# EASTERN OREGON–WASHINGTON PROVINCE (005)

**By Marilyn E. Tennyson**

## INTRODUCTION

Province 5, Eastern Oregon - Washington, is bounded on the west by the approximate crest of the Cascade Range, on the north by the International Boundary, on the east by the Idaho State line, and on the south by a series of county boundary segments through central Oregon that approximate the northern limit of the Great Basin. The province is about 300 mi long in a north-south direction and 200 mi long in an east-west direction, encompassing about 60,000 sq mi.

The surface of the province is dominated by the middle to late Miocene Columbia River Basalt Group, a series of basalt flows as much as 11,000 ft thick, which erupted from feeders in easternmost Oregon and Washington and adjoining Idaho. Beneath the basalt, Paleozoic and Mesozoic rocks, including subduction complexes, ophiolitic rocks, volcanic arcs, and associated sedimentary rocks record a complex history of accretion of allochthonous terranes and arc tectonism during Mesozoic time. Such rocks crop out beneath the northern, eastern, and southern margins of the basalt and probably underlie the entire Columbia Plateau. Emplacement and uplift of the Idaho Batholith in Cretaceous time immediately followed the end of accretion. Middle and Upper Cretaceous marine sedimentary rocks, perhaps continuous with similar rocks in the Sacramento Basin of northern California, were deposited unconformably on the accretionary complex in the southwestern part of the province. Paleogene nonmarine sedimentary and volcanic rocks were deposited and erupted extensively across the region during an episode of regional transtension and diffuse arc volcanism, which included detachment faulting in northeastern Washington, strike-slip faulting and folding in central and western Washington, and voluminous volcanism in central Oregon. Very thick sequences of Paleocene to Eocene fluvial arkosic sandstone and interbedded mudstone and coal are widespread but discontinuous throughout the province; in central Washington, for example, Eocene nonmarine arkosic sedimentary rocks exceed 20,000 ft in thickness in the northwest-trending Chiwaukum Graben, whereas they are only locally present and at most a few hundred feet thick in north-central and northeastern Oregon. Exploratory drilling and corroborative magnetotelluric surveys have confirmed the presence of at least 5,000-10,000 ft of nonmarine arkose, mudstone, coal, and volcanic rocks below Columbia River Basalt in central Washington. In the western part of the province, uppermost Oligocene to Quaternary calc-alkaline volcanic rocks of the Cascade arc overlie the Paleogene sequence and overlie, interfinger with, and underlie the Miocene Columbia River Basalt. Large, dominantly east-west-trending folds and reverse faults of Miocene to Quaternary age deform the basalt, particularly in the western part of the province.

The only commercial production from this province was from a small gas field (Rattlesnake Hills) in southern Washington that was discovered during the drilling of a water well in 1913. It was developed in 1930 and produced an estimated 1.3 BCFG (McFarland, 1979), mostly methane with about 10 percent nitrogen (Wagner, 1966), from two vesicular zones in basalt flows sealed by clay interbeds, at depths between 700 and 1,300 ft. The trap was a faulted anticline, and the gas probably was generated from Eocene coal in the nonmarine sequence below the basalt (Johnson and others, 1993). The field was abandoned in 1941. During the 1980's, several important test wells were drilled in the northwestern Columbia Plateau. They demonstrated the presence of thick lower Tertiary nonmarine sedimentary sequences beneath the basalt, and gas shows were present in almost all of them. Some drillstem tests were run, but the amount of gas present was not commercial. In north-central Oregon, there have been a number of wells drilled either through Miocene basalt into underlying sedimentary rocks or directly into Mesozoic or Paleogene rocks exposed in windows in the basalt cover, but none has resulted in a commercial discovery. No new wells have been drilled since the late 1980's.

Two conventional hypothetical gas plays were formally assessed in this province: the Northwestern Columbia Plateau Gas Play (0501) and the Central and Northeastern Oregon Paleogene Gas Play (0502). One unconventional hypothetical continuous-type play was considered, the Columbia Basin–Basin-Centered Gas Play (0503) described by B.E. Law.

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# CONVENTIONAL PLAYS

## 0501. NORTHWESTERN COLUMBIA PLATEAU GAS PLAY (HYPOTHETICAL)

This hypothetical gas play coincides with the inferred extent, beneath the Miocene Columbia River Basalt Group, of a 4,000 – 20,000-ft-thick sequence of lower Tertiary fluvial and lacustrine sedimentary rocks, deposited mostly in fault-controlled basins and interbedded with volcanic and volcaniclastic rocks. The boundaries of the play are somewhat conjectural, because they depend on the inferred presence of sedimentary rocks. The northeastern boundary is the projection of the Entiat Fault (the northeastern boundary of the Chiwaukum Graben) beneath the basalt. The southwest margin is the approximate southeastward projection of the southeast-trending faults at the south end of the Straight Creek Fault. The northern and southern margins are somewhat arbitrary and consist of the northern limit of the basalt and the Columbia River respectively. The play is about 125 mi long and 60 mi wide.

**Reservoirs:** Potential reservoirs are of poor to fair quality. They consist of Eocene or Oligocene arkosic fluvial sandstones of the Swauk, Chumstick, Roslyn, and Wenatchee Formations. Marginally adequate porosity (up to 13-16 percent) has been reported in sandstone from three of the wells that penetrated this section (Lingley and Walsh, 1986), although the Chumstick and Wenatchee Formations are reported to have excellent reservoir properties in outcrops near the edge of the basalt. Zeolitization is widespread in outcrops of the Chumstick Formation and probably detracts from permeability in the subsurface as well. The sub-basalt sedimentary section reaches thicknesses of 4,000 to 7,000 ft, although sandstone accounts for only part of the section.

**Source rocks:** Potential source rocks are lacustrine and fluvial shales in the Swauk and Chumstick Formations and possibly coal sequences in the Roslyn Formation. Reported TOC values from outcrops are 0-6 percent (0.03-1.10 percent in the Swauk Formation, 0.92-17.9 percent in the Roslyn Formation, 0.13-5.97 percent in the Chumstick Formation) (V. Frizzell, unpub. data). Organic matter is mostly type III. Vitrinite reflectance values (0.24-1.38 percent) in exposed rocks indicate that maturity is probably adequate beneath the basalt, as does data from subsurface samples. Maturation of the most likely source rocks probably took place during Miocene burial by 5,000-13,000 ft of basalt, as suggested by both Lopatin modeling and the presence of marginally mature sedimentary interbeds in the lower part of the basalt sequence (Lingley and Walsh, 1986). Isotopic data indicate the presence of thermogenic gas in intra-basalt aquifers (Johnson and others, 1993). Gas was tested in several wells drilled into the sub-basalt sedimentary rocks. $R_o$ values in exposed rocks (0.82-1.29 percent Swauk Formation; 0.45-1.38 percent Roslyn Formation; 0.25- 0.89 percent Chumstick Formation) also suggest that maturity should be adequate beneath basalt, as does data from subsurface samples (Lingley and Walsh, 1986).

**Timing and migration of hydrocarbons:** Maturation may have begun during Oligocene in the lean early Eocene section but was probably mostly middle Miocene and younger in the middle and upper Eocene section, based on Lopatin modeling and on the presence of mature sediments interbedded with lowermost Columbia River Basalt.

**Traps:** Potential traps include large, Miocene and younger anticlines and thrust faults involving basalt as well as pre-basalt structures. Stratigraphic traps are also possible but would be very difficult to find. Seals consist of shale interbeds in the fluvial sequences or possibly basalt flows. Drilling depths required to penetrate the basalt range from about 5,000 to 13,000 ft.

**Exploration status:** The only production in the province came from the Rattlesnake Hills field, reservoired in vesicular basalt (700 – 1,200 ft depth). It produced about 1.3 BCFG during the 1920's-1940's. Eight deep exploratory wells have been drilled since the 1950's. Several of these were been drilled to sub-basalt depths of 6,000-11,000 ft (total depths to 17,518 ft), proving the presence of at least 11,000 ft of sedimentary rocks. Significant subcommercial shows (5–6 MMCFGPD, 6 BCPD) were encountered in one well; most of the wells had gas shows.

**Resource potential:** This play is considered to have a very high probability of at least a few, and possibly many, small gas accumulations and a lower probability of large gas accumulations. Significant flows of gas were tested in several of the wells that penetrated the basalt, but it has not been demonstrated that reservoir strata are of adequate quality, thickness, and lateral persistence to contain a conventional gas accumulation larger than a few tens of BCFG, despite the possible presence of traps big enough to hold hundreds of BCFG.

### 0502. CENTRAL AND NORTHEASTERN OREGON PALEOGENE GAS PLAY (HYPOTHETICAL)

The Central and Northeastern Oregon Paleogene Gas Play is a hypothetical gas play with some potential for condensate and oil. It is defined by the limits of the area where potential reservoir and source rocks are known or inferred to be coextensive, although thick volcanic sequences obscure the distribution of both source and reservoir.

Paleocene and Eocene nonmarine sandstone or fractured Eocene volcanic rocks are potential reservoir rocks. Another potential reservoir is fractured or vesicular basalt flows and sedimentary interbeds in the Columbia River Basalt Group. Gas, perhaps with some paraffinic oil, is presumed to have been generated from Cretaceous marine mudstone underlying the reservoir sequence or from Paleocene or Eocene coal or mudstone interbedded in the reservoir sequence. Traps are primarily structural.

**Reservoirs:** A variety of potential reservoir rocks are or may be present in this play. Fluvial or deltaic sandstone of the Paleocene or Eocene "Herren Formation" of Shorey (1976) that crops out in two localities on the north flank of the Blue Mountains is reported to have average porosity of 12 percent (range 8 – 21 percent), and average eight mD permeability (range 0.4  73.0 mD) (Riddle, 1990). This unit is, at most, about 2,000 ft thick and consists of feldspathic sandstone, carbonaceous shale, and coal. It overlies Mesozoic accreted terranes and granitic rocks and underlies Eocene volcanic rocks of the Clarno Formation. Its distribution beneath the thick and widespread cover of younger Cenozoic volcanic rocks is very poorly known.

Lithic arkose and volcaniclastic rock of the Eocene Clarno Formation have average 17 percent porosity (range 4-38 percent) and average permeability of 8 mD (up to 43 mD) (Riddle, 1990). Loss of drilling fluid and water production from the Clarno in one well indicate that it contains permeable intervals, probably fractured tuff (L. Fisk, F & F Georesources Associates, Inc., written commun., 1993). Vesicular flows within the Miocene Columbia River Basalt Group produced 1.3 BCFG at Rattlesnake Hills in southern Washington and are used as a source of irrigation water, so it is also possible that gas reservoirs are present in rocks of the Columbia River Basalt Group. Cretaceous rocks in the Mitchell, Oregon, area have low porosity and permeability in surface outcrops (Riddle, 1990) and are not considered to be a likely reservoir.

**Source rocks:** Cretaceous mudstone of the Mitchell, Oregon area contains 0.21 to >3 percent TOC, with an approximate mean of about 1 percent, including both structured and amorphous organic matter (Fisk and Fritts, 1987; Sidle and Richers, 1985). Samples of carbonaceous mudstone and lignitic coal from the Herren Formation are reported to contain 0.04-23.9 percent TOC. The Clarno Formation contains 0.17-4.47 percent TOC, and Clarno lignite and mudstone has potential as a source of gas and (or) paraffinic oil (Kuo, 1988). Subsurface samples yielded $R_O$ values of 0.33 to 0.85 percent (Kuo, 1988). Other indications that oil, condensate, or gas has been generated include asphalt-filled fractures and cavities reported from numerous localities in central Oregon, gas in water wells, and gas and oil shows in exploratory wells. Analyses of gas from some of the wildcats and water wells indicate that methane and nitrogen are the main constituents in most cases, but significant ethane, propane, and heavier constituents have been shown to be present in several wells.

**Timing and migration of hydrocarbons:** Burial beneath thick areas in the Eocene to Miocene sequence is probably necessary for maturation to have occurred. A high geothermal gradient is likely in this volcanic province. $R_o$ patterns have been interpreted as evidence of a geothermal "event" in early Miocene time that might have caused regional maturation (Summer and Verosub, 1992).

**Traps:** Miocene and younger folds and faults are the most likely traps. Some of the folds are very large, with wavelengths of several miles. Stratigraphic traps are possible in the fluvial rocks of the "Herren Formation." Volcanic rocks and shale interbedded with and overlying the potential reservoir units are likely seals. Depths of traps could range from a few hundred ft to greater than 10,000 ft.

**Exploration status:** About 20 wells have been drilled in this large area, so it is fairly poorly explored. An 8,726-ft-deep well on the north flank of the Blue Mountains uplift, drilled in 1957, encountered Eocene Clarno volcanics on Mesozoic basement. A well more than 9,000 ft deep that was farther east, north of Heppner, on the north flank of the uplift in 1989 targeted pre-Clarno sandstone but was abandoned within the Clarno. Several wells in the "Ochoco Basin" drilled between 1955 and 1981 demonstrated the presence of sedimentary rocks beneath the volcanic sequence but found no commercial accumulations. Gas and (or) oil shows have been reported in a number of the wildcats, and 4 MMCFG was produced from the fractured Clarno Formation in one well near Clarno (L. Fisk, F&F Georesources, written commun., 1993). There has been little or no recent activity.

**Resource potential:** Given the large area involved and the number of untested traps along with widespread seeps and shows, it seems likely that at least a few small accumulations may be present. The possibility of one or more larger accumulations (tens of BCFG) exists, although it is not considered likely because the lateral persistence of good reservoir rocks is undemonstrated.

## UNCONVENTIONAL PLAY

*by B.E. Law*

***0503. COLUMBIA BASIN-BASIN CENTERED GAY PLAY (HYPOTHETICAL)***

The following collective list of characteristics is unique to basin-centered gas accumulations, a form of continuous-type accumulations: (1) regionally extensive accumulations that occupy the more central, deeper parts of basins, (2) absence of down dip water contacts, (3) overlain by a normally pressured transition zone containing gas and water, 4) abnormally overpressured or underpressured, (5) pressuring phase is gas, (6) produce little or no water, (7) low-permeability--commonly less than 0.1 mD, (8) contain thermogenic gas, (9) source of gas is from interbedded or adjacent rocks, 10) top of accumulations occurs at 0.75 to 1.0 percent vitrinite reflectance, (11) structural and stratigraphic trapping aspects are of secondary importance, and (12) the "seal" is a relative permeability barrier and is due to the presence of multiple fluid phases in low-permeability reservoirs. Because it is unlikely that all these characteristics can be identified in any single well, the most important characteristics to recognize are abnormal pressures (4), thermal maturity (10), and the abnormal pressure fluid phase (5).

The continuous-type Columbia Basin–Basin-Centered Gas Play (0503) underlies the widespread Miocene Columbia River Basalt in eastern Washington. The thickness of the basalt is highly variable. The few wells that have drilled through the basalts show that it is commonly in excess of 5,000 ft thick. The subvolcanic rocks are also quite variable. Through most of the play area, the subvolcanic rocks consist of lower Tertiary fluvial and lacustrine rocks of highly variable thicknesses. Interpretations of subsurface data from six widely spaced wells indicate the presence of a basin-centered gas accumulation. The well data show that the top of a thick, overpressured interval begins at depths ranging from 8,300 to 12,700 ft. Within the overpressured interval, large amounts of gas have been recovered on drill-stem tests. Although some water has also been recovered, most of the zones recovered gas with no water. The areal and spatial extent of the accumulation are imprecisely known because of insufficient deep drilling and uncertainties about the geometry of pre-volcanic basins.

**Reservoirs:** The reservoirs consist of Eocene arkosic fluvial sandstones. The quality of these reservoirs is unknown, although they are thought to contain large amounts of volcanic material that have resulted in very low permeability. Porosity values ranging from 6 to 15 percent have been calculated from well logs (Lingley and Walsh, 1986).

The thickness of the gas-bearing interval is at least 6,400 ft. The maximum thickness is unknown because the gas-bearing interval has not been entirely drilled through.

**Source Rocks and Geochemistry:** The sources of gas are assumed to be the interbedded coal beds and carbonaceous rocks. Regional source rock studies in Washington and Oregon indicate that nearly all organic matter in the region is a type III kerogen, capable of generating mainly gas with little liquids. The level of thermal maturity within the gas-bearing interval is sufficiently high (0.6 percent $R_o$) to generate gas.

**Timing and Migration:** Because gas is generated within or in close proximity to reservoirs in basin-centered gas accumulations, the temporal relationships between gas generation, migration, and development of a trap are not nearly as important as they are in conventional accumulations. It is not known when the reservoirs were charged with gas. It appears as though present-day temperatures are in or near equilibrium with measured levels of thermal maturity.

**Traps and Seals:** See discussion of seals in introduction to basin-centered gas accumulations.

**Depth of Occurrence:** The depth of reservoirs within the play ranges from 8,300 to over 17,000 ft. The maximum depth of reservoirs is uncertain due to the constraints of drilling in the play.

**Exploration Status:** The play is immaturely explored. There are five wells that penetrate the gas accumulation and several production tests have been made. These tests flowed gas at initial rates of as much as 3.1 MMCF/D. Previous exploration activity in the play area has focused on more conventional structural and stratigraphic plays. The region has not been evaluated in the context of basin-centered gas accumulations.

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