Appendix 7: Comparison of Queen Charlotte Basin Petroleum Situation with Other Offshore Basins[5]

1. COOK INLET (ALASKA)

The following information is extracted and reworked in part from Magoon, (1994) and Thompson et al. (1991).

Overview

Geographically, Cook Inlet on Alaska's southern coast is bordered to the northwest by the Alaska-Aleutian Range and Talkeetna Mountains, and the Kenai Peninsula-Kenai Mountains on the southeast (Figure 14). Discovery of the first field was in 1957 at Swanson River, and the subsequent history of petroleum exploration and geology in the area has been discussed by numerous studies (e.g., Magoon and Claypool, 1981; Magoon and Egbert, 1986; Magoon and Kirschner, 1990). Hydrocarbon production is from six oil fields (Trading Bay, McArthur River, Middle Ground, Granite Point, Beaver Creek, Swanson River) and three gas fields in upper Cook Inlet. Oil fields occur near the basin margin, where Tertiary reservoir rocks unconformably overlie Middle Jurassic source strata (Figure 22.3). Several accumulations are also in Oligocene-Miocene sandstones within thrust faulted Pliocene anticlines (similar to Queen Charlotte Basin).

Total petroleum resources (produced and remaining) in Cook Inlet are 2.2 Bbbl of oil and 10 Tcf of gas (Magoon and Kirschner, 1990). The largest accumulations are the McArthur River oil field (570 Mbbl) and the Kenai gas field (2.3. Tcf), both of comparable magnitude to largest fields predicted for Queen Charlotte Basin (Hannigan et al., 1998). Exploration is based on a two-part geological model of Magoon and Claypool (1981):

1) Burial and maturation of Jurassic source rocks occurred during Cretaceous and Early Tertiary, followed by updip migration of hydrocarbons into conglomerate and sandstone reservoirs of Oligocene age;

2) Hydrocarbons remobilized during Pliocene and Pleistocene deformation, filling new traps created in faulted anticlines and upturned stratigraphic pinchouts.

[5] Submission to Dr. D. S. Strong, Chair, Scientific Review Panel, BC Offshore Hydrocarbon Development prepared by Dr. Michael J. Whiticar, School of Earth and Ocean Sciences, University of Victoria, BC December, 2001.

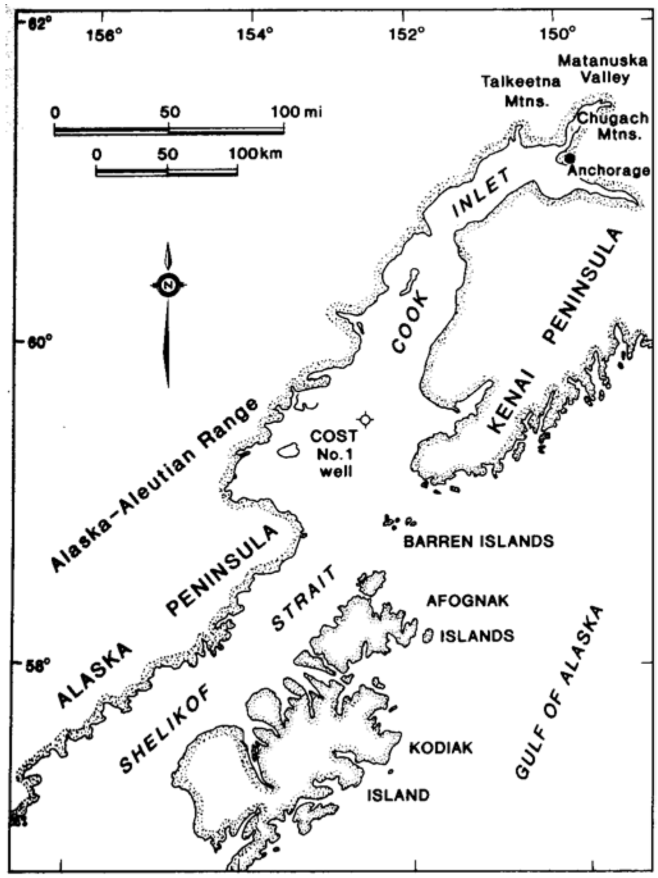

Figure 14: Geography of the Cook Inlet region, Alaska (modified from Magoon and Egbert, 1986, Fig. 32).

Figure 1. Location map of Cook Inlet, Alaska, (after Magoon and Egbert, 1986

Basin History and Stratigraphy

Cook Inlet evolved from a backarc basin setting during Mesozoic time to a forearc basin in the Cenozoic. During the Mesozoic, the Aleutian Range-Talkeetna Mountain magmatic arc was active producing mainly volcanic flows and volcaniclastic sediments, as well as sand, silt, and gravel all rich in feldspar and lithic fragments. Four sequential tectonic episodes are defined by unconformities separating clastic successions from Early Cretaceous to late Cenozoic. Cretaceous strata are mostly marine while Tertiary strata are predominantly nonmarine. Cross section (Figure 22.4) shows the generalized structural style with numerous high-angle reverse faults indicating considerable compression throughout the Mesozoic and Cenozoic with minor normal faults near the Swanson River field.

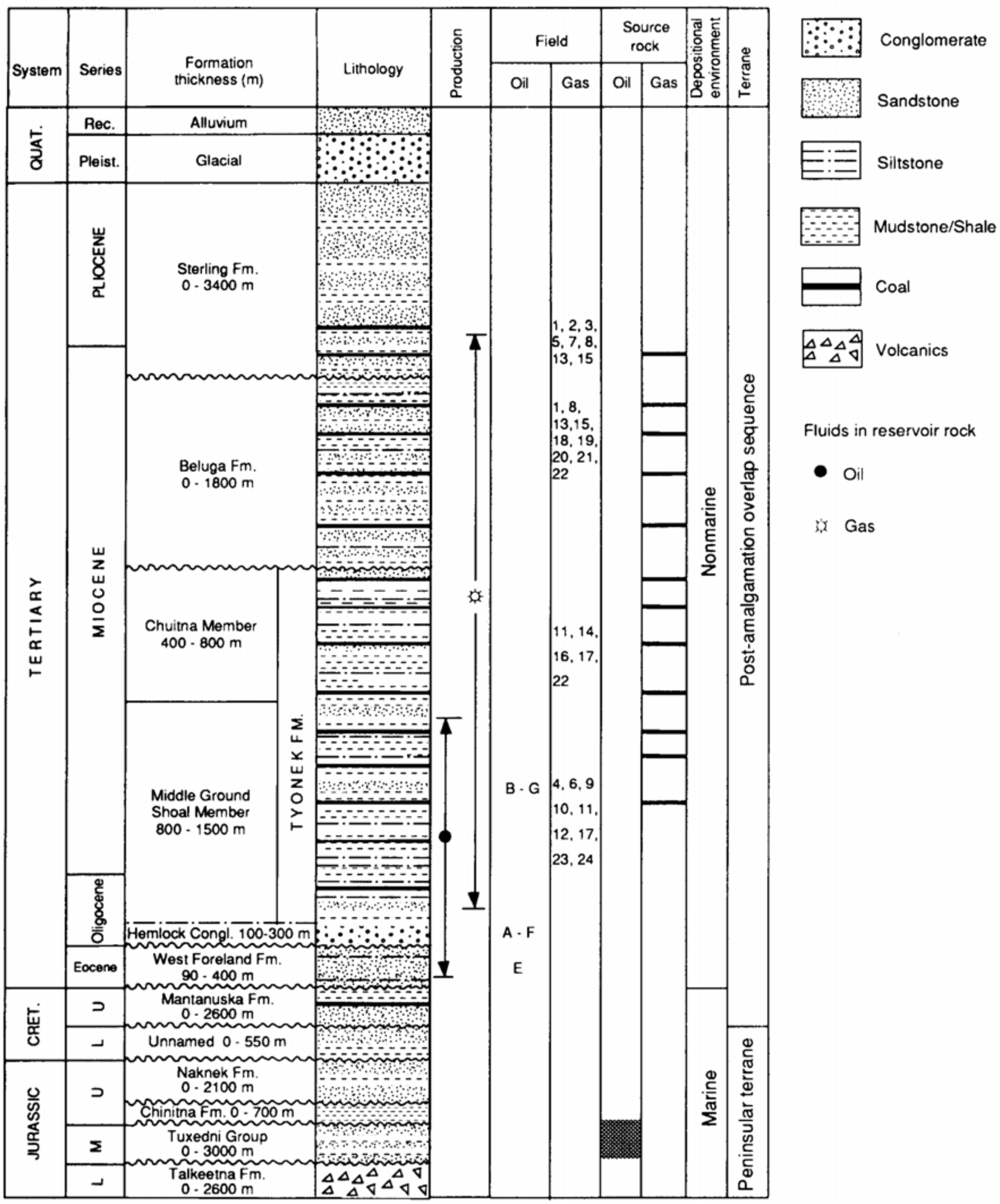

Figure 2. Statigraphic column for Cook Inlet (from Magoon, 1994)

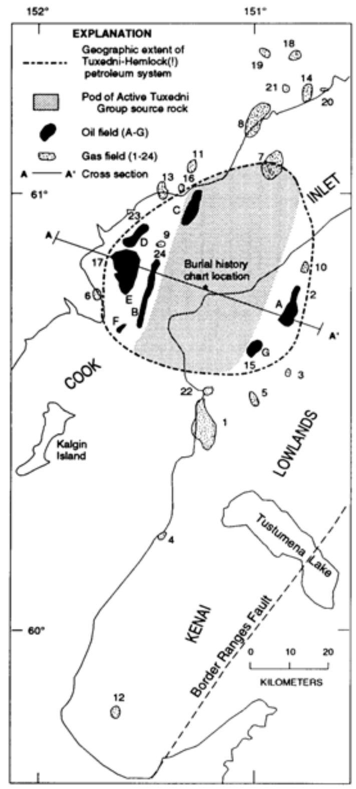

Figure 3 Cook Inlet oil and gas fields (from Magoon, 1994)

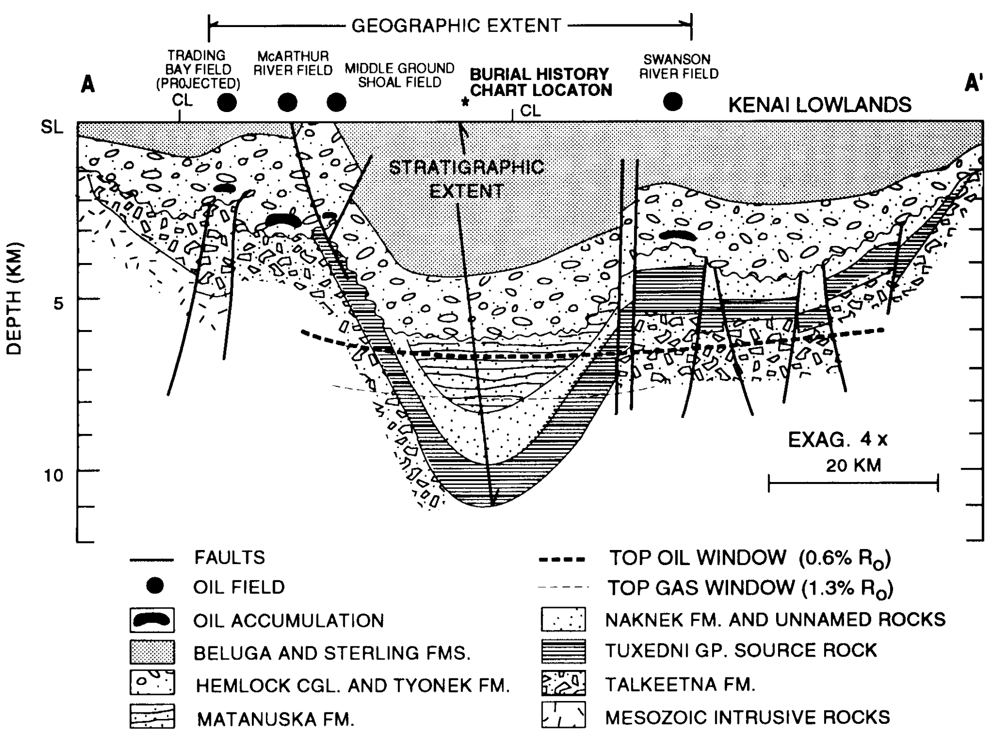

Figure 4 Geological cross section of Cook Inlet showing oil window maturity (from Magoon, 1994).

The Lower Jurassic Talkeetna Formation comprised of volcaniclastic sediments (along with the Alaska-Aleutian batholith) act as the economic basement for the petroleum province. The Tuxedni Group (dark gray, clay-rich siltstone) of Middle Jurassic age is important as the primary source rock for commercial oil deposits in the region. Upper Jurassic Naknek Formation contains a high percentage of feldspathic sandstone and conglomerate, but due to laumontite cementation is considered a poor reservoir (Bolm and McCulloh, 1986). An unconformity separates the Lower Cretaceous rocks from the Upper Cretaceous sequences, with the sandstone Matanuska and Kaguyak Formations containing little organic matter but do, in some places, act as a potential reservoir. Another unconformity separates Upper Cretaceous from Cenozoic strata. The West Foreland Formation consists of tuffaceous conglomerates to siltstones with minor amounts of coal. The Hemlock conglomerate is conglomeratic sandstone, with the Tyonek, Beluga, and Sterling formations comprised of varying amounts of sandstone, siltstone, shale and coal. Each of these rock units is a reservoir for oil or gas somewhere in the basin.

Petroleum System

The Tuxedni Group underlies most of Cook Inlet east of the Middle Ground Shoal oil field and subcrops in beneath Cenozoic strata east of Swanson River (Figure 22.4). Thickness is estimated at 1 km in the deepest part of the basin between the McArthur River and Swanson River fields. Thermal maturity of the source rock ranges from immature to mature, with TOC ranging from 2.1 wt% for immature samples to 0.9 wt% for mature samples. Based on basin modeling of Magoon (1994), the top of the oil window was reached during the Paleocene (63 Ma) and the gas window was achieved in the late Miocene (10 Ma).

Approximately 80% of recoverable oil is contained in the Hemlock Conglomerate, 20% in the Middle Ground Shoal member of the Tyonek Formation, and minor amounts in the West Foreland. Average porosity for conglomeratic sandstones is 17% (12-22%), with average permeability of 80 md (10-360 md). Seal rocks for most oil accumulations are presumed to be siltstones of the West Foreland and Tyonek Formations, and underclays associated with coals within the Tyonek Formation. Typical pools are located in faulted anticlines at average drill depths of 2560 m. A typical oil has an API gravity of 34 +/- 6 degrees, a gas-oil ratio (GOR) of 600 (175-3850), sulfur content of 0.1%.

Migration of oil is inferred based on cross sections and burial history models. Source rocks are currently within the gas window, although very little gas appears to have been generated (GOR <1000). Oil generated over the last 63 Ma has migrated updip to the flanks of the basin, and trapped stratigraphically until structural traps formed during Miocene deformation (10 Ma). Oil generated or migrated before deposition of the Hemlock Conglomerate (30 Ma) could have been lost to erosion. Based on a synclinal basin geometry, oil migrated laterally through sandstone within the source rock or in the overlying Naknek Formation to the Cretaceous-Tertiary unconformity, across the unconformity, through the West Foreland Formation and into the Hemlock Conglomerate.

A model similar to Cook Inlet may apply to the Queen Charlotte Basin. Thompson et al. (1991) noted that surface mapping showed some fault-bounded blocks have been stripped of Middle Jurassic strata, placing Triassic/Jurassic Kunga-Maude source rocks adjacent to potential Cretaceous reservoir strata. Applying this to offshore areas creates a scenario much like that in Cook Inlet, whereby source rocks are overlain unconformably by Lower Cretaceous and Tertiary sandstones (Figure 16). One could expect updip migration of hydrocarbons into overlying sandstones and possible secondary migration along the youngest set of Tertiary extension faults. Pliocene deformation in both basins has produced faulted anticlines which can constitute traps for oil and gas accumulation.

Similarities to Queen Charlotte Basin

- Basins evolved in intra-arc and forearc settings
- Jurassic source beds
- Cretaceous and Tertiary clastics for reservoir beds
- Major regional unconformities on top of Upper Jurassic/Lower Cretaceous and Upper Cretaceous sequences

- Variety of type and stratigraphic distribution of oil shows (e.g. seeps)
- Timing of oil generation and migration (late Tertiary, after burial of Jurassic source rocks beneath thick cover of Tertiary strata)
- Traps include faulted anticlines as a result of Pliocene deformation/compression

Hannigan et al. (1998) and Dietrich (1995) also note that Mist Lake gas field in the forearc Willamette Basin of northern Oregon occurs in Eocene sandstones with compositional and reservoir characteristics of Neogene sandstones in the Queen Charlotte Basin.

Differences to Queen Charlotte Basin

- Neogene tectonic/structural history. During Eocene, a regime of convergence accompanied by subduction gave way to northward transcurrent motion of oceanic plates along the continental margin replacing the forearc setting with a strike-slip margin in the Queen Charlotte region. Cook Inlet contains comparatively fewer strike-slip related extensional faults (Hannigan et al., 1998).
- Source rock distribution in Queen Charlotte Basin is more sporadic due to heating associated with Middle Jurassic plutonism and uplift and erosion of source strata during Late Jurassic and Cretaceous.
- Quality of seismic data for Queen Charlotte Basin is considered to be insufficient to assess the thickness, distribution, and structure of pre-Tertiary source and reservoir strata.

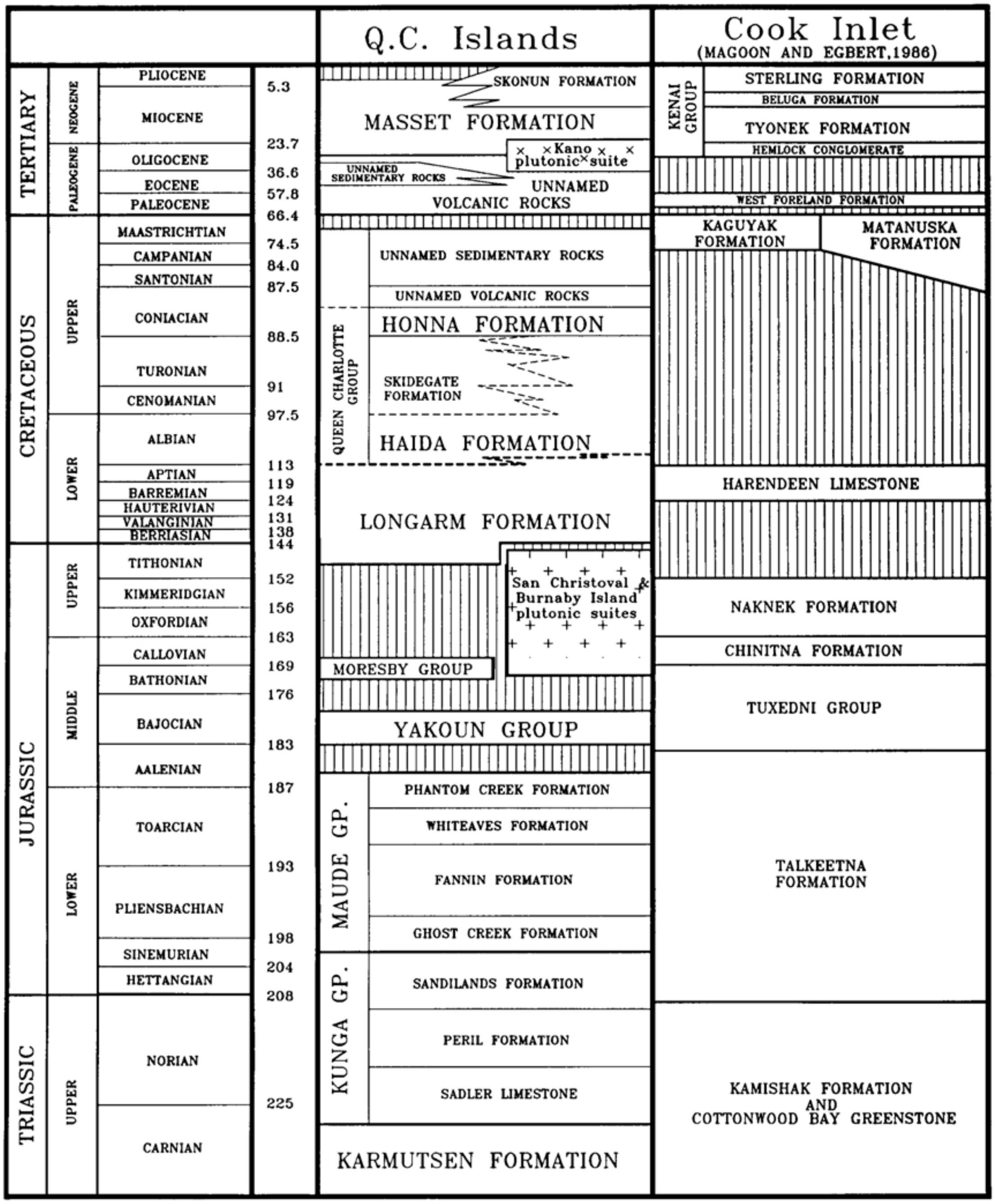

Figure 6. Comparison of geologic stratigraphic columns of Cook Inlet and Queen Charlotte Basin (after Magoon and Claypool, 1981 and Magoon and Egbert, 1986)

2. CALIFORNIA

Biostratigraphic studies indicate correlations with basins in southern California and northern Mexico (Hamilton and Cameron, 1989).

Petroleum geology of Great Valley and southern California continental borderland basins may provide useful comparisons based on similar age and tectonic setting (Hamilton and Cameron, 1989). The Queen Charlotte Basin has been compared to the borderland based on similar Neogene tectonic history and structural characteristics (Rohr and Dietrich, 1992). Several Neogene strike-slip basins occur in the California borderland region including the oil rich Los Angeles Basin estimated at 10 Bbbl (Biddle, 1992). The primary difference between the basins is type of source rocks, thereby limiting comparison of petroleum yield estimates. However, strike-slip basins are considered to be above average in terms of hydrocarbon potential.

3. EAST COAST

Hannigan et al. (1998) note that no direct analogues can be drawn between the Queen Charlotte Basin and other Canadian oil provinces. In ranking median recoverable resource estimates, the Queen Charlotte Basin with 2.6 Bbbl of oil and 20 Tcf of gas has a gas endowment comparable to the Scotian Shelf (18 Tcf, Wade et al, 1989) and oil reserves of about half those in the Jeanne D'Arc Basin (4.7 Bbbl, Sinclair et al., 1992). The Jeanne D'Arc also contains an estimated 13 Tcf of gas along with 1 Bbbl of oil for the Scotian Shelf. All these basins are overshadowed by a potential 7 Bbbl of oil and 68 Tcf of gas proposed for Beaufort-MacKenzie Basin in the Canadian Arctic (Dixon et al, 1994).

References

Armentrout, J.M. and Suek, D.H. 1985. Hydrocarbon exploration in western Washington and Oregon. AAPG Bulletin, v.69, p. 627-643.

Biddle, K.T. 1992. The Los Angeles Basin. In: Active Margin Basins, K.T. Biddle (ed.), AAPG Memoir, 32, p. 5-23.

Bolm, J.G. and McCulloh, T.H. 1986. Sandstone diagenesis. In: Geologic Studies of the Lower Cook Inlet COST No. 1 Well, Alaska Outer Continental Shelf. L.B. Magoon (ed.), USGS Bulletin 1596, p. 51-53.

Dixon, J., Morell, G.R., Dietrich, J.R., Procter, R.M., and Taylor, G.C. 1994. Petroleum resources of the Mackenzie Delta and Beaufort Sea. Geological Survey of Canada Bulletin 474, 44 pgs.

Magoon, L.B. 1994. Tuxedni-Hemlock petroleum system in Cook Inlet, Alaska, U.S.A. In: The Petroleum System – From Source to Trap. L.B. Magoon and W.G. Dow (eds.). AAPG Memoir, 60, p. 359-370.

Magoon, L.B. and Claypool, G.E. 1981. Petroleum geology of the Cook Inlet Basin: an exploration model. AAPG Bulletin, v.65-6, p. 1043-1061.

Magoon, L.B. and Egbert, R.M. 1986. Framework geology and sandstone composition. In: Geologic Studies of the Lower Cook Inlet COST No. 1 Well, Alaska Outer Continental Shelf. L.B. Magoon (ed.), USGS Bulletin 1596, p. 65-99.

Magoon, L.B. and Kirschner, C.E. 1990. Geology and petroleum resource potential of six onshore Alaska provinces. USGS Open File Report 88-450T.

Sinclair, I.K., McAlpine, K.D., Sherwin, D.F., and McMillan, N.J. 1992. Petroleum resources of the Jeanne D'Arc Basin and environs: Part I: Geological Framework. Geological Survey of Canada, Paper 92-8.

Thompson, R.I., Haggart, J.W., and Lewis, P.D. (1991). Late Triassic through early Tertiary evolution of the Queen Charlotte Basin, British Columbia. In: Evolution and Hydrocarbon Potential of the Queen Charlotte Basin, British Columbia. G.J. Woodsworth (ed.). Geological Survey of Canada, Paper 90-10, p. 3-29.

Wade, J.A., Campbell, G.R., Procter, R.M and Taylor, G.C. 1989. Petroleum resources of the Scotian Shelf Geological Survey of Canada, Paper 88-19, 26 pgs.

Zieglar, D.L. and Spotts, J.H. 1978. Reservoir and source bed history of Great Valley, California. AAPG Bulletin, v.62, p. 813-826.