The Potential for Petroleum Systems in the Fore-Arc of Western Washington and Oregon

James S. Jackson
Department of Geology
Portland State University
P. O. Box 751
Portland, OR 97207
jjackson@pdx.edu

Abstract

Eocene sediments deposited in a fore-arc located west of an ancestral Cascade Range include coal-bearing sequence covering much of the Puget-Willamette Lowland. To the west, these terrestrial deposits pass into marine deposits beneath the Pacific Ocean. Syndepositional normal faulting and strike-slip faulting are evident in several onshore sub-basins, which are interpreted to represent a transtensional setting. Eocene volcanism locally affected sedimentation. Eocene fluvial sandstones overlie by intra-formation claystones are potential reservoir-seal couplets. Eocene coals and carbonaceous claystones represent a potential gas-prone source interval. Onshore exploration has discovered small oil and gas accumulations. The most intriguing indication of active petroleum system in the Puget Sound region is a set of active normal faults, which resulted in west-striking thrust faults are present in the Puget Sound region. Strike-slip faults are present in western Oregon, where they continue offshore. North-south trending thrust faults also occur offshore both Oregon and Washington. In the southern Lowland, normal faults were modified by episodes of late Eocene and Miocene transpression, which resulted in mild inversion of older normal faults.

Locally preserved sediments indicate that subsidence continued through Miocene and Pliocene time, and was followed in the Puget Lowland by extensive Pleistocene glaciation. Models of vitrinite reflectance data from wells located onshore indicate that, from the Eocene to the Present, the regional geothermal gradient ranged from 28 to 41°C/km. The eastern margin of the Lowland was bordered by the Cascade volcanic arc, and was subjected to advective heat flow.

At present, active faulting affects the region in several discrete zones. East-west striking thrust faults are present in the Puget Sound region. Strike-slip faults are present in western Oregon, where they continue offshore. North-south trending thrust faults also occur offshore both Oregon and Washington. In the southern Lowland, normal faults were modified by episodes of late Eocene and Miocene transpression, which resulted in mild inversion of older normal faults.

Structures formed by early Miocene or earlier events may have trapped migrating hydrocarbons. Structures formed or modified by Holocene faulting very probably post-date hydrocarbon generation and migration.

Introduction

The Cascade fore arc is located between the Cascade Range on the east and the subduction zone bounding the Juan de Fuca plate on the west. The fore-arc can be divided into three zones: the Puget-Willamette Lowland, the Olympic and Coast Ranges, and the offshore shelf including the accretionary complex. Vancouver Island lies north to the north and the Klamath Mountains lie to the south of the fore-arc. Exploration began in 1890 with a well near well drilled near Everett, WA. Oil shows were reported in this well, which was abandoned due to mechanical problems. Over 700 subsequent wells reveal several Eocene sub-basins within the fore arc. The Mist field in northwest Oregon is the sole conventional discovery in the fore arc. Several recent coal bed methane tests have not yet led to commercial gas production.

The fore-arc is underlain on the west by basaltic of the Siletz and Crescent formations, erupted 62 to 48 Ma. These units may be interpreted as a predecessor to the later volcanic ranges eroded to the east. The 40 to 17 Ma volcanics of the Western Cascades underlie the eastern fore-arc. The fore-arc subsided rapidly in the middle Eocene (Niem et al 1992). The Tyee Formation prograded north into the basin from Klamath Mountains. The Chuckanut Formation was deposited in a wrench or rift basin on the northern basin of the fore-arc. The volcanic units as well as coal-bearing deitates and marine sediments fill central fore-arc basin (Figure 3a).

An angular unconformity within the upper Eocene (39 Ma) interval reflects a change in the subduction zone (Niem et al 1992), coeval with the onset of Western Cascade volcanism and the subsidence of several sub-basins within the foreland. Sediments shed from uplands in southwest Washington and western Oregon filled these basins (Figure 3b). Deep marine sediments deposited in sub-basins are preserved along the present coast where they are represented by the Lincoln Creek, Keasy, and Bestendorf formations.

Renewed uplift of the Coast Range in the early Miocene uplift is associated with deltaic sedimentation prograding over the underlying marine sediments within the Puget-Willamette Trough. The topography of the resulting Coast Range was reduced in the central coast by 15 Ma, when the Columbia River Basalt Group lava flows erupted from vents in eastern Oregon and Washington. Units with the Grand Ronde Formation flowed down major rivers that crossed both the Western Cascades and the Coast Range to reach the present-day Pacific Coast. Wells drilled west of Astoria encountered the lavas within the middle Miocene interval. (Figure 3c).

The fore-arc acquired its present topography in the late Miocene, as the Olympic Range rose as an antclimax, and the High Cascades volcanoes erupted onto an rising Cascade Arch. Since the Pliocene, the normal faulting along east-west trends has affected the Puget Sound region, while northwest and northeast trending strike slip faults have affected the Willamette Valley and adjacent Coast Range. Beginning about one million years ago, eruptions of basalt lavas in the Portland sub-basin have created a volcanic field of shield volcanoes (Figure 3d).
The Juan de Fuca/Tofino Basin bounds the north coast of the Olympic Peninsula and extends beneath the Straits of Juan De Fuca. Gas seeps occur near the Washington coast emanating from Upper Eocene to Lower Miocene sandstones. Over 19,000 feet of sandstone, claystone, and coals are present, representing deltaic to deep water depositional settings.

Drilled in 1967, Pan Am well 141 found no reservoir above the Hoh Formation melange at 3,400' md. Thrusting toward the subduction zone is typical on seismic data in this portion of the shelf. Faults west of well 141 may be strike-slip faults, as interpreted by Snively and Kvenvolden.

Grays Harbor basin well Medina-1 produced 12,000 barrels of oil. No source is identified for this oil. The well found reservoir quality sandstones in the Quinault and Montesano formations. Seals are present in this basin, but no regional seal has been found above the Montesano Formation.

Drilled in 1966, Shell well 150 tested 10.5 and 26 MMCFG/D from sandstones within the Hoh Formation melange. Mud diapirs arising from the Hoh Formation are common on seismic data acquired on this portion of the shelf.

Seismic data acquired near the Columbia River images listric normal faults that sole out in the Hoh Formation.

Drilled to 10,007', the Unocal Grebe well encountered only bathyal siltstones in lower Miocene through Eocene formations. The Stonewall Bank is interpreted by Yeats et al (1998) as one of several anticlines formed above west-vergent blind thrust faults. The synclines flanking these features are filled with Plio-Pleistocene strata, which rest unconformably upon the late Miocene. Growth of the Stonewall anticline began 2-3 Ma. It is estimated that 1500 meters of sediment, including lower Miocene strata were eroded at the Grebe well (Yeats et al 1998).
The wells drilled both onshore and offshore in the Cascade fore-arc show a range in geothermal gradients, with higher gradients recorded near the active volcanic arc. The gradients are higher than those in other fore-arc basins, due in part to warm, young oceanic slab beneath the fore-arc. Local uplift varies across the basin, as reflected in the map of depth to Ro=0.5 (Figure 5).

Eocene coals and carbonaceous shales are found in the Bellingham, Seattle, Tacoma, Chehalis, of the Puget Trough, and Coos Bay sub-basin on the central Oregon Coast (Walsh and Lingley 1991, Allen and Baldwin 1944). These are the only identified potential source rock intervals in the Cascade fore-arc. Work carried out by Parke Snively and colleagues at the USGS has identified oil and gas seeps along the flanks of the Olympic Peninsula. These have been characterized without identifying a corresponding source. Snively et al have also identified units within the Hoh and Ozette Formation melanges which have some potential as gas-prone source rocks. They have been unable to correlate these with any known oil or gas.

Conclusion

A wedge of middle Eocene and younger continental and marine sediments was deposited on an igneous basement located between the present Cascade range and the subduction zone of the Juan de Fuca plate. This fore-arc basin experienced multiple episodes of subsidence and uplift, resulting in the creation of several sub-basins within the fore-arc. Neotectonic faulting in the Puget Sound region has created many late-formed structures that likely post-date hydrocarbon migration. At least one episode of inversion has created structures in the subsurface such as the Mist Field and the Jackson Prairie gas storage field. Sandstones of Eocene and Miocene age form adequate reservoir unit. Intraformation claystones provide locally adequate seals. Significant coals occur within several sub-basins, which may serve as source rocks for gas or hosts of coal-bed methane production. The tectonic setting above a subducting slab has not resulted in very low geothermal gradient throughout the region.

Intermittent magmatism commencing in the Oligocene resulted in higher geothermal gradients on the eastern margin of the fore-arc and near local volcanic centers within the fore-arc. The offshore region has very few wells, little modern 2D seismic and no 3D commercial seismic data. Veen et al (1998) observe that foram stages used to define the stratigraphic section of the fore-arc are time-transgressive, and so a revised stratigraphic sequence should be devised. Although the region has little commercial to this date, insufficient modern work has been performed, especially offshore, to condemn it.

References Cited


Acknowledgments

Partial funding provided by a grant from the United State Bureau of Land Management to the Geology Department, Portland State University. Nancy Ketrenos of the BLM, Jack Meyer of Northwest Natural Gas, Bill Lingley, Tim Walsh, and Dave Norman of the Washington Department of Natural Resources were very generous in sharing their knowledge of the region. Connie Manson of the DNR Library provided invaluable guidance to the use of the DNR's collections. Discussions with Mike Cummings, Paul Hammond, Tom Benson, Dick Thomas and Bob Van Atta of Portland State University, and Alan Niem of Oregon State have shaped some of the views expressed in this poster without imparting any of the errors that be found in the poster.