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

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Abstract

Eocene sediments deposited in a fore-arc located west of an ancestral Cascade Range include acoal-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 effected sedimentation. Eocene fluvial sandstones overlain 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 an active petroleum system are oil seeps found on the coast of the Olympic Peninsula. To date, no source rock has been found that might generate these oils.

Locally preserved sediments indicate that subsidence continued into 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.

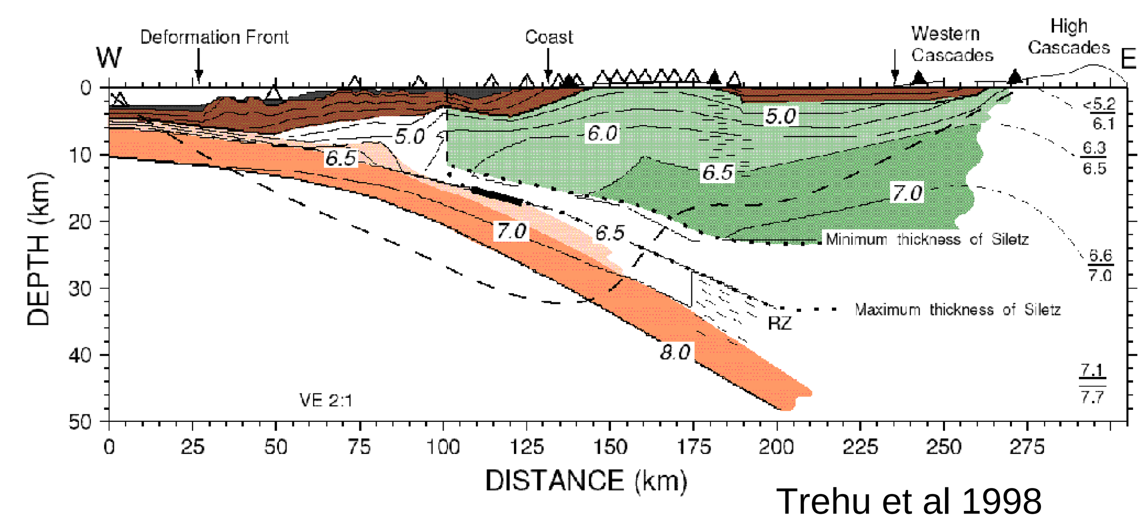
Structures formed by early Miocene or earlier events may have trapped migrating hydrocarbons. Structures formed or modified by Holocene faulting very probably post-date hydrocarbon generation and migration.

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 Klamth 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.

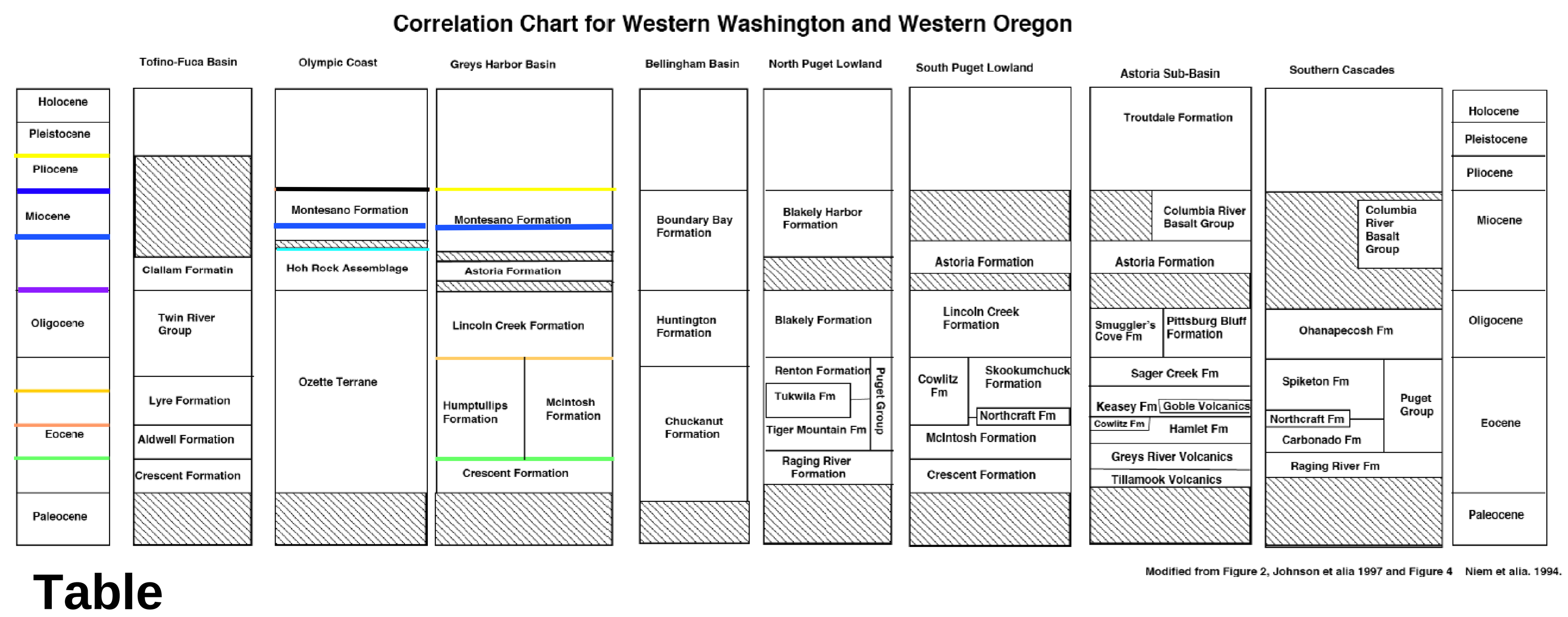
The fore-arc is underlain on the west by basalts of the Siletz and Crescent formations, erupted 62 to 48 Ma. These units may be interpreted as a predecessor to the later volcanic ranges erupted to the east. The 40 to 17 Ma volcanics of the Western Cascades underlie the eastern fore-arc. The fore-arc 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 deltaic 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



Trehu et al 1998

Figure 1. Regional Cross-section



Table

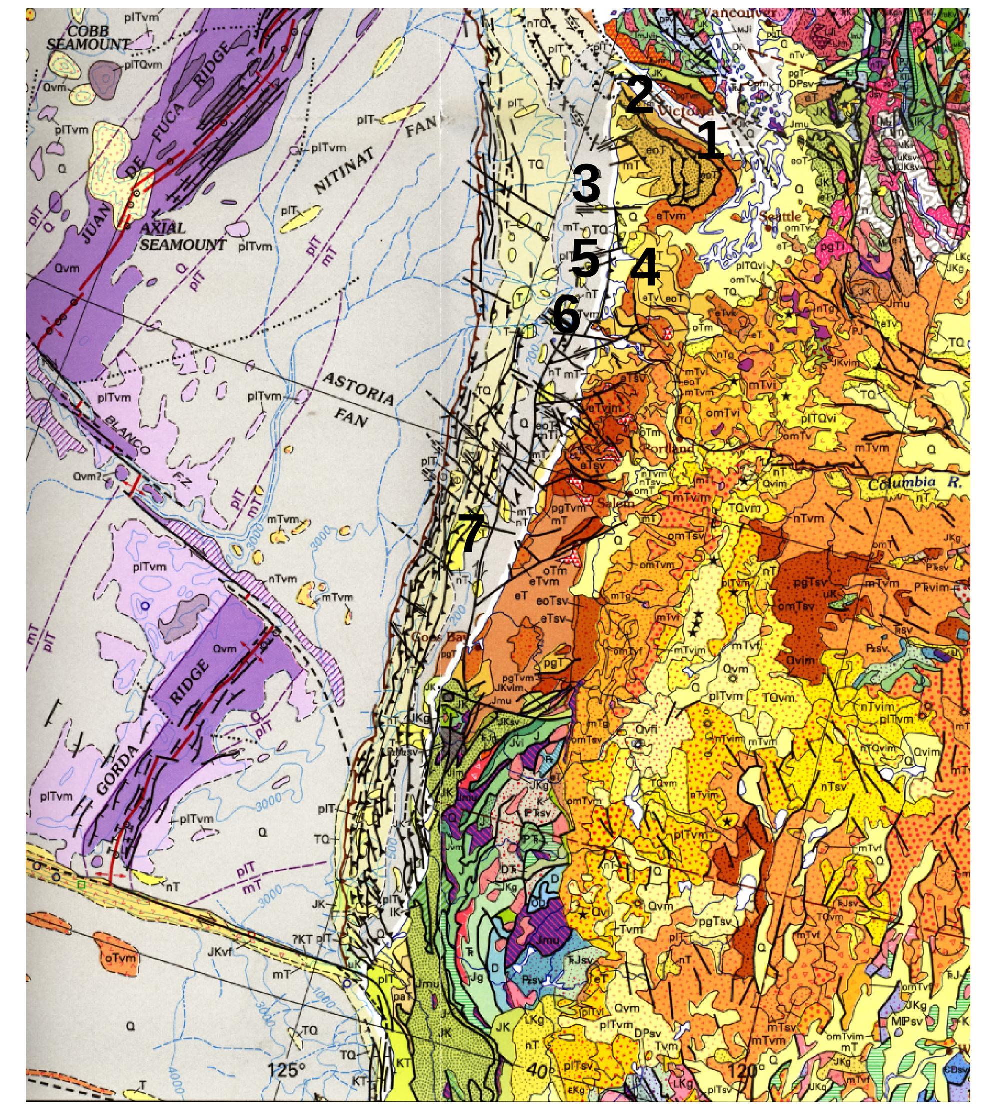

Reed et alia 2005)

Figure 2. Geologic Map

(1-7) Locations of offshore seismic data and cross-section.

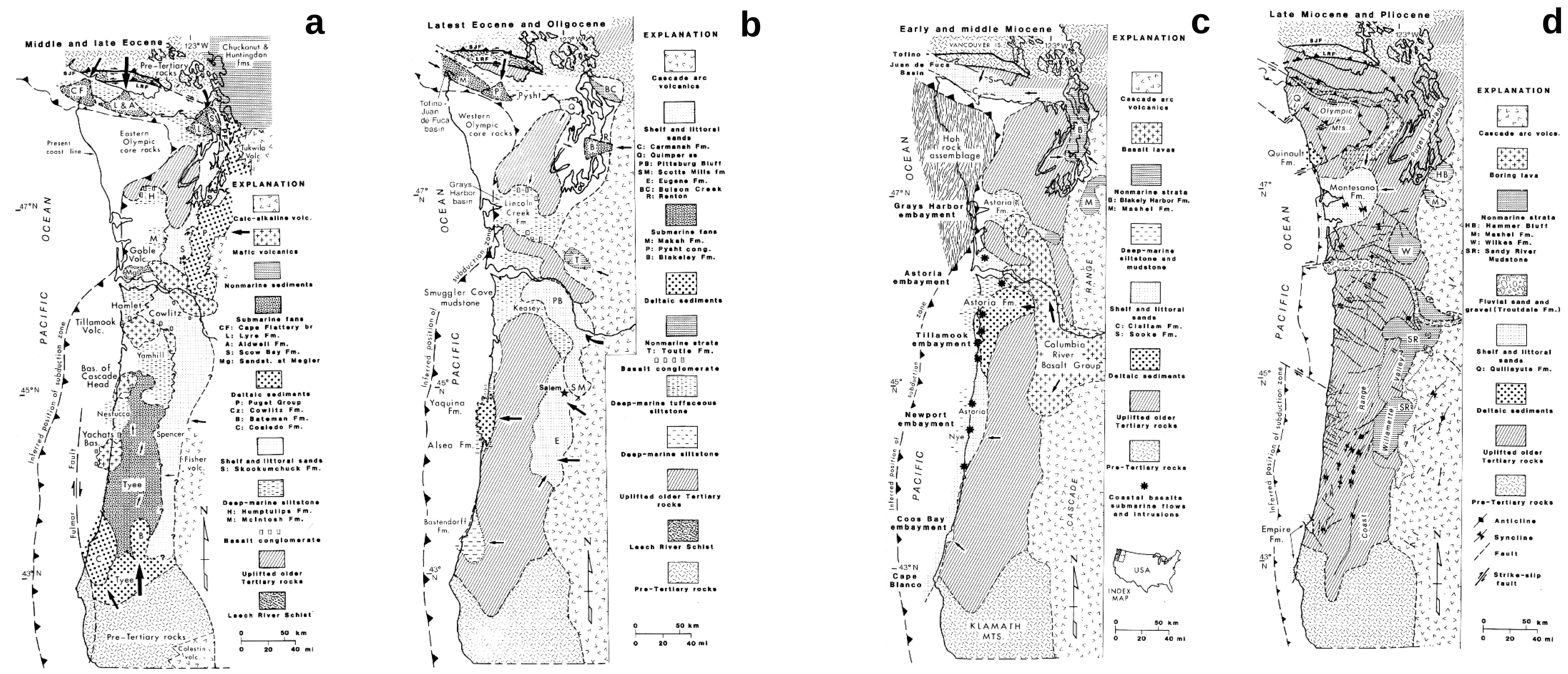


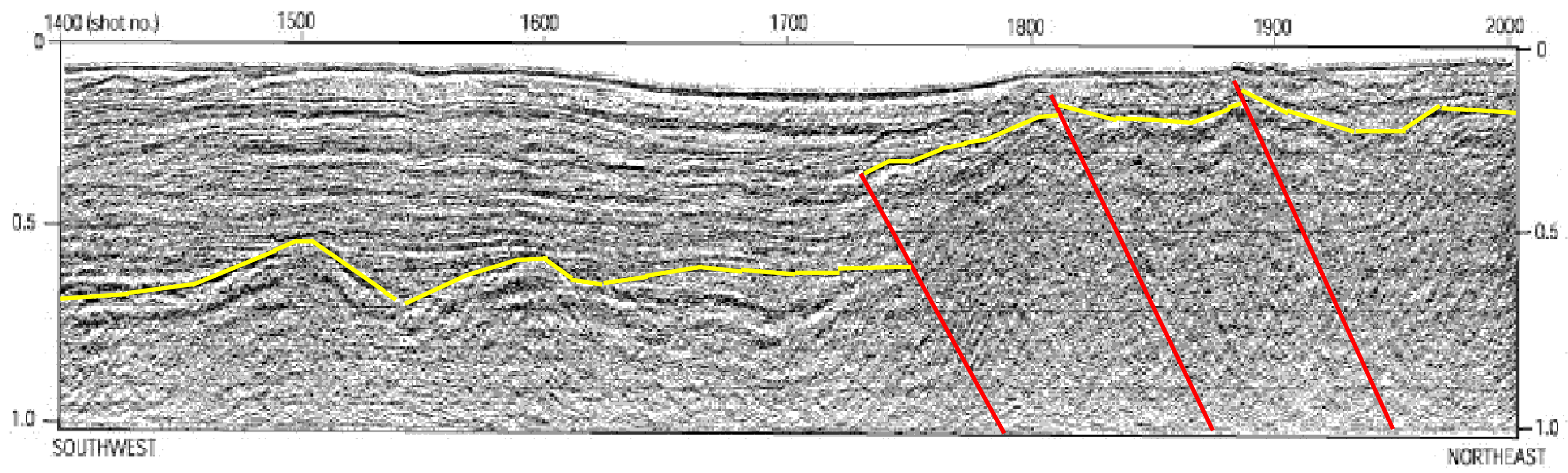
Figure 3. Paleogeography of the Cascade Fore Arc (Niem et al 1992)

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 topgraphy in the late Miocene, as the Olympic Range rose as a anticlinorium, and the High Cascades volcanoes erupted onto an rising Cascade Arch. Since the ?Pliocene, the normal faulting along east-west trends has effected the Puget Sound region, while northwest and northeast trending strike slip faults have effected the Willamette Valley and adjacent Coast Range. Begining about one million years ago, eruptions of basalt lavas in the Portland sub-basin have created a volcanic field of shield volcanoes (Figure 3d).

1



Modified from Johnson et al 2002

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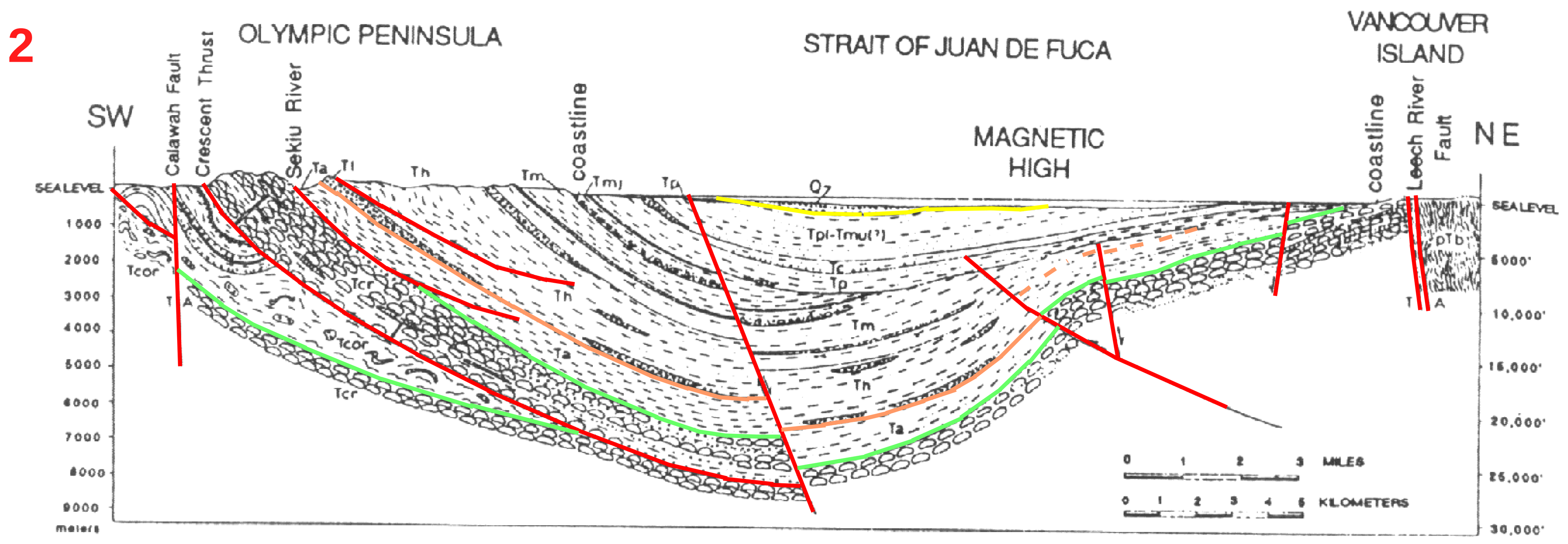
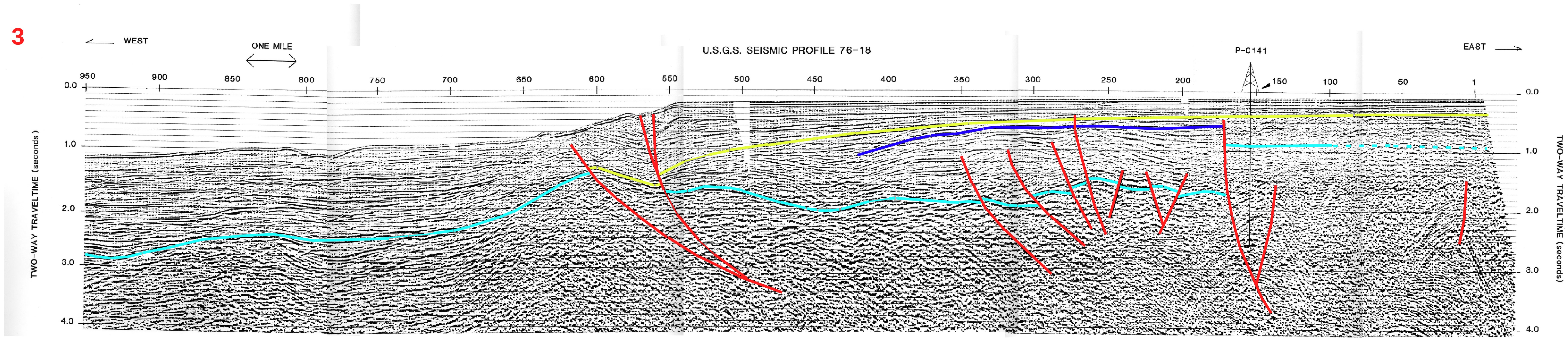


Modified from Niem and Snavely 1993

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.

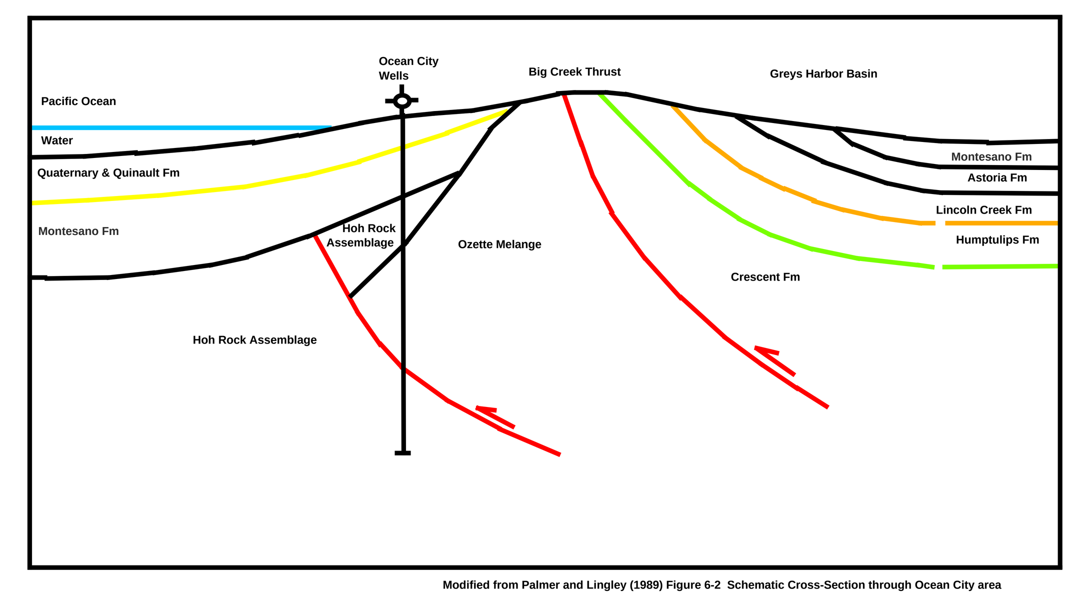
3



Modified from Palmer and Lingley 1988

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 Snavely and Kvenvolden.

4



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.

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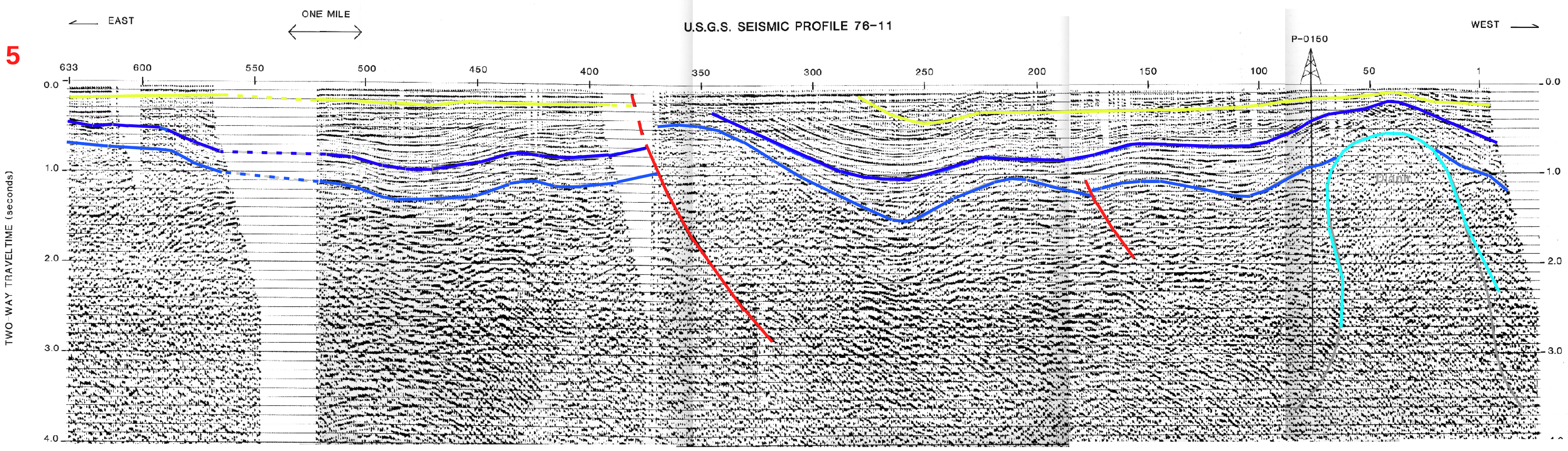

Modified from Palmer and Lingley 1988

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.

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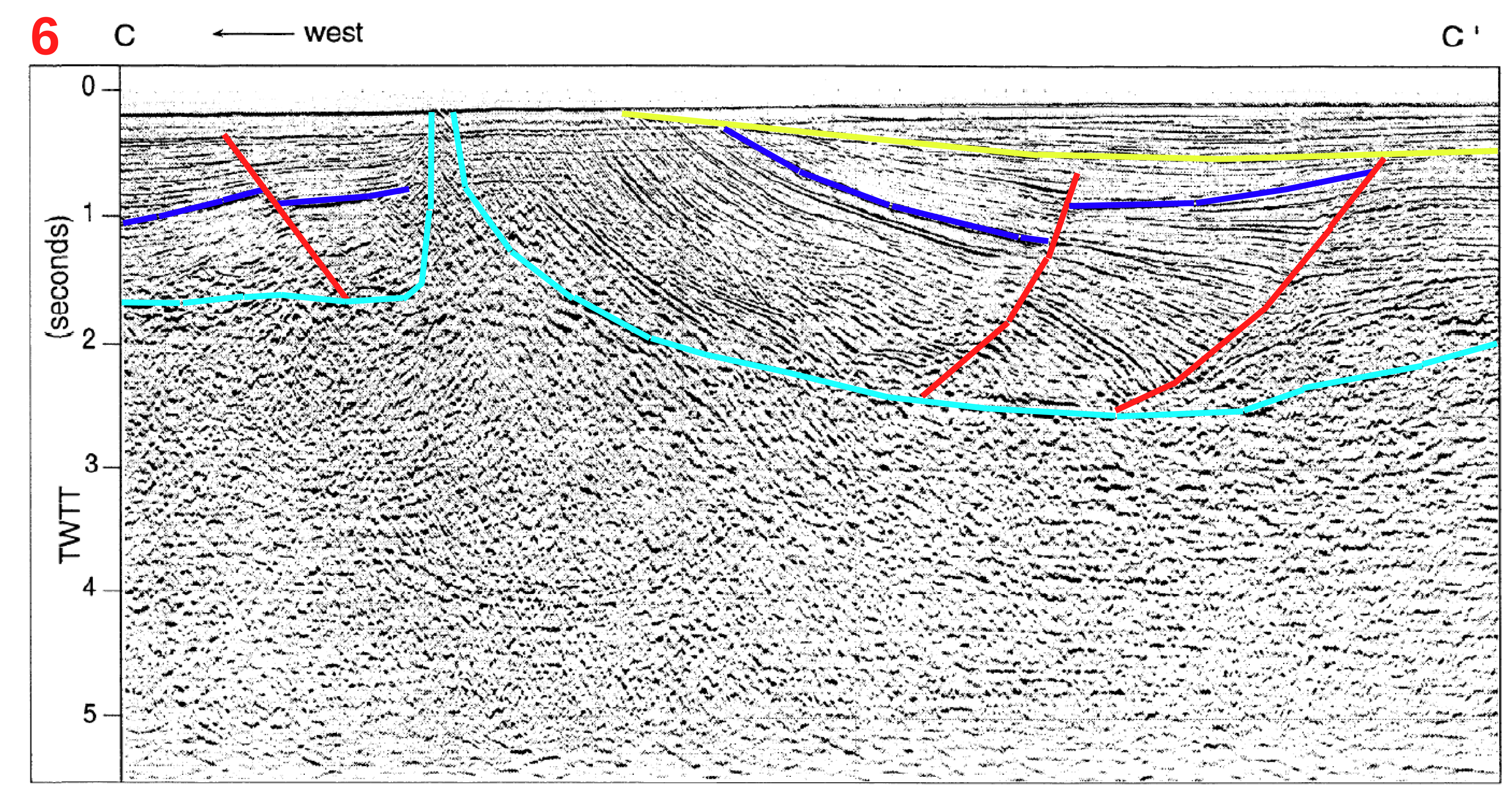

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Seismic data acquired near the Columbia River images listric normal faults that sole out in the Hoh Formation.

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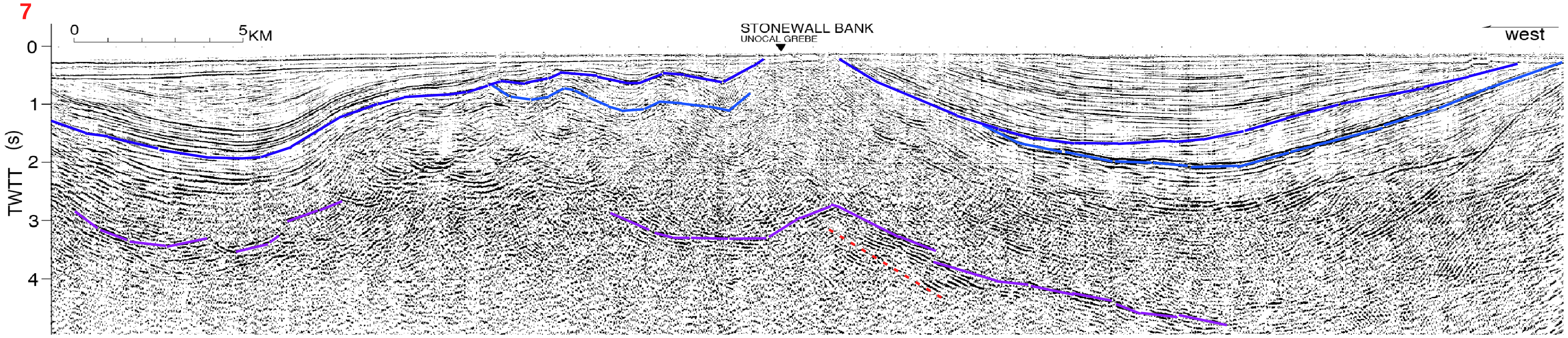

Modified from Yeats et al 1998

Drilled to 10,0007', 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).

Petroleum Geochemistry

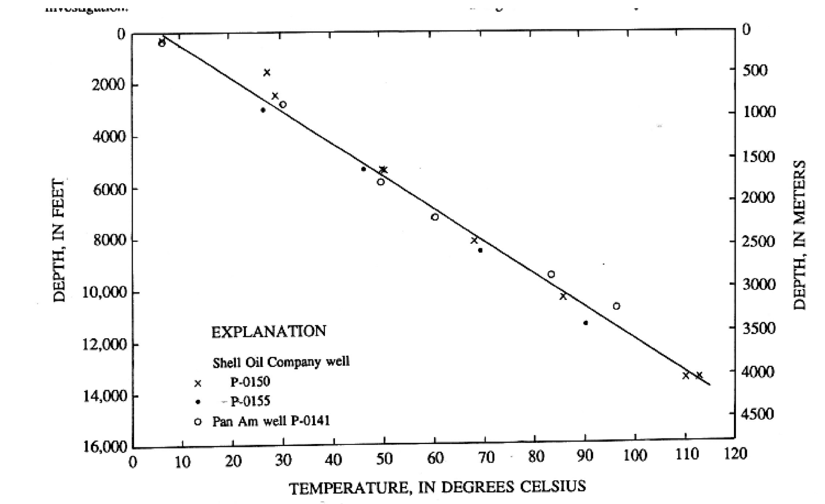

Figure 1 Uncorrected geothermal gradient of 2.60 °C/100 m based on bottom-hole temperatures from wells. Temperature of about 7.5 °C was assigned for sea-floor depth of 100 m (McGary, 1971). Snavely and Kvenvolden 1989

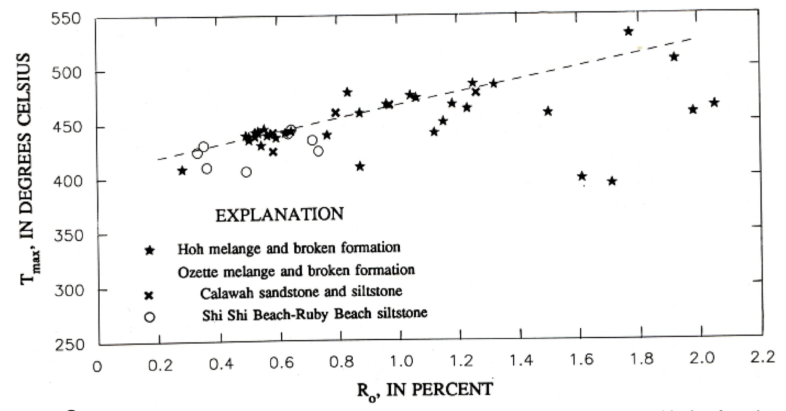

Figure 2 Rock-Eval temperature (T_{max}) versus vitrinite reflectance (R_o) for Ozette and Hoh melanges and broken formations. Dashed line is expected relation as determined by Dow and O'Connor (1982). T_{max} values for samples that have small S_2 peaks (less than 0.2 mg hydrocarbon/g rock) are not shown. Snavely and Kvenvolden 1989

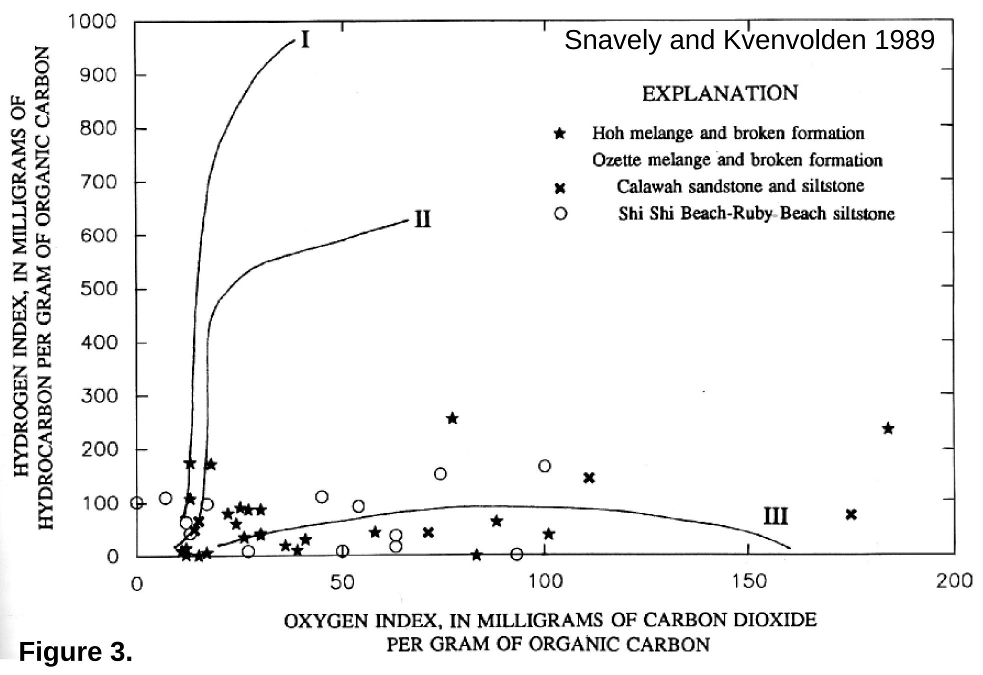

Figure 3.

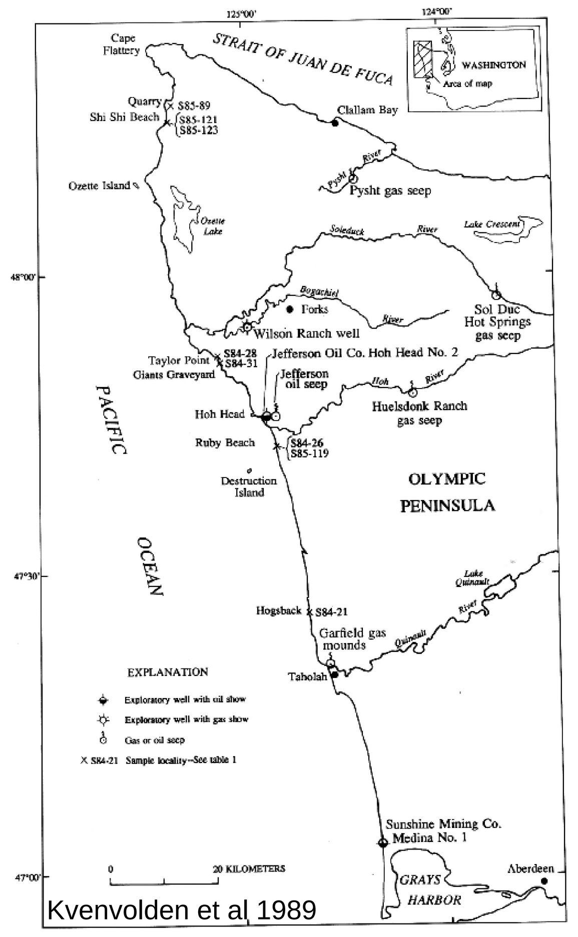

Figure 4. Seeps and well shows of oil and gas

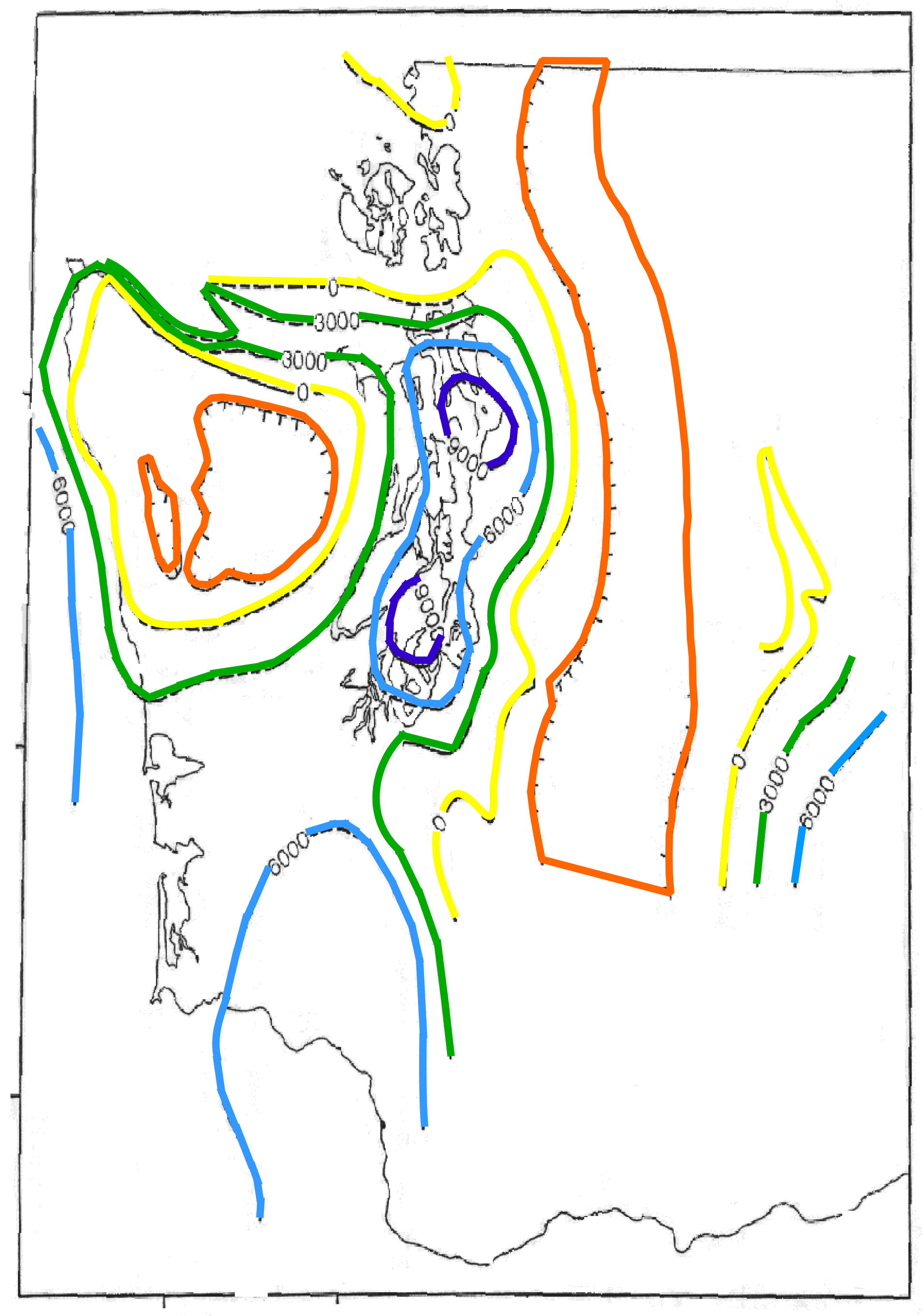

Figure 5. Depth to Ro = 0.50% (Modified from Walsh and Lingley 1991)

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, Chehals, 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 Snavely 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. Snavely 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 da Fuca plate. This fore-arc basin experienced multiple episodes of subsidence and uplift, resulting 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. Intra-formation 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. Yeats 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

Allen, J. E. and Baldwin, E. M. 1944 Geology and coal resources of the Coos Bay Quadrangle, Oregon: AAPG Bulletin v. 28, p. 1780.

Armentrout, J. M. and Suek, D. H. 1985 Hydrocarbon exploration in western Oregon and Washington AAPG Bulletin v. 69, pp. 627-663.

McFarland, C. R. 1983 Oil and gas exploration in Washington 1900-1982, Information Circular 75, Washington Department of Natural Resources.

Johnson, S. Y. 1985 Eocene strike-slip faulting and non-marine basin formation, and sedimentation in Washington. In Biddle, K. T., and Christie-Blick, N. (ed.s): Strike-slip deformation, basin formation, and sedimentation, SEPM Special Publication 37, pp. 283-302.

Johnson, S. Y., Tennyson, M. E., Lingley, W. S., and Law, B. E. 1997 Petroleum geology of the state of Washington, U. S. Geological Survey Professional Paper 1582.

Johnson, S. Y., Dadisman, S. V., Childs, J. R., and Stanley, W. D. 1999 Active tectonics of the Seattle Fault and central Puget Lowlands-Implications for earthquake hazards GSA Bulletin v.111, pp.1042-1053.

Kvenvolden, K. A., Rapp, J. B., Hostettler, F. D., and Snavely, P. D 1989 Comparison of molecular markers in oil and gas extracts in Preliminary Evaluation of the Petroleum Potential of the Tertiary Accretionary Terrane, West Side of the Olympic Peninsula, Washington USGS Bulletin 1892.

McNeil, LC, Godfinger, C, Kulm, LD, and Yeats, RS 2000 Tectonics of the Neogene Cascadia forearc basin: Investigations of a deformed late Miocene uncoformity GSA Bulletin v.112, pp 1209-1224.

Niem, A. R. and Snavely P. D. 1991 Geology and preliminary hydrocarbon evaluation of the Tertiary Juan de Fuca basin, Olympic Peninsula, northwest Washington: Washington Geology v. 19, no. 4, pp. 27-34.

Niem, A. R., McKnight, B. K., and Meyer, H. J. 1994 Sedimentary, volcanic, and tectonic framework of forearc basins and the Mist Gas Field, northwest Oregon In Swanson, D. A. and Haugerud, R. A. (ed.s) Geologic field trips in the Pacific Northwest: 1994 Geological Society of America Annual Meeting.

Palmer, S. P., and Lingley, W. S. 1989 An assessment of the oil and gas potential of the Washington outer continental shelf, Washington Sea Grant Progam, 83 pp + plates.

Trehu, A. M., Asudeh, I., Brocher, T. M., Luetgert, J. H., Mooney, W. D., Nabelek, J. L., and Nakamura, Y. 1996 Crustal architecture of the Cascade Forearc http://quakes.oce.orst.edu/papers/cascadia.science/science.

Snavely, P. D. and Kvenvolden, K. A. 1989 Geology and hydrocarbon potential in Preliminary Evaluation of the Petroleum Potential of the Tertiary Accretionary Terrane, West Side of theOlympic Peninsula, Washington USGS Bulletin 1892.

Stanley, W. D., Gwilliam, W. J., Latham, G., and Westhusing, K. 1992 The southern Washington Cascades conductor-a previously unrecognized thick sedimentary sequence? AAPG Bulletin v. 76, pp 1569-1585.

Walsh, T. J. and Lingley, W. S. 1991 Coal maturation and the natural gas potential of western and central Washington, Open File Report 91-2, Washington Department of Natural Resources.

Yeats, R. S., Kulm, L.D., and Goldfinger, C 1998 Stonewall anticline: An active fold on the Oregon Continental shelf GSA Bulletin, v 110, pp. 572-587.

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