangle, Oregon: U.S. Geological Survey Open-File Report 83-591, scale 1:250,000.

Wells, R. E., Simpson, R. W., Bentley, R. D., Beeson, M. H., Mangan, M. T., and Wright, T. L., 1989, Correlation fo Miocene flows of the Columbia River Basalt Group from the central Columbia River Plateau to the coast of Oregon and Washington, in Reidel, S. P. and Hooper, P. R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 113-129.

Wells, R. E. and Snavely, P. D., Jr., 1989, Paleogene geologic history of the Oregon-Washington continental margin: Geological Society of America Abstracts with Programs, v. 21, no. 5, p. 157.

Wolfe, E. W. and McKee, B. H., 1972, Sedimentary and igneous rocks of the Grays River quadrangle, Washington: U.S. Geological Survey Bulletin 1335, 70 p.

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

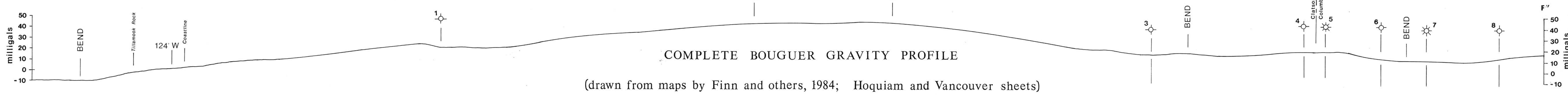
OIL AND GAS INVESTIGATION 17

Onshore-Offshore Geologic Cross Section from the Mist Gas Field, Northern Oregon Coast Range, to the Northwest Oregon Continental Shelf and Slope

by Alan R. Niem, Parke D. Snavely, Jr., and Wendy A. Niem

This project was funded by the U.S. Department of Interior, Minerals Management Service, Co-operative Agreement No. 14-12-0001-30387. Contract management was provided by the University of Texas Bureau of Economic Geology and the Oregon Department of Geology and Mineral Industries

Plate 1

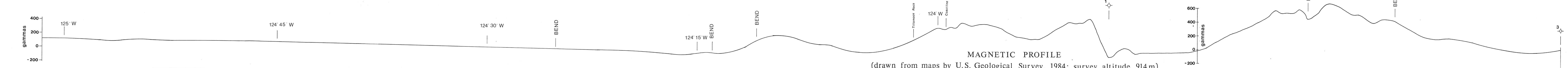


COMPLETE BOUGUER GRAVITY PROFILE

(drawn from maps by Finn and others, 1984; Hoquiam and Vancouver sheets)

FREE-AIR GRAVITY PROFILE

(drawn from maps by Dehlinger and others, 1967)



MAGNETIC PROFILE

(drawn from maps by U.S. Geological Survey, 1984; survey altitude 914 m)

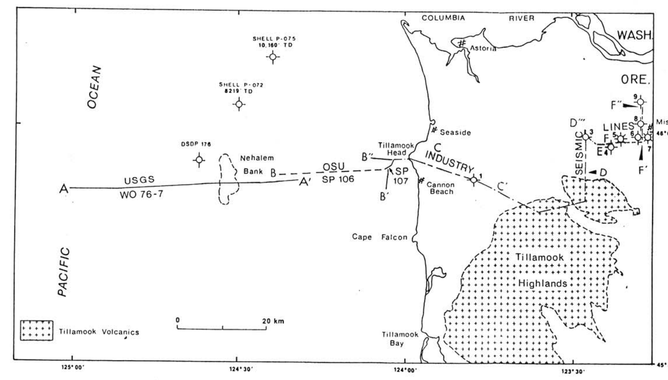


Fig. 1 Index map showing location of geologic-seismic cross section

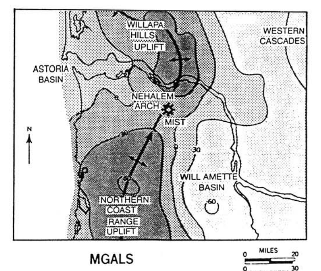
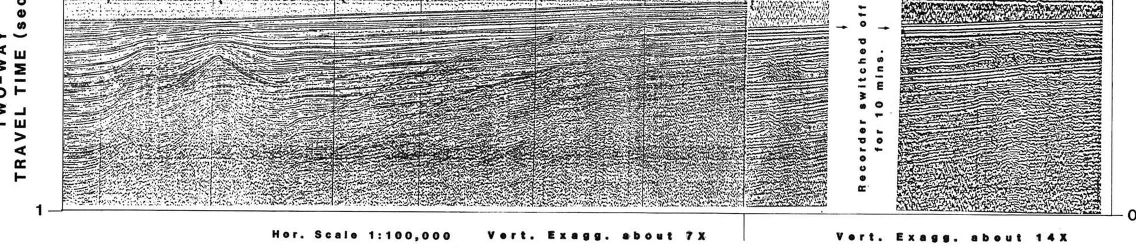


Fig. 2 Regional Bouguer gravity anomaly map for northwest Oregon and southwest Washington (modified from Armentrout and Suek, 1985).



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Alan R. Niem[1], Parke D. Snavely, Jr.[2], and Wendy A. Niem[1]

[1] Oregon State University
[2] U.S. Geological Survey

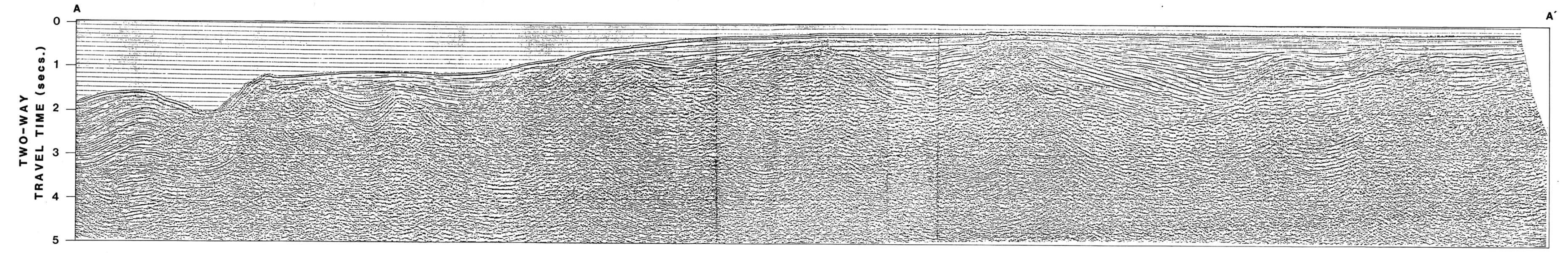
1990

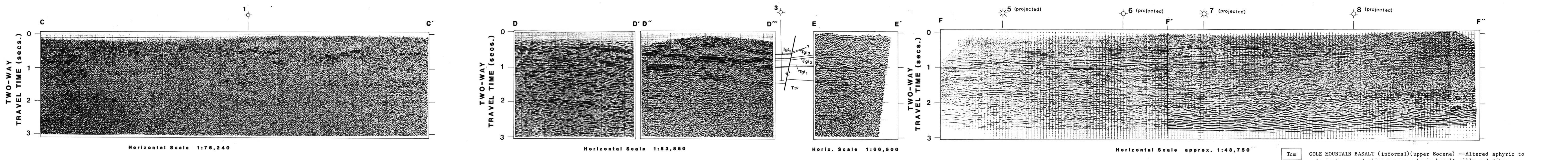
TIME-ROCK CHART

	AGE	LOWER SLOPE	UPPER SLOPE AND OUTER SHELF	INNER SHELF	ONSHORE	MILLIONS OF YEARS*
QUAT.	Holocene	Qh	Qh	Qh	Qal	
QUAT.	Pleistocene	Qp	Qp	Qp		2
TERTIARY	Pliocene	Tp	Tp	Tp		
TERTIARY	Miocene		Tmu; Tmo; Tmlm; Tb; Tgi; Tmlm	Tmu; Tmlm; Tgi; Tmlm	Tfi; Tfe; Tsp; Tgi; Tge; Ta	24
TERTIARY	Oligocene		?	?	Tsc; Tpb	37
TERTIARY	Eocene		Toe	Toe; Ttv	Ts; Tk; Tcm; Th; Ths; Thr; Tc; Ttv	46

Tgi and Tfi also intrude Ta, Toe, Th, Tk, and Tsc.

* Absolute ages based on Geological Society of America, Decade of North American Geology Geologic Time Scale (1983). Relative ages based on Armentrout and others (1983).





SEISMIC-REFLECTION PROFILES

GEOLOGIC CROSS SECTION

EXPLANATION OF GEOLOGIC UNITS

(after Niem and Niem, 1985; also see discussion of geologic units in text)

ONSHORE

Qal QUATERNARY ALLUVIUM (Holocene and Pleistocene) --Unconsolidated gravel, sand, silt, and clay in and along stream beds; includes some small areas of elevated fluvial terraces. Too thin to show in cross section.

Qls LANDSLIDE DEPOSITS (Holocene and Pleistocene) --Chaotic mixtures of weathered mudstone blocks, logs, and some sandstone clasts in a weathered sandy mud matrix; only larger deposits shown.

Tfe/Tfi COLUMBIA RIVER BASALT GROUP
WANAPUM BASALT, FRENCHMAN SPRINGS MEMBER (middle Miocene) --Subaerial porphyritic tholeiitic basalt flows and pillow lava and breccia (Tfe) and minor invasive sills and dikes (Tfi) (equivalent to Cape Foulweather Basalt of Snavely and others, 1973).

Tge/Tgi GRANDE RONDE BASALT (middle Miocene) --Aphyric tholeiitic basalt as subaerial columnar-jointed flows and pillow lava and palagonite breccia (Tge) and as extensive thick invasive sills (Beeson and others, 1979; Niem and Niem, 1985) and dikes (Tgi); some sills with irregular peperitized tops in brecciated strata. Includes both high MgO and low MgO N2 and R2 basalt chemical subtypes (equivalent to Depoe Bay Basalt of Snavely and others, 1973). K/Ar age is 14.0 +/- 2.7 to 15.9 +/- 0.3 Ma. Subscripts 1, 2, and 3 show correlation of individual sills. Tillamook Head sill is marked with string of x′s.

Tsp SCAPPOOSE FORMATION of Van Atta and Kelty (1985) (middle Miocene) --Loose, cross-bedded fluvial arkosic micaceous sand, weathered Columbia River Basalt and tuffaceous gravel, lacustrine blue mud with carbonized plant rootlets, and peat. Locally interbedded with Columbia River Basalt.

Unconformity

Ta ASTORIA FORMATION (middle and lower Miocene) --Massive to laminated micaceous bathyal mudstone and thin turbidite sandstone beds. Mostly consists of Cannon Beach member (informal; Niem and Niem, 1985) but includes some shallow-marine to deltaic arkosic sandstone at the base (informal Angora Peak member; not shown in cross section or on map). Saucesian.

Tsc SMUGGLER COVE FORMATION (informal) (lower Miocene to upper Eocene) --Thick-bedded bioturbated tuffaceous claystone and siltstone with a few glauconitic sandstone beds, graded sandstone beds, and tuffs. Refugian-Saucesian.

Tpb PITTSBURG BLUFF FORMATION (Oligocene to upper Eocene) --Thick, well-indurated beds of tuffaceous to arkosic shallow-marine sandstone, some glauconitic sandstone, and subordinate tuffaceous siltstone-claystone. Silty sandstone is bioturbated, concretionary, and mollusk-bearing. Refugian-Zemorrian.

Ts SAGER CREEK FORMATION (informal)(upper Eocene) --Laminated deep-marine mudstone rhythmically interbedded with thin micaceous and carbonaceous graded feldspathic sandstone, locally in nested turbidite channels. Unit is channelized into Keasey Formation.

Tk KEASEY FORMATION (upper Eocene) --Thin- to thick-bedded tuffaceous outer shelf to bathyal mudstone with a few arkosic sandstone lenses, sandstone dikes, and tuffs; locally glauconitic mudstone at base. Together with upper mudstone member of the Cowlitz Formation, unit forms the seal in the Mist Gas Field.

Unconformity

Tcm COLE MOUNTAIN BASALT (informal)(upper Eocene) --Altered aphyric to plagioclase- and clinopyroxene-phyric basalt sills and dikes intruded into the Hamlet and Cowlitz formations and along the Keasey/Hamlet contact. Locally includes extrusive submarine pillow lava and hyaloclastite. Normal polarity.

Tc COWLITZ FORMATION (upper Eocene) --Friable, thick-bedded to hummocky cross-bedded shallow-marine to deltaic micaceous, arkosic sandstone (C & W reservoir in Mist Gas Field) with local coal. Sandstone is overlain by thick micaceous mudstone and minor arkosic sandstone (upper mudstone member of the Cowlitz formation) that forms the seal in the Mist Gas Field). Narizian.

Th / Ths / Thr HAMLET FORMATION (informal)(upper Eocene) --Carbonaceous and mica-bearing mudstone with a few thin turbidite beds of graded arkosic micaceous sandstone and basaltic sandstone. Basal Roy Creek member (Thr) is shallow-marine basalt conglomerate and pebbly mollusk-bearing basaltic sandstone that unconformably overlies Tillamook Volcanics. Lower part of unit also includes a thin sequence of shallow-marine micaceous lithic to arkosic hummocky bedded sandstone with subordinate basaltic sandstone and debris flow deposits (Ths) above the basal member. Unit interfingers with Tillamook Volcanics in subsurface in Columbia County 31-27-65 well and in Mist Gas Field in IW32-10 well. Narizian.

Unconformity

Ttv TILLAMOOK VOLCANICS (upper and middle Eocene) --Subaerial aphyric to abundantly plagioclase- and pyroxene-phyric high titanium basalt and basaltic andesite flows. Upper part of 3,000-m-thick unit includes minor volcanic mudflow breccia, fluvial basalt conglomerate, scoriaceous tuff, differentiated andesite to dacite flows; some basaltic and arkosic sandstone, and siltstone occur in subsurface near Mist. Unit includes normal and reverse polarized flows. Probable economic basement. Basal part of unit is composed of pillow lava and breccia (not exposed in map area)(Wells and others, 1983).

INNER CONTINENTAL SHELF

(modified from Snavely and McClellan, 1987)

Qh HOLOCENE DEPOSITS --Clayey silt.

Qp PLEISTOCENE DEPOSITS --Clayey silt.

Tp PLIOCENE STRATA --Claystone and siltstone.

Tmu UPPER MIOCENE STRATA --Siltstone and claystone.

Tmlm / Tb / Tgi MIDDLE AND LOWER MIOCENE STRATA --Sedimentary rocks equivalent to Astoria Formation (unit Ta) onshore and intruded by middle Miocene sills and dikes of Grande Ronde and Frenchman Springs basalt (labeled Tb); may contain some extrusive pillow lava and breccia. Unit Tgi offshore = Grande Ronde Basalt of Tillamook Head sill (marked with string of x′s).

Tml? LOWER MIOCENE STRATA --Mudstone, siltstone, and possibly some thin turbidite sandstone beds equivalent to upper part of unit Tsc onshore and to Nye Mudstone in Newport basin.

Toe MIOCENE, OLIGOCENE, AND EOCENE STRATA --Claystone and siltstone equivalent to units Tsc, Tk, and Th onshore which are projected and queried beneath the inner continental shelf.

UPPER SLOPE AND OUTER CONTINENTAL SHELF

Qh HOLOCENE DEPOSITS --Clayey silt.

Qp PLEISTOCENE DEPOSITS --Clayey silt, undeformed to gently deformed.

Tp PLIOCENE STRATA --Claystone and siltstone.

Tmu UPPER MIOCENE STRATA --Siltstone and claystone.

Tmlm MIDDLE AND LOWER MIOCENE STRATA --Sedimentary rocks equivalent to Astoria Formation (unit Ta) onshore and intruded by middle Miocene sills and dikes of Grande Ronde and Frenchman Springs basalt (labeled Tb).

Tmo MELANGE AND BROKEN FORMATION (Middle Miocene to upper Oligocene) --Accretionary wedge of intensely sheared and broken well-cemented arkosic quartzose sandstone and indurated siltstone cut by zeolites and quartz veins.

LOWER CONTINENTAL SLOPE

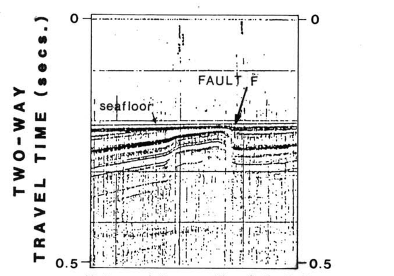
Qh HOLOCENE DEPOSITS --Clayey silt.

Qp PLEISTOCENE DEPOSITS --Thrusted and folded abyssal clayey silt.

Tp PLIOCENE STRATA --Thrusted and folded abyssal and lower slope claystone and siltstone and some turbidite sandstone beds.

(see References Cited in accompanying discussion)

Reviewed by Dave Huggins (ARCO Oil and Gas Co.),
L. D. Kulm (Oregon State University),
N. S. MacLeod (Consulting Geologist).

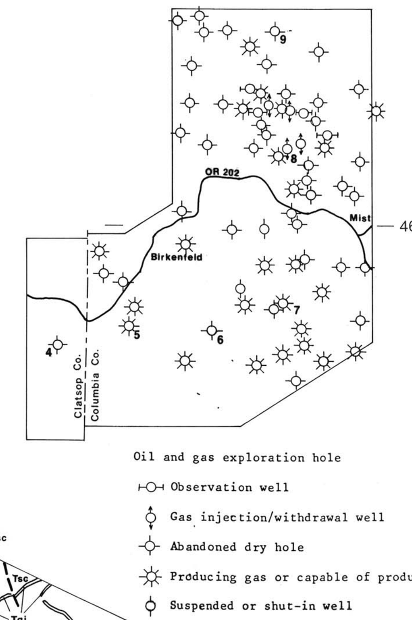


High resolution profile of Fault F cutting Holocene sediments

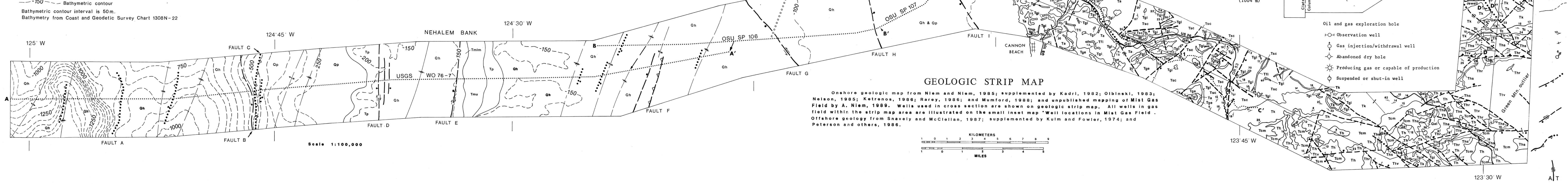
LIST OF WELLS ON GEOLOGIC STRIP MAP

	Well	Total Depth
1	Diamond Shamrock Crown Zellerbach 11-28	5,700 ft (1743 m)
2	Nehama Weagant Jewell 1-23	3,190 ft (976 m)
3	Quintana Petroleum Watzek 30-1	7,069 ft (2162 m)
4	ARCO Oregon 34-25-66	2,455 ft (751 m)
5	DY Neverstill 33-30	2,225 ft (680 m)
6	Tenneco Columbia County 24-28-65	1,928 ft (590 m)
7	ARCO Columbia County 31-27-65	6,700 ft (2049 m)
8	Oregon Natural Gas Development IW 32-10 (Columbia County 32-10)	7,807 ft (2387 m)
9	Reichhold Energy Adams 32-34	3,284 ft (1004 m)

WELL LOCATIONS IN MIST GAS FIELD



Oil and gas exploration hole
- Observation well
- Gas injection/withdrawal well
- Abandoned dry hole
- Producing gas or capable of production
- Suspended or shut-in well



—-150— Bathymetric contour
Bathymetric contour interval is 50 m.
Bathymetry from Coast and Geodetic Survey Chart 1308N-22

Scale 1:100,000

GEOLOGIC STRIP MAP

Onshore geologic map from Niem and Niem, 1985; supplemented by Kadri, 1982; Olbinski, 1983; Nelson, 1985; Ketrenos, 1986; Rarey, 1986; and Mumford, 1988; and unpublished mapping of Mist Gas Field by A. Niem, 1989. Wells used in cross section are shown on geologic strip map. All wells in gas field within the strip map area are illustrated on the small inset map "Well locations in Mist Gas Field". Offshore geology from Snavely and McClellan, 1987; supplemented by Kulm and Fowler, 1974; and Peterson and others, 1986.

GEOLOGIC SYMBOLS

- Contact, dashed where inferred (offshore inferred contacts are solid; dashed contacts are reflectors within a unit)
- Strike and dip of bedding
- Vertical bedding
- Average dip of strata in well, from dipmeter logs
- Fault, dashed where inferred; dotted where concealed; bar and ball on downthrown side; arrow indicates dip direction of fault plane
- Oblique-slip fault, dashed where inferred arrows show inferred horizontal motion bar and ball on downthrown side
- Thrust fault, teeth on upper plate dashed where inferred; dotted where concealed by Qal or Qh
- Oblique-slip fault (cross section), A = away from reader; T = toward reader arrows indicate relative vertical motion
- Axis of anticline, dashed where inferred or concealed
- Axis of syncline, dashed where inferred or concealed
- Approximate location of seismic reflection line
- Line of cross section, where located away from seismic reflection line
- Line of magnetic profile where located away from line of cross section (offshore only)
- Indicates same unit on both ends of arrow