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

GEOLOGIC MAP OF THE ASTORIA BASIN, CLATSOP AND NORTHERNMOST TILLAMOOK COUNTIES, NORTHWEST OREGON

1985

OGI-14
Oil and Gas Investigation of the Astoria Basin, Clatsop and Northernmost Tillamook Counties, Northwest Oregon

By Alan R. Niem and Wendy A. Niem

Plate 1

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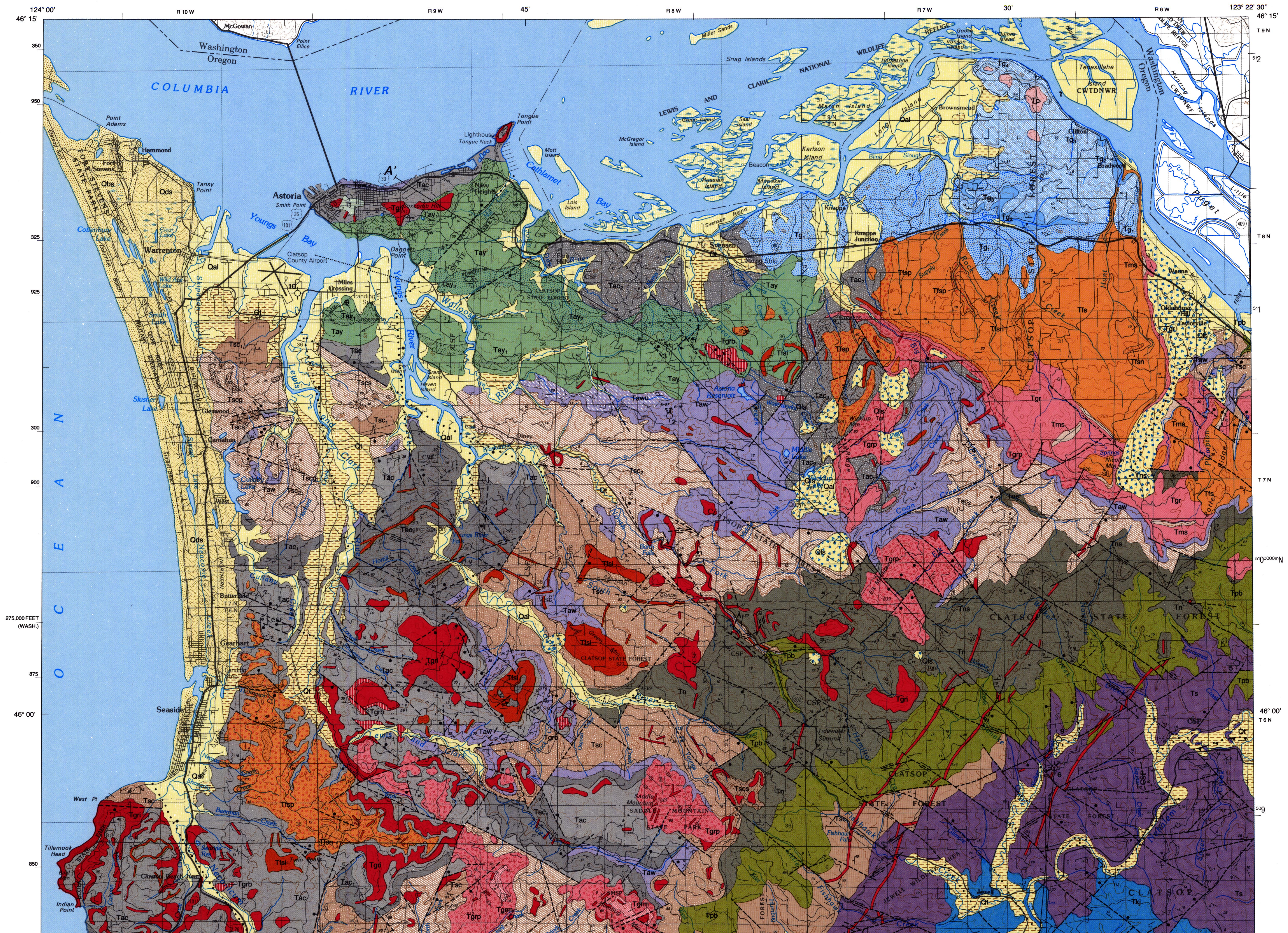

SCALE 1:100,000

CONTOUR INTERVAL 50 METERS

Geology by Alan R. Niem and Wendy A. Niem
Field assistance by Moin Kadri
Field work conducted from 1972 to 1984
Map reviewed by Parke D. Snavely, Jr. (U.S. Geological Survey) and Ray E. Wells (U.S. Geological Survey)
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OIL AND GAS POTENTIAL

Early oil and gas reconnaissance investigations that included the Astoria basin were conducted by Washburne (1914) and Warren and others (1945). Eleven exploration wells, many with noncommercial gas shows, have been drilled in the basin (Plates 1 and 2). Much of the drilling activity has occurred since the 1979 discovery of commercial quantities of gas in the Clark and Wilson sandstone of the upper Eocene Cowlitz Formation in the Mist gas field 4 mi to the east (Newton, 1979; Bruer, 1980). The gas field occurs on the east flank of the northern Coast Range gravity high (Bromery and Snavely, 1964) or Nehalem arch of Armentrout and Suek (1985), which separates the Astoria basin on the west from the north Willamette basin on the east.

The more than 10,000-ft-thick Tillamook Volcanics represent economic basement in the area. These rocks are exposed in uplifted fault blocks in the southeast part of the map area and have been encountered in several wells in the basin (Plate 2). The Tertiary sedimentary section that overlies the volcanic basement generally thins over the gravity high and thickens toward the basins. The deepest part of the basin in northwest Oregon lies approximately 7 mi southeast of Astoria and contains more than 10,000 ft of upper Eocene to middle Miocene strata. The sedimentary section probably exceeds 15,000 ft in the offshore part of the basin (Snavely and others, 1977; Armentrout and Suek, 1985).

The most promising reservoir target is the thick, friable, arkosic, micaceous Clark and Wilson sandstone of the Cowlitz Formation that occurs only in the easternmost part of the basin. Incomplete drill-stem tests yielded an estimated 10,000-20,000 cfd from the Clark and Wilson sandstone in the Boise Cascade 11-14 well (daily driller's report). The Clark and Wilson sandstone rapidly thins across the northern Coast Range gravity high from 750 ft in the Mist gas field (Bruer, 1980) to less than 25 ft south of Jewell and pinches out into the bathyal Hamlet mudstone (Olbinski, 1983; Nelson, 1985). The structural high appears also to have controlled dispersal of the Cowlitz in southwest Washington, as Wells (1981) reports a similar sandstone pinchout at the same longitude. Bruer and others (1984) show that the Cowlitz Formation (Clark and Wilson sandstone) unconformably onlaps the high and is, in turn, truncated by the overlying Keasey Formation, which commonly acts as a seal at Mist. The Cowlitz in the Astoria basin does not have as good reservoir potential as it has in the north Willamette basin because the arkosic sandstone is thinner, contains more diagenetic clay, and has lower permeabilities than in the Mist area (average permeability in the Astoria basin is 79 millidarcies [md] compared to 200 md in the Mist field [Armentrout and Suek, 1985]). Less promising but deeper reservoir targets are the shallow-marine lithic arkosic sandstones of the Sunset Highway member of the Hamlet formation. However, these sandstones are thinner and less permeable (30 md) than the Cowlitz sandstone and appear to be more restricted to the southeast part of the basin.

Other units that could act as reservoirs (i.e., porosities 16.8 to 39.7 percent; permeabilities 13.8 to 1,262 md) either are breached by erosion or not buried deeply enough (e.g., Gnat Creek formation and Angora Peak and Youngs Bay members of the Astoria Formation), are too thin and discontinuous (e.g., feldspathic sandstones, unit **Tscs**, in Smuggler Cove formation and Sager Creek formation), pinch out (e.g., Pittsburg Bluff Formation), or have low permeability and effective porosity due to compaction and formation of diagenetic clay rim cements and iron oxides in pore throats. Occlusion of pore space by calcite, zeolites, or smectite-chlorite clays is particularly evident in the basaltic sandstones of the Roy Creek and Sunset Highway members of the Hamlet formation.

However, two members of the Miocene Astoria Formation projected onto the inner continental shelf appear to be attractive offshore targets (Cooper, 1981). These units are the thick, permeable, deltaic to shallow-marine Angora Peak arkosic sandstone (southwest of Cannon Beach) and the highly friable, submarine channel, arkosic sandstones (**Tay**$_1$ and **Tay**$_2$) of the Youngs Bay member northwest of Seaside. These units may have been deposited at the mouth of the ancestral Columbia River (Niem, 1976) and Astoria canyon head-fan system (Nelson, 1978; Coryell, 1978). The overlying bathyal Cannon Beach mudstone and encasing Youngs Bay mudstone could act as seals. Structural traps in the offshore area are possible along north-south normal faults and anticlines (Snavely and others, 1977; Johnson and others, 1984), around shale diapirs, and over a seaward projection of a high of Tillamook Volcanics between the Tillamook and Astoria embayments (Wells and others, 1983). Late middle Miocene subduction of thermally mature Hoh mélange beneath this forearc sequence on the inner continental shelf could allow oil and wet gas to migrate upward into structural and stratigraphic traps (Snavely, in preparation; Snavely and Wells, 1984).

Some arkosic sandstones of the Northrup Creek formation (**Tns**) and the thick, shallow-marine permeable Wickiup Mountain sandstone of the Astoria Formation (270 md; Cooper, 1981) could be low-priority reservoir targets for exploration in the northernmost part of the map area if suitable updip stratigraphic pinchouts or fault traps can be defined seismically in this homoclinal sequence.

Thick, bathyal mudstones and some carbonaceous sandstones of the Cowlitz Formation; the Hamlet, Sager Creek, Northrup Creek, and Smuggler Cove formations; and Cannon Beach and Youngs Bay members of the Astoria Formation are marginal to adequate gas-prone source rocks. Although the total organic carbon (TOC) levels in these units are fair to high (av. 1.1 percent; 84 well and surface samples), visual kerogen is primarily gas-prone terrestrial organic matter—mainly structured woody debris, vitrinite, amorphous matter, and some exinite (alginite). Hydrogen indices and genetic potentials ($S_1 + S_2$; see Law and others, 1984) are low, and oxygen indices are commonly high (100), also suggesting that the organic matter is generally oxidized type-III kerogen, which is typically low yielding, gas prone, and hydrogen deficient (Tissot and Welte, 1978). The Jewell member of the Keasey Formation, the Pittsburg Bluff Formation, and the Wickiup Mountain member of the Astoria Formation are poor to fair source rocks because of marginal amounts of total organic carbon (av. 0.62 percent; 84 samples). In addition, all these units are generally thermally immature (av. $R_0 = 0.42$ percent; 38 well and surface samples, generally R_0 0.55 percent). Geochemical analysis indicates that the Watson oil seep near Olney is likely a man-made dump of biodegraded, southern California asphaltic crude oil related to early 20th century logging operations (Murphy, 1981; Niem, unpublished information, 1978, 1984). In summary, these rocks are likely sources only for biogenic methane or early diagenetic gas but not oil (Tissot and Welte, 1978). However, the area is riddled with middle Miocene and upper Eocene intrusions that have thermally matured to supermatured these rocks for tens to hundreds of feet (R_0 = 0.95 to 2.36 percent; av. 1.8 percent; six samples), thereby creating possible sources for thermogenic gas. One well with a thick gabbroic sill (Crown Zellerbach 31-17 well) has significant concentrations of ethane and propane in addition to methane (i.e., approx. $C_1/[C_2 + C_3]$ ratios 15 from calibrated gas chromatographs on mud log), suggesting a thermogenic effect. Thermogenic dry gas has also been reported by Armentrout and Suek (1985) in the Mist gas field.

The Astoria basin occurs in a major zone of distributed shear between the Tillamook Volcanics on the south, which show 45° of clockwise rotation (Magill and others, 1981; Nelson, 1985), and upper Eocene volcanic rocks in southwest Washington, which have undergone considerably less rotation (23°; Wells and Coe, 1985). The basin is broken by an extensive network of conjugate northwest-trending right-lateral and northeast-trending left-lateral oblique-slip faults and older major east-west oblique-slip faults that could produce fault traps. The faults, many with subhorizontal slickensides, show tens to hundreds of feet of horizontal and vertical separation, as indicated by offsets of middle Miocene dikes (piercing points; Nelson, 1985) and juxtaposition of volcanic and sedimentary units. The northwest- and northeast-trending faults and a few associated small east-west thrust faults (Nelson, 1985) reflect late middle Miocene north-south compression and wrench-fault tectonics. In the southeast corner of the map, U.S. Highway 26 traverses the length of a small pull-apart depression between a highly faulted, uplifted block of Tillamook Volcanics on the north and the main mass of Tillamook Volcanics to the south. The style and intensity of basement faulting in this area approximates the faulting in the subsurface in the Mist gas field. The major high-angle east-west faults, with shear zones as much as 100 ft wide, show greater separation of upper Eocene units and volcanic basement than of Miocene volcanics and strata, suggesting that the faults were initiated in the late Eocene (perhaps as dip-slip faults) and reactivated in the late middle Miocene as left-lateral(?) oblique-slip faults. Three major middle Miocene dikes were intruded along northeast-trending faults(?) in eastern Clatsop County. Some dikes, however, parallel the conjugate northeast- and northwest-trending joint pattern that is well developed in the middle Miocene breccias and pillow lavas. A few faults are truncated by late Eocene or Miocene unconformities. The unconformities along with sandstone pinchouts and truncations by submarine channel-fills could act as stratigraphic traps.

Folds are rare; those that are recognized are broken by extensive faulting and intrusions, creating a myriad of dip directions and juxtaposed rock units. Some northwest-trending en echelon folds are associated with the major east-west oblique-slip faults. All the mapped folds have limited closure.

EXPLANATION

Unconsolidated Deposits

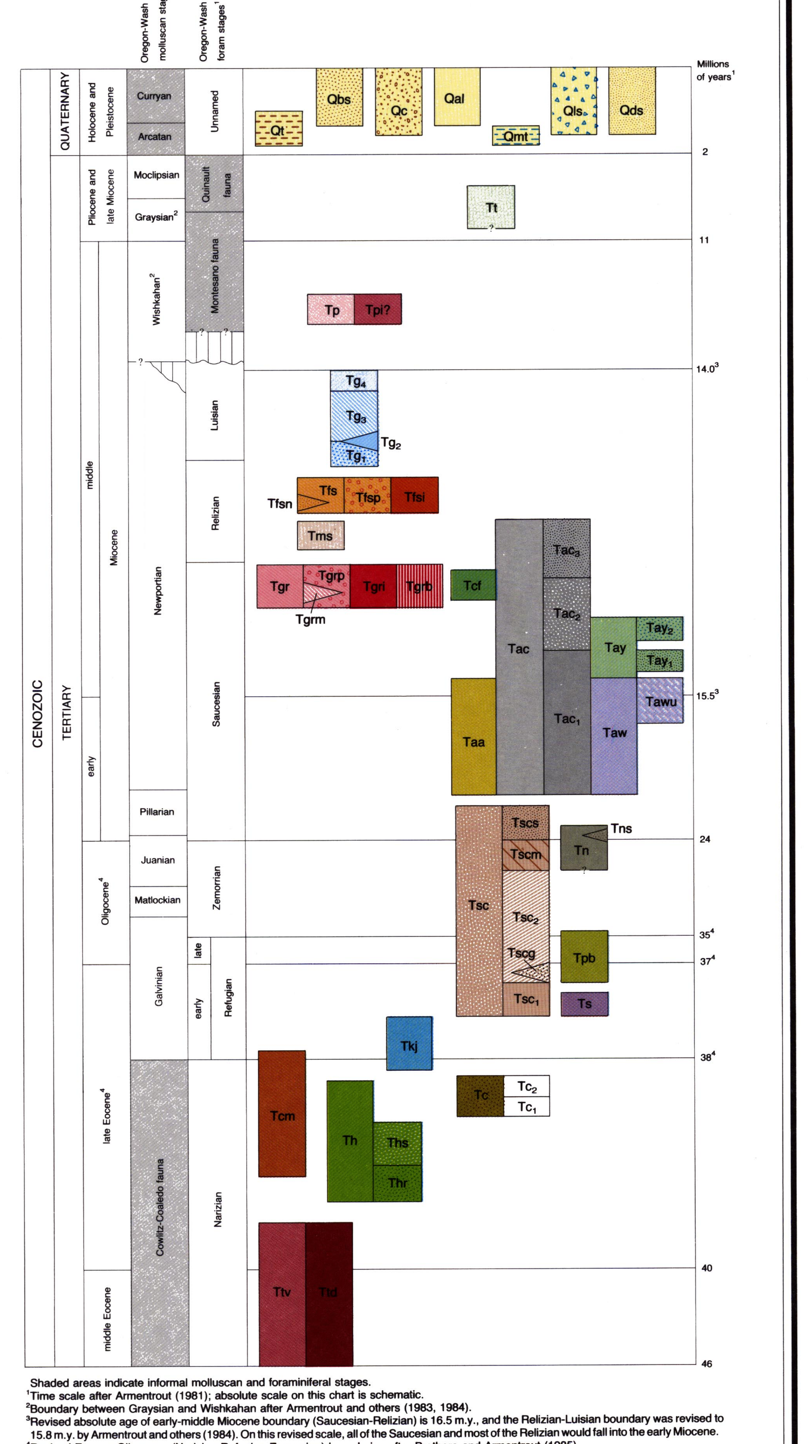
Qal — **Quaternary alluvium (Holocene)**—Unconsolidated flood-plain deposits of clay, silt, sand, and basalt gravel along and in major rivers and streams; also includes sand bars, islands, and bioturbated to laminated estuarine clay, silt, and fine sand in low-lying coastal areas in and along Columbia River, Youngs Bay, and other major river mouths

Qbs — **Quaternary beach sand (Holocene)**—Moderately well-sorted, fine- to medium-grained quartzo-feldspathic sands with heavy mineral laminae; also includes black winter-beach lag sand deposits up to a few meters thick of magnetite, ilmenite, and other heavy minerals (Twenhofel, 1946) locally developed on Clatsop Spit; unit includes basalt gravels of well-rounded pebbles, cobbles, and boulders around Miocene basalt headlands along southern coast of Clatsop County

Astoria Formation

Tac — **Cannon Beach member (informal) (middle to lower Miocene)**—Well-bedded sequence of laminated to massive micaceous mudstone (**Tac**), with subordinate, rhythmically thin-bedded feldspathic sandstone and mudstone in lower part of unit (**Tac**$_1$). Sandstone is fine grained, micaceous and carbonaceous, graded, micro cross-laminated to laminated (Bouma bc and cd intervals) and contains load casts and convolute bedding. Locally, there are nested channels of thin-bedded sandstone and mudstone in unit **Tac**$_1$. Bathyal foraminiferal assemblages recovered from the mudstone are referred to Saucesian-Relizian(?) Stages of Kleinpell (1938); molluscan fossils are assigned to Newportian Stage of Addicott (1976, 1981). Previously, this member was informally called Silver Point member by Niem and Van Atta (1973), Smith (1975), Neel (1976), Cooper (1981), Wells and others (1983), and Niem and Niem (1984), but this name is preempted. Member is 200 m thick at Silver Point, thinning offshore toward outer continental shelf and thickening to a few thousand meters toward Astoria (Nelson, 1978; Cooper, 1981). Unit **Tac**$_1$ conformably overlies Angora

TIME ROCK CHART



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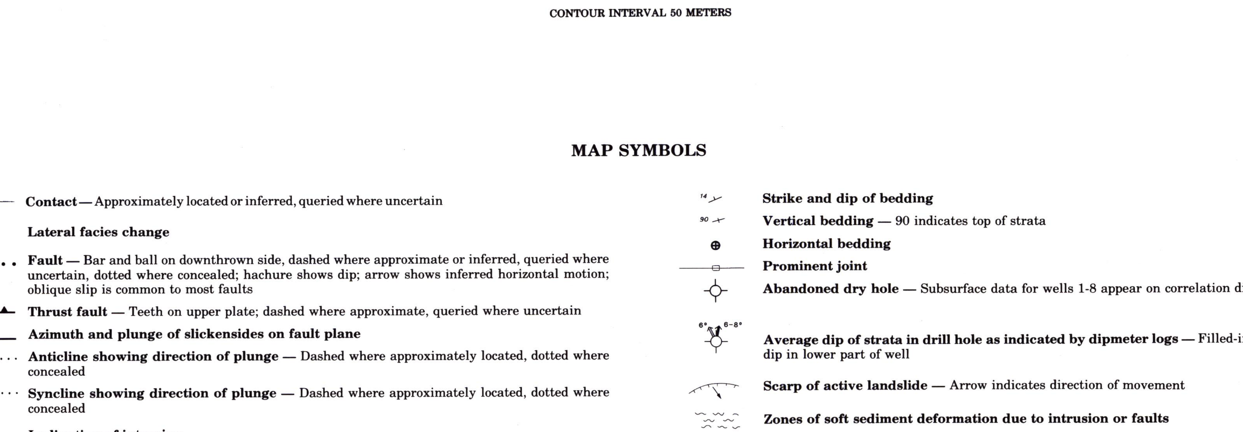
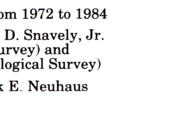
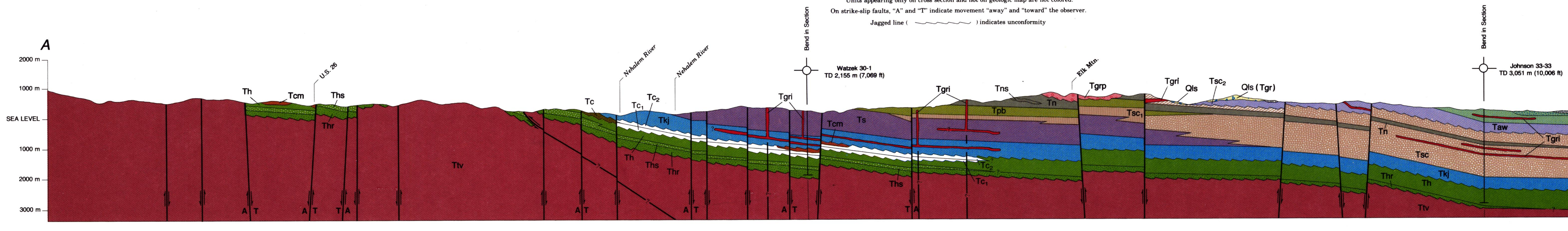


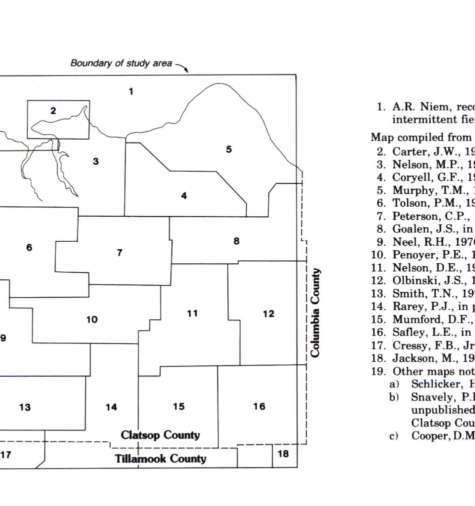


MAP LOCATION

Geologic Cross Section



SOURCES OF DATA



REFERENCES

CORRELATION OF EXPLORATION WELLS, ASTORIA BASIN, N.W. OREGON

Explanatory text for Plate 2

Oregon Department of Geology and Mineral Industries Oil and Gas Investigation 14 (1985)

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INTRODUCTION

The purpose of Plate 2 is to present the lithologic, biostratigraphic, electric log, and gas show data for eight wells drilled in the onshore part of the Astoria basin, northwest Oregon, and to give our interpretations of subsurface correlations between wells. This plate should be used in conjunction with the geologic map (Plate 1). Much of the lithologic information is based on analysis of well cuttings in storage at the Oregon Department of Geology and Mineral Industries, Portland. However, additional cuttings; sidewall cores; electric, sonic, dipmeter, neutron and density logs; mud logs; and well history summaries were provided to us by Alan Seeling of Diamond Shamrock Corp., John Van Bladeren and H. Jack Meyer of Oregon Natural Gas Development Corp., Douglas Hastings of Chevron USA, and Bernard J. Guarnera of Boise Cascade Corp.

METHODS

Subsurface rock units were correlated by combining lithologic log descriptions with neutron, density, sonic, and electric log responses (only gamma ray, spontaneous potential, and resistivity are shown on Plate 2) and projecting geologic units mapped on the surface (Plate 1) into the subsurface. Sea level is used as datum. Many faults have been mapped between the wells (Plate 1) but are not included on Plate 2 in order to simplify the diagram and to emphasize correlation of stratigraphic units.

Lithologic logs were constructed by mounting more than 1,400 representative splits of washed well cuttings (intervals ranged from 10 to 30 ft) on cloth strips and studying the cuttings together with available sidewall cores using a binocular microscope. Major element analyses of hand-picked, ultrasonic-cleaned cuttings of the volcanic and intrusive rocks were made by X-ray fluorescence at Washington State University under the direction of Peter R. Hooper. The results of these analyses were plotted on silica variation diagrams and binary graphs of the major oxides and were compared with analyses of over 400 outcrop samples of the major volcanic and intrusive units in the Astoria basin.

Biostratigraphic correlations relied on detailed micropaleontological work by Daniel R. McKeel. In addition, 75 samples were prepared for analysis for coccoliths, diatoms, and foraminifers by David Bukry (U.S. Geological Survey, now with Minerals Management Service), John Barron (U.S. Geological Survey), and Kristin McDougall (U.S. Geological Survey), respectively. McKeel prepared 1,614 ditch and sidewall samples from the eight wells for both planktonic and benthic foraminifers. Permission to use McKeel's proprietary company reports in this investigation was granted by the well operators, Diamond Shamrock Corp. and Oregon Natural Gas Development Corp., and also by Reichhold Energy Corp. (Mike Alger), ARCO Exploration Co. (Robert J. Deacon and Martin B. Lagoe), and Tenneco Oil Co. (Jere Jay). For the Hoagland No. 1 well, McKeel reviewed specimens that had already been mounted on 57 slides that were available from the Oregon Department of Geology and Mineral Industries. McKeel's report for each well consists of a listing of species in each sample with the age (stage), paleobathymetric interpretation, and summary for each distinctive interval. A summary of his paleobathymetric interpretations is represented by stippled columns to the right of the lithologic log for each well on Plate 2.

AGE AND BIOSTRATIGRAPHIC CORRELATION

The strata illustrated on Plate 2 range in age from Narizian (late middle Eocene) to Relizian (middle Miocene). However, in five of the wells only Narizian and Refugian (late Eocene) strata were encountered. The foraminiferal stages shown adjacent to each well are based principally on McKeel's age assignments. Stage names follow the California benthic foraminiferal stages of Kleinpell (1938), Schenck and Kleinpell (1936), and Mallory (1959). The Pacific Northwest biostratigraphic zones recommended by Rau (1981) and insights of McDougall (1980) also influenced McKeel's stage assignments. The time-rock chart on Plate 1 shows how these foraminiferal stages relate to the Tertiary epochs. In addition to foraminiferal stages, age range assignments made by Bukry based on calcareous nannofossils (e.g., coccoliths) for selected samples are shown in small lettering (e.g., CP 14) to the right of the paleobathymetry columns. A time correlation chart in the lower right corner of Plate 2 (modified from Rarey, in preparation) shows the relationship of nannofossil zones of Bukry (1981) to foraminiferal stages (modified from Armentrout, 1981). In general, there is good overlap between nannofossil zone assignments and foraminiferal stages in the wells.

The highest occurrences of several key foraminiferal species were used in biostratigraphic correlation of the wells. These marker species are useful for correlation to other wells in adjacent areas (such as at Mist; McKeel, 1983) and in the Willamette Valley (McKeel, 1984, 1985). *Uvigerina atwilli* was recognized in all the wells, and several species of planktic foraminifers were noted. The most important was the Refugian *Turborotalia insolita* which is present in all the wells except the Johnson 33-33 well. McKeel (1983) reported that this species also was very useful for stratigraphic work in the Nehalem basin (Mist gas field). Other planktic foraminifers which assisted correlations were *Globigerinatheka index* and *Globigerina brevis*. The biostratigraphic correlation lines generally coincide with the lithostratigraphic correlation lines. Key short-ranging late Eocene to earliest Oligocene nannofossil guide taxa, that are present in several wells, are *Isthmolithus recurvus* Deflandre, *Reticulofenestra reticulata* (Gartner et Smith), and *Reticulofenestra umbilica* (Levin) (Bukry, written communication, 1984).

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LITHOLOGIC CORRELATIONS

More than 10,000 ft of Tertiary sandstone and mudstone (see the Patton 32-9 and Johnson 33-33 wells) overlie the Eocene Tillamook Volcanics and are commonly intruded by middle Miocene Grande Ronde and Wanapum (Frenchman Springs Member) basalt sills and dikes. Unconformities occur at the top of the Tillamook Volcanics and at the bases of the Cowlitz, Keasey, Sager Creek, Northrup Creek, and Astoria formations.

Tillamook Volcanics

The middle to upper Eocene Tillamook Volcanics are the oldest rocks penetrated in four widely separated wells (Hoagland No. 1, Boise Cascade 11-14, Clatsop County 33-11, and Crown Zellerbach 11-28). The unit consists of a thick sequence of basalt to basaltic andesite flows, breccias, debris flows, basaltic tuffs, and minor interbeds of mudstone, sandstone, and conglomerate that formed as an oceanic island in a forearc basin (Rarey, in preparation). These rocks are distinguished from the slightly younger upper Eocene Cole Mountain basalt and from the middle Miocene basalt intrusions on the basis of geochemistry, petrography, and stratigraphic position. Generally, the Tillamook Volcanics are higher in total iron, total alkalies, TiO_2, P_2O_5, and MnO and lower in CaO and MgO than Cole Mountain basalts with similar SiO_2 values (Rarey, in preparation). The Tillamook Volcanics also typically contain less total iron (<13.5 percent) and more P_2O_5 (>0.65 percent) than the middle Miocene Frenchman Springs basalt. Those Tillamook Volcanics with values of SiO_2 similar to Grande Ronde Basalt (i.e., >53 percent) generally contain more P_2O_5 (>0.45 percent) and more Na_2O (>3.5 percent) than the Grande Ronde basalt (Rarey, in preparation).

The Tillamook Volcanics appear in well cuttings as dull medium grayish black to brownish black smectite-altered, aphyric to porphyritic to vesicular basalt chips with white zeolites and calcite and as soft clay-altered lapilli. Rare reddish mudstone chips represent baked or weathered interbeds or paleosols. A distinctive pilotaxitic flow texture (i.e., flow alignment of plagioclase microlites), visible in thin sections, commonly characterizes the Tillamook Volcanics from the overlying middle Miocene and upper Eocene intrusive basalts (Rarey, in preparation).

The Tillamook Volcanics show a large increase in resistivity and a negative deflection of the spontaneous potential (SP) curve from the shale line. In addition, the gamma ray response commonly displays a noticeable decrease in value at the top of the volcanic rocks.

A few thin beds of micaceous arkosic sandstone and mudstone, some with gas shows, are intercalated with Tillamook basalts in the Hoagland No. 1 well. These may correlate with the lower Narizian(?) Megler arkosic turbidite sandstone of southwest Washington directly across the Columbia River (Wells, 1979). However, in Wells' opinion (personal communication, 1985), the Megler sandstones are interbedded with the uppermost part of the Crescent basalts (now renamed basalt breccias and flows at Fort Columbia; Wells, in preparation) and may be older than the Tillamook Volcanics. Alternatively, the basalts at the bottom of the Hoagland No. 1 well may be upper Crescent basalt and Megler turbidite strata in an uplifted fault block although the geochemistry of these flows in cores support the interpretation that these are Tillamook Volcanics. Bruer and others (1984) suggested that regionally the Tillamook Volcanics interfinger with arkosic sandstone and mudstone of the Yamhill Formation in the subsurface in Columbia County.

Hamlet formation

The Tillamook Volcanics are overlain by the mudstone-dominated upper Eocene Hamlet formation. The Hamlet formation is largely late Narizian in age, based on nannofossil and foraminiferal data in the wells and from molluscan, nannofossil, and foraminiferal assemblages collected in outcrop (Rarey, in preparation; Mumford, in preparation). Two members occur in the formation: a basal mollusk-bearing basaltic conglomerate and sandstone (Roy Creek member) and an interbedded micaceous lithic arkosic and basaltic sandstone (Sunset Highway member). The Roy Creek member unconformably overlies the Tillamook Volcanics (unit Tc_1 of Olbinski, 1983 and Nelson, 1985; Rarey, in preparation; Safley, in preparation; Mumford, in preparation). This nearshore to fluvial deposit is widespread, overlying the volcanics throughout the Tillamook highlands (unit Thr on Plate 1 and unit Tbs in Wells and others, 1983). It consists of conglomerate and basaltic sandstone which appear in well cuttings as a mixture of angular porphyritic and aphyric basalt fragments and rare, rounded, very small pebbles in a basaltic sandstone matrix. The Roy Creek conglomerate was recognized in four wells (Crown Zellerbach 11-28, Watzek et al. 30-1, Boise Cascade 11-14, and Patton 32-9). The unit is not present above the Tillamook Volcanics in the Hoagland No. 1 well probably due to incomplete recovery or that the deposit is thin or absent. Another possibility is that the Tillamook Volcanics in this well were a middle to late Eocene erosional high that shed detritus into the adjacent low (e.g., Patton 32-9). The Roy Creek member also appears to thin and pinch out toward the Clatsop County 33-11 well which is toward the northern Coast Range gravity high of Bromery and Snavely (1964) or Nehalem arch of Armentrout and Suek (1985).

The gamma ray log response of the Roy Creek member is similar to that of the Tillamook Volcanics. The resistivity is moderate to high, due to induration of the unit (clasts are cemented by calcite, zeolites, and chlorite), but the SP response is variable.

The Sunset Highway member of the Hamlet formation, which consists predominantly of interbedded micaceous lithic arkosic and basaltic sandstones, occurs in only one well (Watzek et al. 30-1). However, Olbinski (1983) correlated this upper Narizian unit (which he called unit Tc_2) with arkosic sandstone that has an epidote-rich heavy-mineral suite and basaltic sandstone on the surface (see cross section on Plate 1). This high-energy shelf sandstone has been mapped over a large part of southeastern Clatsop County (unit Ths in southeast corner of map on Plate 1). Well cuttings of the Sunset Highway member consist of predominantly fine-grained, basaltic to arkosic sandstone with small mica flakes. Some chips indicate that the sandstone is laminated. The top contact of the member is gradational with the overlying siltstone and mudstone of the Hamlet formation. Although neither the gamma ray nor SP response of the unit is distinguishable from that of the Hamlet mudstone, the resistivity is somewhat higher. On the surface, the shallow-marine Sunset Highway sandstone rapidly lenses out into the deeper marine (bathyal) Hamlet mudstone to the west and north (Rarey, in preparation). In the subsurface, the unit thins out due to a similar facies change and/or is cut out by an unconformity at the base of the overlying Cowlitz Formation (e.g., Clatsop County 33-11), or is limited in distribution due to paleotopographic control in the basin. The foraminifers are mixed neritic and bathyal faunas, indicating mixing of faunas and/or well cuttings.

The Sunset Highway member may equate to the Clatskanie sandstone of the Yamhill Formation of Bruer and others (1984) that occurs below the Clark and Wilson (C & W) sandstone in the Mist gas field (Deacon, personal communication, 1985).

The Hamlet formation above the Roy Creek and Sunset Highway members is composed predominantly of siltstone and mudstone with a few thin beds of arkosic turbidite sandstone (units $Tc_{3\text{-}4}$ of Olbinski, 1983 and Nelson, 1985; Safley, in preparation; Mumford, in preparation). The Roy Creek and Sunset Highway members and overlying bathyal Hamlet mudstone reflect a gradual marine transgression over the Astoria basin. In the Boise Cascade 11-14 and Watzek et al. 30-1 wells, the formation appears to unconformably underlie the sandstone-rich Cowlitz Formation. It thins and is completely cut out by the unconformity at the base of the C & W sandstone of the

Cowlitz Formation in the Clatsop County 33-11 well, possibly reflecting the influence of the nearby Nehalem arch of Armentrout and Suek (1985). The formation thickens basinward to the west both on the surface (Rarey, in preparation; Mumford, in preparation) and in the subsurface, where it includes bathyal carbonaceous mudstones that are facies equivalent to the shallower marine Cowlitz sandstones. Glauconite is rare in the Hamlet formation, except in the Hoagland No. 1 and Patton 32-9 wells. The Hamlet, west of the Boise Cascade 11-14 well, is overlain by the tuffaceous Keasey Formation. The gamma ray and SP curves show no distinctive signatures, but there is a slight increase in resistivity from Keasey to Hamlet formation and a slight decrease in resistivity from the Cowlitz into the Hamlet.

In the Hoagland No. 1 and Patton 32-9 wells in northwestern Clatsop County, the Hamlet formation can be divided informally into an upper resistance unit and a lower less resistive unit. In well cuttings, the upper dominantly mudstone unit is only slightly more sandy and glauconitic, and the lower Hamlet mudstone is slightly more carbonaceous. However, these two dominantly bathyal mudstone units cannot be distinguished in surface mapping (Plate 1; Rarey, in preparation) and thus have been included in the Hamlet formation in this study. In a regional subsurface study, Bruer and others (1984) included the upper resistive unit in the Cowlitz Formation and the lower unit in the Yamhill Formation with an unconformity between the two. Unfortunately, the regional outcrop distribution of the Yamhill, that was defined in the central Oregon Coast Range, is unclear (Wells and others, 1983). Upper Narizian strata of the Hamlet formation that crop out in the Astoria basin can also be directly correlated to outcropping strata of the Nestucca Formation and an unnamed upper Narizian sequence in nearby Tillamook County (Wells and others, 1983). Like the Hamlet, the Nestucca consists of upper Narizian deep-water mudstone and a basal basaltic conglomerate and sandstone that unconformably overlie the Tillamook Volcanics. Farther south, the Nestucca unconformably overlies the lower(?) Narizian Yamhill (Snavely and others, 1976) that interfingers with the Tillamook Volcanics in the Hebo quadrangle (Snavely, personal communication, 1985). Until the stratigraphic definition and relationship of the Yamhill, Nestucca, and upper Narizian strata in the Astoria basin are resolved, we will use the local informal terms, Hamlet formation and Sunset Highway and Roy Creek members, in the Astoria basin.

Cowlitz Formation

The Cowlitz Formation in the subsurface consists of two units: the C & W sandstone and an overlying unnamed thin sequence of siltstone and sandstone. The C & W sandstone of the Cowlitz Formation is the gas reservoir in the Mist field (Newton, 1979; Bruer and others, 1984; Armentrout and Suek, 1985; Alger, 1985). In the Astoria basin, the C & W sandstone is thinner, and its distribution is limited to eastern Clatsop County (Plates 1 and 2). This unit is largely fine-grained arkosic sandstone that contains small flakes of mica. The lower part is silty sandstone with a few thin beds of sandstone. Although the SP and gamma ray values are variable for the C & W sandstone in Clatsop County, the resistivity shows an increase over that of the overlying Keasey mudstone and underlying Hamlet formation.

Preliminary study by Olbinski (1983) and Nelson (1985) suggests that the C & W sandstone in the Watzek et al. 30-1 well contains a zircon-rich heavy-mineral assemblage and can be correlated to a similar zircon-bearing arkosic sandstone at the surface (unit Tc, Plate 1) along the north flank of the Green Mountain outlier of Tillamook Volcanics in the southeast corner of the map (Plate 1). Farther east, the outcrop of the C & W rapidly thickens and includes arkosic sandstones with an epidote-rich heavy-mineral suite that may equate to the gas-producing C & W sandstone at Mist (Olbinski, 1983). Further study is necessary to determine if these heavy-mineral suites are statistically distinctive for correlation of individual sandstone bodies within the C & W sandstone. The unit thins from the Boise Cascade 11-14 well and the Watzek et al. 30-1 well toward the Clatsop County 33-11 well farther east. We attribute this marked decrease in thickness to thinning toward the Nehalem arch of Armentrout and Suek (1985) in the vicinity of the Clatsop County 33-11 well. In Columbia County on the other side of this high, the C & W sandstone thickens again to 750 ft (Bruer, 1980; Bruer and others, 1984).

The dominantly shallow-marine C & W sandstone undergoes a facies change to outer neritic to bathyal mudstones of the Hamlet formation to the west and northwest from the Boise Cascade 11-14 and Watzek et al. 30-1 wells and is not present in the Johnson 33-33 well, Crown Zellerbach 11-28 well, Patton 32-9 well, or Hoagland No. 1 well. Sedimentary structures and fossils indicate that the C & W sandstone that crops out in the Astoria basin is largely a shallow-marine wave-dominated shelf deposit (Olbinski, 1983; Nelson, 1985; Safley, in preparation). Following the practice of Bruer and others (1984), we include in the Cowlitz Formation a sequence of upper Narizian micaceous and carbonaceous bathyal siltstone with a few laminated sandstone beds that overlies the C & W sandstone. However, where the C & W sandstone pinches out, the sequence of mudstone-dominated strata is called the Hamlet formation.

Keasey Formation

The upper Eocene Keasey Formation of Warren and Norbisrath (1946) unconformably overlies the Cowlitz and Hamlet formations (Rarey, in preparation). In the Astoria basin, only the Jewell member of Olbinski (1983) and Nelson (1985) is recognized. Cuttings from the Jewell member are predominantly nonmicaceous, light-medium-gray mudstone and some siltstone with scattered small flakes of mica, pyrite, and carbonaceous plant debris. The Jewell member, especially the lower part of the unit is characteristically glauconitic and/or tuffaceous in outcrop compared to the generally slightly darker gray, micaceous, carbonaceous, laminated mudstones of the underlying Cowlitz and Hamlet formations (Olbinski, 1983; Nelson, 1985; Rarey, in preparation). This lithologic change was also noted in the cuttings of several of the wells and was the basis, along with slight decrease in resistivity, for choosing the basal contact of the Keasey.

The Jewell is generally rich in microfossils, most of which are assignable to the early Refugian Stage. However, the basal part of the unit in outcrop (Rau, written communication, 1984) and in the subsurface also contains latest Narizian foraminifers. Late Narizian fauna have also been reported in the basal part of the type section of the Keasey by McDougall (1975). Bruer and others (1984) restricted the Keasey Formation in the subsurface to strata containing Refugian foraminifers and on the basis of age, structural differences and electric log characteristics (Meyer, written communication, 1985) chose the basal contact of the unit a few hundred feet higher than the contact that we drew in the Hoagland No. 1 well. Both Refugian and latest Narizian foraminifers have been reported from the same sample of the basal part of the Jewell member of the Keasey by different micropaleontologists (Rarey, in preparation). In our opinion, the basal part of the Keasey straddles the Refugian-Narizian boundary. It is possible, however, that erosion of the Cowlitz Formation reworked late Narizian foraminifers into the basal Keasey Formation during Refugian time (Meyer, written communication, 1985). McDougall (1980) suggests that the lower part of the Refugian Stage and upper part of the Narizian Stage may overlap due to paleoecological influences on the benthic foraminiferal faunas that define these stages in the Pacific Northwest. Because of this biostratigraphic complexity of the base of the unit, we have chosen the basal contact of the Jewell member on field and on lithologic and electric log characteristics only.

In the Boise Cascade 11-14 well, the Jewell member contains a 100-ft-thick basaltic conglomerate and sandstone that may be detritus shed from a Goble Volcanic high to the northeast of the well or debris eroded off Tillamook Volcanics of the Nehalem arch of Armentrout and Suek (1985) to the east and southeast. Laminae of carbonaceous and micaceous arkosic sandstone in the lower Jewell mudstone are common only in the Crown Zellerbach 31-17 well. These sandstone laminae may reflect reworking of some of the C & W sandstone off a high such as the one noted in the Clatsop County 33-11 well. This reworked basaltic and arkosic material and abundance of glauconite in the lower part of the unit suggest an unconformity at the base of the Jewell member of the Keasey Formation. This unconformity also has been noted in wells in Columbia County (Bruer and others, 1984). Part of the Cowlitz Formation in Clatsop County, therefore, may be cut out by the unconformity at the base of the Jewell member.

The SP and resistivity curves for the Jewell member are nearly straight lines that are typical of mudstone. This pattern is broken only by a few resistive middle Miocene basalt intrusions in the unit, by thin sandstones in the Hoagland No. 1 and Crown Zellerbach 31-17 wells, and by resistive basaltic conglomerate and sandstone beds in the Boise Cascade 11-14 well. The gamma ray curve, however, shows a characteristic pronounced decrease in value at the top of the Jewell member compared to the overlying formations and helps to define the top of the unit in the subsurface. Foraminifers in the Keasey Formation in Clatsop County are bathyal faunas with some neritic forms mixed in locally (as in the basaltic conglomerate and sandstone in the Boise Cascade 11-14 well). The highest occurrences of *Turborotalia insolita* and *Globigerina brevis* are recorded in this unit.

Sager Creek formation

The Keasey Formation is unconformably overlain by the upper Eocene Sager Creek formation in the Boise Cascade 11-14, Clatsop County 33-11, and Watzek et al. 30-1 wells. Field studies in the Astoria basin suggest that the Sager Creek formation (Vesper Church unit of Olbinski, 1983 and Nelson, 1985) is a deep-marine channelized sequence containing thin-bedded turbidite sandstones and laminated mudstone that cuts into the tuffaceous Keasey mudstone. The Sager Creek may represent a nested channel slope facies that was a precursor of the overlying prograding shallow-marine-deltaic Pittsburg Bluff Formation. In outcrop, the Sager Creek consists of highly carbonaceous and micaceous laminated mudstone and thin, very fine-grained arkosic sandstone. Unlike the underlying tuffaceous Keasey mudstone, the Sager Creek is only rarely glauconitic (Olbinski, 1983; Nelson, 1985). Cuttings of the Sager Creek formation consist of mudstone chips with abundant carbonaceous and micaceous sandstone laminae. Only a few of the fine-grained feldspathic turbidite sandstone beds are sufficiently thick to cause a slight increase in resistivity (most notable in the Watzek et al. 30-1 well). Carbonaceous plant debris is finely disseminated through the unit and is locally concentrated in sandstone laminae or appears as small blocky chunks of coalified wood. The abundance of organic material probably causes the gamma ray response of the Sager Creek formation to be markedly higher than that of the underlying tuffaceous Keasey Formation. The SP curve is almost a straight line.

The Sager Creek formation is best developed in eastern Clatsop County and thins to the west. It pinches out between the Boise Cascade 11-14 and Johnson 33-33 wells and intertongues with the Smuggler Cove formation in the Crown Zellerbach 31-17 well before it lenses out toward the Crown Zellerbach 11-28 well in the southwest. This latter relationship is also shown in surface mapping, as the Sager Creek (unit Ts on Plate 1) interfingers with and pinches out into the lower part of the Smuggler Cove formation (unit Tsc) toward the southwest. The paleobathymetry of the late Refugian foraminifers in the Sager Creek formation ranges from bathyal to neritic. McKeel, in a report to Diamond Shamrock (1983), suggested a possible unconformity within the lower part of the unit at a depth of 1,750 ft in the Clatsop County 33-11 well, where he noted a rapid shallowing of water depth. A minor lithologic change coincides with the change in water depth. The lower part of the Sager Creek formation in the Clatsop County 33-11 well is predominantly uniform carbonaceous and finely micaceous siltstone which has low resistivity compared to the overlying part which has more numerous thin beds of turbidite sandstone and mudstone and resulting slightly higher resistivity.

Pittsburg Bluff Formation

In Clatsop County, the upper Eocene Pittsburg Bluff Formation which overlies the Sager Creek formation is predominantly silty, fine-grained tuffaceous quartzo-feldspathic shallow-marine sandstone. This upper Refugian unit was recognized in cuttings only in the Boise Cascade 11-14 well, where it is 200 ft thick (unit Tpb on Plates 1 and 2). The subsurface unit can be correlated to surface exposures of thicker mollusk-bearing bioturbated shallow-marine Pittsburg Bluff sandstone that crops out between the Boise Cascade 11-14 well and the Watzek et al. 30-1 well (wells 4 and 6 on Plate 1). The sandstone pinches out to the west into deeper marine glauconitic tuffaceous siltstone and mudstone of the Smuggler Cove formation before it reaches the Johnson 33-33 well. Surface mapping also shows that the Pittsburg Bluff pinches out into a glauconitic sandstone unit of the Smuggler Cove formation to the southwest (unit Tscg on Plate 1; Rarey, in preparation). The resistivity of the Pittsburg Bluff sandstone in the Boise Cascade 11-14 well is low. There is a small negative deflection of the SP curve, but the gamma ray values are slightly higher than in the overlying Northrup Creek formation or the underlying Sager Creek formation. The log data indicate that the silty Pittsburg Bluff sandstone in this area would not be a good reservoir. Foraminifers from this unit indicate that the sandstone was deposited in bathyal depths, an environment that is considerably deeper than that indicated for the correlative shallow-marine Pittsburg Bluff sandstone that crops out to the southeast of the Boise Cascade 11-14 well (Plate 1; Olbinski, 1983; Nelson, 1985). Therefore, the Pittsburg Bluff strata in the well are probably a deeper water facies of the formation (perhaps equivalent to the Klaskanine tongue of Peterson, 1984).

Northrup Creek formation

Unconformably overlying the Pittsburg Bluff Formation is the Northrup Creek formation which in outcrop is Zemorrian (Oligocene) to early Saucesian (early Miocene) in age. Only the older part of the unit (Zemorrian and some late Refugian?) is recognized in the Boise Cascade 11-14 well. Outcrops and cuttings of this formation consist of well-laminated carbonaceous siltstone-mudstone with abundant laminae of fine-grained micaceous and carbonaceous quartzo-feldspathic sandstone. Many thin to thick graded beds of clean feldspathic turbidite sandstone also occur. Near the top of the unit in the Boise Cascade 11-14 well is a 390-ft thick interval of quartzo-feldspathic sandstone that may correlate to a thick, shallow-marine arkosic sandstone that crops out southeast of the well (unit Tns on Plate 1). This laminated mudstone- and siltstone-dominated formation contains both large and small flakes of mica. As on the surface, carbonaceous material is ubiquitous and is commonly concentrated in the 1 to 3 mm thick sandstone-siltstone laminae. Organic matter is also present as discrete coalified wood fragments. There are a few tuffaceous intervals in the unit. The resistivity, SP, and gamma ray curves show little change within the unit except where some sandstone beds cause a slight increase in resistivity and decrease in gamma ray values. The Northrup Creek formation is thickest in the Boise Cascade 11-14 well (more than 2,600 ft) and crops out between the Boise Cascade 11-14 and Clatsop County 33-11 wells to the southeast (wells 4 and 5 on Plate 1). It rapidly thins and intertongues with the upper part of the Smuggler Cove formation to the west (e.g., Johnson 33-33 well).

Smuggler Cove formation

The Smuggler Cove formation is a thick, widespread sequence of deep-water (bathyal) tuffaceous silty mudstone and sandy siltstone of late Refugian, Zemorrian, and early Saucesian age (Oswald West formation of Cressy, 1974; Penoyer, 1977; Murphy, 1981). The Smuggler Cove formation conformably overlies the Keasey in the Hoagland No. 1, Patton 32-9, Johnson 33-33, Crown Zellerbach 31-17, and Crown Zellerbach 11-28 wells. Mudstone cuttings of the Smuggler Cove are tuffaceous and bioturbated or glauconitic (e.g., in the Patton 32-9 well). Small micas and carbonaceous debris are finely dispersed in the unit, and there are minor sandstone beds. The resistivity, SP, and gamma ray log responses are nearly straight-line curves that are typical responses for mudstone. However, a few thin sandstone beds show as an increase in resistivity and corresponding decrease in gamma ray value. The Smuggler Cove formation interfingers with the carbonaceous and micaceous sandy Sager Creek formation in the Crown Zellerbach 31-17 well and with the Northrup Creek formation in the Johnson 33-33 well. We found little evidence, other than a little glauconite, for the unconformity within the Smuggler Cove formation in the Patton 32-9 well that Bruer and others (1984) drew at about 1,350 ft. There is no change in paleobathymetry and no major change in lithology or electric or gamma ray log responses. However, Bruer and others (1984) noted some change in dip direction on the dipmeter log at their Zemorrian-Saucesian boundary (Meyer, personal communication, 1985).

Astoria Formation

The lower to middle Miocene Astoria Formation consists of four members: the Angora Peak, Wickiup Mountain, Youngs Bay, and Cannon Beach members (Plate 1). Of these, the Wickiup Mountain member was encountered in only two wells and the overlying Youngs Bay member was penetrated in only the Johnson 33-33 well. Thick, shallow-marine (neritic), cross-bedded to laminated sandstone of the Wickiup Mountain member of the Astoria Formation (Big Creek sandstone of Coryell, 1978; Nelson, 1978; Cooper, 1981) unconformably overlies the deep-marine tuffaceous mudstone of the Smuggler Cove formation on the surface in northern Clatsop County (Plate 1). This Saucesian unit dips homoclinally northward and is readily recognized in the cuttings of both the Patton 32-9 and Johnson 33-33 wells. The cuttings consist of fine-grained arkosic sandstone that is, in part, carbonaceous and micaceous. Thin interbeds of sandy siltstone with bathyal foraminiferal assemblages become more abundant upsection, reflecting a gradual marine transgression. This siltier, deep-water upper part of the Wickiup Mountain member is also recognized in outcrop (unit Tawu on Plate 1; Coryell, 1978; Nelson, 1978). The resistivity values for the lower sandstone-rich part of the Wickiup Mountain member are greater than for the underlying tuffaceous mudstones of the Smuggler Cove formation. The SP curve shows a negative deflection, and the gamma ray values are slightly less than for the Smuggler Cove formation. Water depth as indicated by foraminifers decreased rapidly from bathyal depths in Smuggler Cove time to neritic depths during Wickiup Mountain time. Abrupt changes in paleobathymetry between 1,550 and 1,670 ft in the Wickiup Mountain member in the Johnson 33-33 well may be attributable to a short-lived transgression and/or to sloughed cuttings from higher in the well.

The Youngs Bay member of the Astoria Formation (Pipeline member of Coryell, 1978 and Nelson, 1978) consists of mudstone and siltstone that contain Saucesian to Relizian bathyal microfossil assemblages and some thin beds of medium-grained arkosic sandstone. The mudstone is characteristically micaceous and locally contains finely disseminated carbonaceous material. This unit correlates with the mudstone-dominated unit Tay (Plate 1) on the surface which is exposed in a homocline. Coryell (1978), Nelson (1978), and Cooper (1981) interpreted the Wickiup Mountain member as part of a high-energy wave-dominated deltaic-shoreline-shelf sand complex of the Astoria Formation that prograded over the deep-marine Smuggler Cove slope facies in early to middle Miocene time. A subsequent early to middle Miocene transgression deposited slope mudstones (unit Tay) and the sandstone-dominated channelized canyon head deposits (units Tay_1 and Tay_2 on Plate 1) of the overlying Youngs Bay member.

INTRUSIONS

Sills and dikes and associated basaltic breccias, pillow lavas, and subaerial flows of the middle Miocene Columbia River Basalt Group form numerous rugged ridges, mountains, and headlands in the Astoria basin (Plate 1). These rocks belong to the Grande Ronde Basalt, Frenchman Springs member of the Wanapum Basalt, and Pomona member of the Saddle Mountains Basalt of Swanson and others (1979). Of these, Grande Ronde and Frenchman Springs basalt intrusions were encountered in the wells. Grande Ronde intrusions are generally lower in TiO_2, total iron, and P_2O_5 and higher in SiO_2 than Frenchman Springs basalt. Three chemical subtypes of Grande Ronde basalt are shown on Plate 2. These are low MgO, high MgO, and undifferentiated Grande Ronde Basalt. Intrusives with more than 4.2 percent MgO are defined as high MgO; intrusive rocks with less than 4.2 percent MgO are termed low MgO Grande Ronde basalt. In addition, these basalts can be further categorized on the abundance of TiO_2 (as defined by Murphy, 1981). Undifferentiated Grande Ronde Basalt and several unlabeled intrusions on Plate 2 were not analyzed geochemically because of insufficient cuttings. Two geochemical subtypes of the Frenchman Springs member, the basalt of Ginkgo(?) and low P_2O_5 basalt of Sand Hollow of Beeson and others (1985), were tentatively recognized in the wells (not shown on Plate 2). The intrusions which range from <10 ft to 380 ft thick invaded upper Narizian (upper Eocene) to Saucesian-Relizian (middle Miocene) strata. Intrusions have been recognized as deep as 7,700 ft.

Seismic records through the wells show that the intrusions are commonly sill-like bodies that are strong reflectors traceable for miles (Olbinski, 1983; Rarey, in preparation; Niem, unpublished data). Although these basalt reflectors generally parallel sedimentary dips, they also can abruptly or gently cut across hundreds of feet of unfaulted strata at low to high angles and then may resume a concordant relationship with the surrounding strata. The geometric configurations and varying relationships of the sills to the host strata have also been observed in outcrop. Since on many seismic records in Clatsop County the only strong reflectors are basalt sills and the sedimentary strata are acoustically transparent or appear as noise, the subsurface structure may be misinterpreted (e.g., apparent faults and folds). Surface studies (e.g., Cressy, 1974; Rarey, in preparation) show that some faulting preceded the Miocene intrusions. These faults may not show up in seismic records in which the only reflectors are basalt sills or inclined dikes.

Middle Miocene basalts are present in all wells, except the Hoagland No. 1 and Clatsop County 33-11 wells, as three to eight intrusions. Well cuttings of the intrusions are generally fresh, aphyric to microphyric, medium-gray chips (i.e., Grande Ronde basalt), and some have rare plagioclase phenocrysts (i.e., Frenchman Springs basalt). In thin section, they generally display an intersertal texture. Thicker Grande Ronde sills are gabbroic and consist of deuterically clay-altered plagioclase and augite with a silicic residuum of intergrown quartz and feldspar in intercrystal spaces. Oscillatory zoned plagioclase phenocrysts are distinctive of the late Eocene Cole Mountain basalt intrusions which crop out in the southeastern part of the Astoria basin (Plate 1; Rarey, in preparation). In the Watzek et al. 30-1 well, a deuterically altered gabbroic sill at 4,560 to 4,700 ft has an anomalous geochemistry and may be interpreted as either an altered low MgO Grande Ronde basalt sill (Olbinski, 1983) or a Cole Mountain basalt sill (Rarey, in preparation).

Baked upper and lower contacts in the adjacent mudstones are common and range from a few inches to hundreds of feet thick. Bleached, well-induratedmud chips and pyrite around the intrusions reflect this baking effect. Intrusions show substantial increases in resistivity and negative deflections of the SP curve near contacts with the adjacent sedimentary rocks. Some thick zones of baked sedimentary rocks also show a strong increase in resistivity.

Extensive study of field relationships, detailed basalt stratigraphy, geochemistry, and paleomagnetic measurements (Niem and others, unpublished data; Magill and others, 1982; Rarey and others, 1984) strongly suggest that these intrusions are distal ends of some middle Miocene Columbia River basalt flows. These flood basalts which originated on the Columbia Plateau followed the drainage of an ancestral Columbia River and entered the sea in the vicinity of northeastern Clatsop County (Snavely and Wagner, 1963; Murphy and Niem, 1982). Where the hot lava encountered sea water, the lava formed thick submarine breccias and pillow lavas with associated autoinvasive sills and dikes that invaded the adjacent water-saturated sediment (Beeson and others, 1979). Byerly and Swanson (1978) and Schmincke (1967) showed that some Columbia River basalts on the Columbia Plateau invaded Miocene lake sediments to form invasive sill-like flows. Beeson and others (1979) suggested that this process occurred at a much larger scale at the Miocene shoreline.

The details of the mechanics of invasion are not clearly understood. Invasion probably occurred through a combination of processes, including sinking of denser lava into less dense water-saturated semiconsolidated sediment, magma fracturing, steam blasting, and intrusion along pre-existing faults, joints, and bedding planes in brittle strata driven by magmatic head. Alternatively, while recognizing the close geochemical, petrographic, and age similarities to the nearby plateau-derived subaerial Columbia River Basalt units, Snavely and others (1973) proposed a local magmatic origin for these middle Miocene sills and dikes which they named Depoe Bay Basalt, Cape Foulweather Basalt, and basalt at Pack Sack Lookout.

GAS SHOWS

A total of 49 noncommercial gas shows were reported in the 8 wells. Gas shows, mainly methane (C_1), were noted on gas chromatograph curves on mud logs in all units except the Roy Creek basaltic conglomerate and sandstone; the Pittsburg Bluff Formation (present only in the Boise Cascade 11-14 well); and the Wickiup Mountain and Youngs Bay members of the Astoria Formation which were penetrated at the top of the Patton 32-9 and Johnson 33-33 wells. Four gas shows occur in thin sandstone and siltstone interbeds in the Tillamook Volcanics in the Hoagland No. 1 well, Boise Cascade 11-14 well, and Clatsop County 33-11 well. The overlying Hamlet formation has more gas shows. They occur in thin-bedded siltstone and sandstone in the Hoagland No. 1 and Patton 32-9 wells and in the thicker bedded lithic arkosic sandstone of the Sunset Highway member in the Watzek et al. 30-1 well. A "tar like" black oil was reported on the mud log from a drill stem test (DST) on a redrill from 9,358 to 9,470 ft (Hamlet formation) in the Patton 32-9 well. However, the oil was undetected by the mud logger in the cuttings. Therefore, it is not known whether this material is from the Hamlet formation or is a drilling contaminant. Another DST in the Patton 32-9 well, run on the interval 9,415 to 9,440 ft in a thin sandstone in the Hamlet formation, had a medium to light blow (mud log). Two failed DST's were attempted in the potentially promising Sunset Highway lithic arkosic sandstone at 6,453 to 6,459 ft and at 6,462 to 6,468 ft in the Watzek et al. 30-1 well.

The Cowlitz Formation is restricted to the eastern part of the Astoria basin (Plates 1 and 2) but shows the best potential as a gas reservoir. Four gas shows occurred in the Boise Cascade 11-14 well, one in the bathyal Cowlitz silty mudstone overlying the C & W sandstone and three in the upper part of the C & W arkosic sandstone. Four DST's were attempted (driller's log to Diamond Shamrock) at 6,247 to 6,294 ft, 6,254 to 6,294 ft, 6,573 to 6,608 ft, and 6,574 to 6,608 ft but misran. During the time the packers performed, flowage rates were 10,000 to 20,000 cfd. The C & W sandstone displayed the highest permeability and porosity of all the sandstone units in the Astoria basin (see further discussion on Plate 1). Commercial production in the easternmost part of the Astoria basin may be possible east-southeast of the Boise Cascade 11-14 well toward the Nehalem arch if suitable fault and stratigraphic traps and thicker sandstones occur updip.

Gas shows were most numerous (16) from the Jewell member of the Keasey Formation, probably because the unit commonly represents the largest percentage of the thickness of strata penetrated in the wells. Nine of the shows were from thick-bedded fractured(?) tuffaceous siltstone and 6 were from minor thin sandstone beds in the Hoagland No. 1, Patton 32-9, Boise Cascade 11-14, Crown Zellerbach 31-17, and Crown Zellerbach 11-28 wells. Interestingly, two gas shows occurred in the local, reworked basalt conglomerate and sandstone in the Boise Cascade 11-14 well. Even though they are highly carbonaceous, the overlying laminated very fine-grained arkosic sandstone and mudstone of the Sager Creek formation had only 6 gas shows (in Boise Cascade 11-14, Clatsop County 33-11, and Watzek et al. 30-1 wells). These thin-bedded turbidite sandstones have low potential as gas reservoirs because of their restricted distribution. The overlying Pittsburg Bluff Formation has no gas shows. This feldspathic sandstone is limited in thickness and distribution in the subsurface because it undergoes a rapid facies change to bathyal mudstone to the west of the Boise Cascade 11-14 well. Thicker sandstones may occur in the subsurface updip, east-southeast of the Boise Cascade 11-14 well, toward the outcrop of the thick-bedded shallow-marine Pittsburg Bluff (Plate 1). The Northrup Creek formation yielded only one gas show; that was from a thin fine-grained arkosic sandstone in the Johnson 33-33 well. The arkosic sandstones of the Northrup Creek are generally too thin (except unit Tns at the to have much reservoir potential.

Nine shows of gas were reported in the massive tuffaceous Smuggler Cove siltstone, mudstone, and minor feldspathic sandstone in the Johnson 33-33 and Patton 32-9 wells. The drillers log reported a possible tar sand at 6,730 ft that had a trace of bright-yellow fluorescence in the Johnson 33-33 well. This interval in the Smuggler Cove formation was perforated and had a flowage rate of 6 cfm (>8,600 cfd) for two minutes. Although the feldspathic sandstones of the Smuggler Cove (unit Tscs on Plate 1) have potential to be reservoirs, in outcrop most are fine-grained, diagenetically altered, and of limited thickness and distribution (Nelson, 1985). The columnar jointed, fractured middle Miocene basalt sills and dikes potentially could act as small gas reservoirs; however, no gas shows have been reported from these basalt units.

Although much of the 10,000-ft Tertiary section is thermally immature and gas-prone in the wells and in outcrop (see discussion on Plate 1), there is an additional factor that increases the potential for thermally mature natural gas in the Astoria basin. That is the presence of numerous middle Miocene intrusions that elevated the temperature of the buried sediments to and through the oil window (>60°C, Tissot and Welte, 1978). As many as 12 of the 49 gas shows are associated with the middle Miocene Grande Ronde and Frenchman Springs basalt intrusions.

Generally, intrusions less than 100 ft thick show little thermal alteration of the host strata. However, field and well studies show that many of the basaltic and gabbroic sills that are more than 100 ft thick retained sufficient heat over a long time to bake the enclosing sedimentary rocks over tens to hundreds of feet and over many square miles. The effects of baking are varied. In some cases, the rocks are merely more indurated above and below the intrusion, thereby showing more resistivity than similar strata farther from an intrusion. In other cases, the strata also have been bleached by the intrusion (e.g., up to 400 ft in the Crown Zellerbach 31-17 well).

Thermal effects on the organic matter may extend far beyond these visual baking effects. Thermal maturation (R_o) values were compared from two wells, Crown Zellerbach 31-17 with a thick gabbroic intrusion and Boise Cascade 11-14 without thick intrusions and a thicker and deeper sedimentary section that covers a wider age range (Fig. 1 on Plate 2). In the Boise Cascade 11-14 well (without thick intrusions), the thermal maturity increases only slightly with depth from Zemorrian Northrup Creek formation, through the Refugian Keasey For-mation, and through the Narizian Cowlitz Formation strata (R_o <0.5). In the Crown Zellerbach 31-17 well, thermal maturity of Refugian Keasey strata begins to increase rapidly (R_o >0.67 to 2.36) 1,150 ft above the intrusion. This thermal effect of an intrusion upon the thermal maturity of the surrounding strata is also evident by significant concentrations of ethane and propane (C_2 and C_3) gas shows from 1,140 to 2,230 ft above the thick gabbro in the Crown Zellerbach 31-17 well compared to the methane (C_1) gas shows in the thermally immature strata in the surrounding wells (see further discussion on Plate 1). Simoneit (1982) and Simoneit and Galimov (1984) showed in the Gulf of California that thermogenic gas can be generated in strata as young as Quaternary as result of heating by a basalt sill. The commercial importance of maturation due to heating by an intrusion(s), however, is yet to be tested.

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ERRATA SHEET FOR OGI-14

The following corrections should be made to the section entitled "Oil and Gas Potential":

1. Paragraph 7, line 8: Add the symbol ">" so that the line reads: "...and oxygen indices are commonly high (>100)...".

2. Paragraph 7, line 14: Add the symbol "<" so that the line reads: "... and surface samples, generally R_0 <0.55 percent."

3. Paragraph 7, line 23: Add the symbol "<" so that the line reads: "...in addition to methane (i.e., approx. $C_1/[C_2+C_3]$ ratios <15...".

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

OGI-14

Oil and Gas Investigation of the Astoria Basin, Clatsop and Northernmost Tillamook Counties, Northwest Oregon

By Alan R. Niem and Wendy A. Niem

Plate 2

NOTICE

The Oregon Department of Geology and Mineral Industries is publishing this plate because the subject matter is consistent with the mission of the Department. To facilitate timely distribution of information, camera-ready copy submitted by the authors has not been edited by the staff of the Oregon Department of Geology and Mineral Industries.

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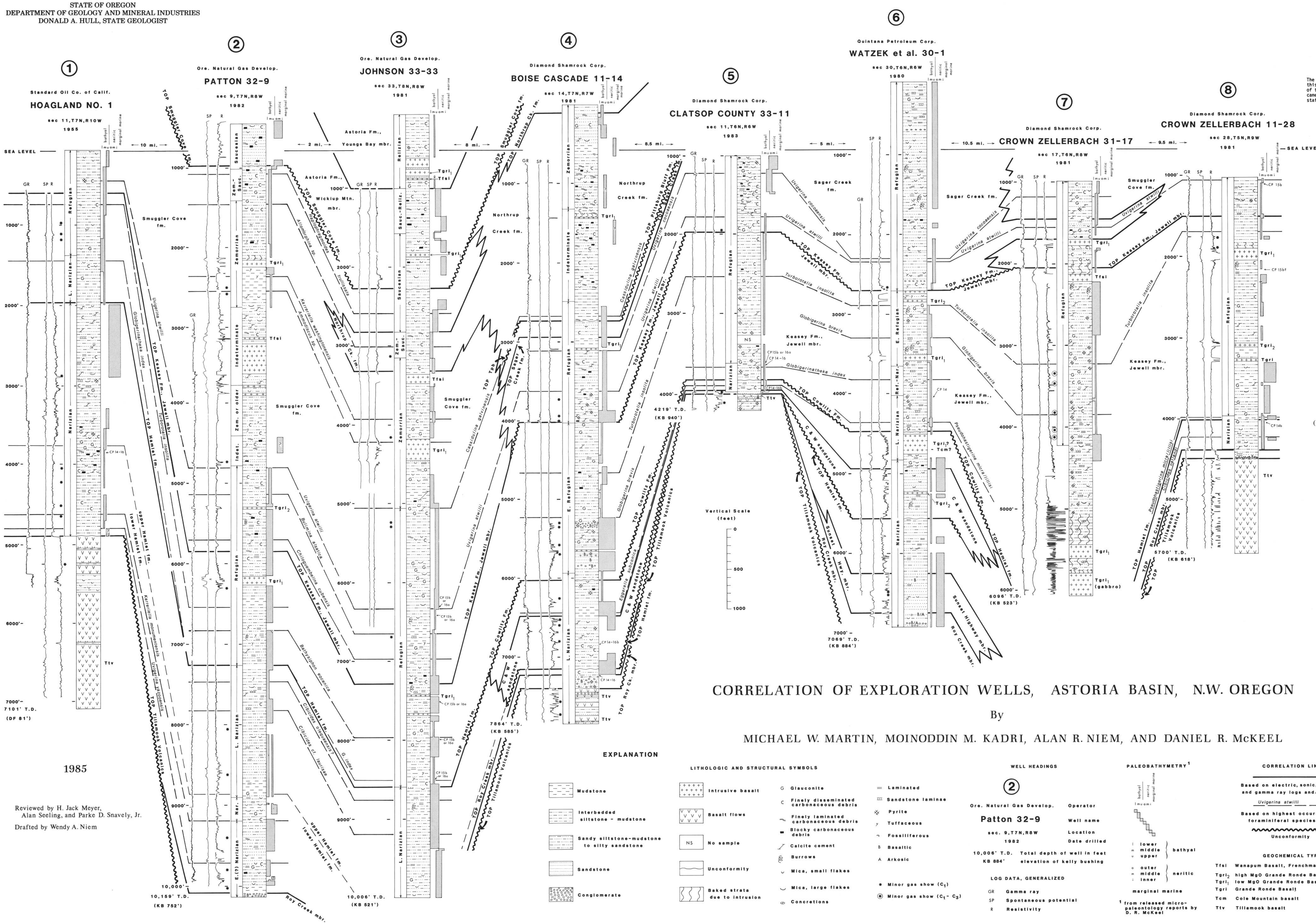

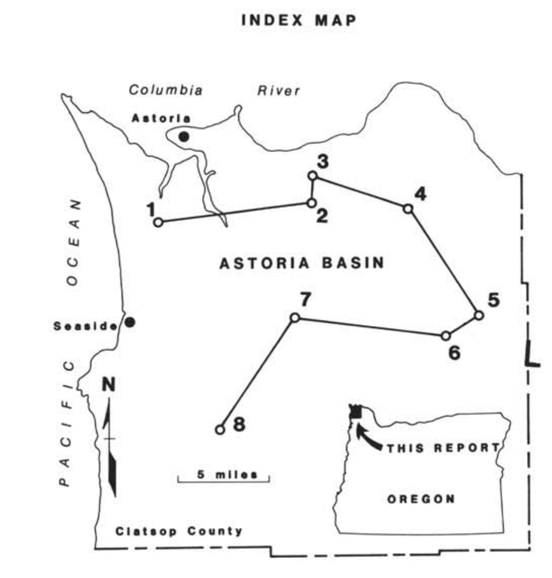

(see accompanying explanatory text for Plate 2)

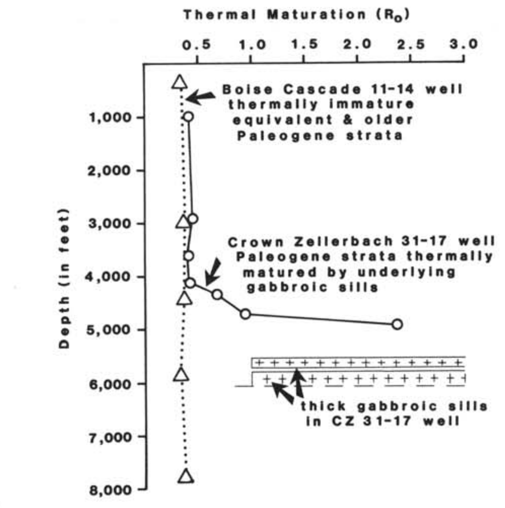

Fig. 1 Comparison of thermal maturation of similar age strata in Crown Zellerbach 31-17 and Boise Cascade 11-14 wells

CORRELATION OF EXPLORATION WELLS, ASTORIA BASIN, N.W. OREGON

By

MICHAEL W. MARTIN, MOINODDIN M. KADRI, ALAN R. NIEM, AND DANIEL R. McKEEL

1985

Reviewed by H. Jack Meyer, Alan Seeling, and Parke D. Snavely, Jr.
Drafted by Wendy A. Niem

EXPLANATION

LITHOLOGIC AND STRUCTURAL SYMBOLS

- Mudstone
- Interbedded siltstone - mudstone
- Sandy siltstone-mudstone to silty sandstone
- Sandstone
- Conglomerate
- Intrusive basalt
- Basalt flows
- NS No sample
- Unconformity
- Baked strata due to intrusion
- G Glauconite
- C Finely disseminated carbonaceous debris
- Finely laminated carbonaceous debris
- Blocky carbonaceous debris
- Calcite cement
- Burrows
- Mica, small flakes
- Mica, large flakes
- Concretions
- Laminated
- Sandstone laminae
- Pyrite
- y Tuffaceous
- Fossiliferous
- B Basaltic
- A Arkosic
- * Minor gas show (C_1)
- ⊛ Minor gas show (C_1 - C_3)

WELL HEADINGS

2	
Ore. Natural Gas Develop.	Operator
Patton 32-9	Well name
sec. 9,T7N,R8W	Location
1982	Date drilled
10,006' T.D.	Total depth of well in feet
KB 884'	elevation of kelly bushing

LOG DATA, GENERALIZED

- GR Gamma ray
- SP Spontaneous potential
- R Resistivity

PALEOBATHYMETRY[1]

bathyal, neritic, marginal marine
lmuomi

- l lower, m middle, u upper — bathyal
- o outer, m middle, i inner — neritic
- marginal marine

[1] from released micropaleontology reports by D. R. McKeel

CORRELATION LINES

- Based on electric, sonic, neutron, density, and gamma ray logs and/or lithologic data
- *Uvigerina atwilli* — Based on highest occurrence of listed foraminiferal species
- Unconformity

GEOCHEMICAL TYPES

- Tfsi — Wanapum Basalt, Frenchman Springs Member
- $Tgri_2$ — high MgO Grande Ronde Basalt
- $Tgri_1$ — low MgO Grande Ronde Basalt
- Tgri — Grande Ronde Basalt
- Tcm — Cole Mountain basalt
- Ttv — Tillamook basalt

GEOLOGIC AGE[1] (foraminiferal stages)

see Plate 1 for correlative Tertiary epochs

abbreviations: L. = late, E. = early

CP = Age range of nannofossil samples

Zone		Stage
CP16c		ZEMORRIAN
CP16a & b		?
CP15b	l. / e.	REFUGIAN
CP15a	late	NARIZIAN
CP14b	late	
CP14a	late	
CP13c	early	
CP13b	early	
CP13a	early	