Petroleum geology framework, West Coast offshore region

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ABSTRACT

The west coast offshore region of western Canada is a large, relatively-unexplored frontier hydrocarbon province. It includes Queen Charlotte (QC) and Georgia basins on the continental shelf inboard of Queen Charlotte Islands and Vancouver Island, and Tofino and Winona basins on the continental shelf and slope west of Vancouver Island (*Fig. 1*). A number of exploration wells drilled on Queen Charlotte Islands and in the adjacent offshore region during the 1950s and 1960s had hydrocarbon shows in Tertiary strata; an offshore-exploration moratorium imposed in the early 1970s, however, has limited subsequent exploration.

The QC Basin is the best-studied basin in the region, and it appears most prospective. Government-based integrated geoscience studies of the QC Islands and adjacent offshore region over the past 15 years have demonstrated that this basin, at least, likely contains an important hydrocarbon system, with estimated total recoverable resources of 2.6 billion barrels of oil and 20 Tcf of gas from the Tertiary succession alone. Some of our studies also indicate the underlying Mesozoic succession in western QC Sound may be even more prospective. Studies indicate both the Tertiary and the underlying Mesozoic succession are prospective.

Oil and tar seeps are known from virtually all stratigraphic units found on the islands. Although the offshore wells encountered hydrocarbon stain in Tertiary strata, the underlying Mesozoic strata were virtually undrilled.

Rocks present on QC Islands, and inferred from stratigraphic and geophysical considerations to be present in the adjacent shelf regions, include a thick and remarkably complete succession of Mesozoic and Tertiary sedimentary and volcanic strata, with minor metamorphosed Paleozoic igneous and sedimentary rocks exposed locally (*Fig. 2*). Economic basement is the thick (ca. 2500 m) and geographically-widespread Upper Triassic Karmutsen Formation volcanic

succession, consisting of flood basalts with interstratified reefal limestones at the very top.

Conformably-overlying uppermost Triassic to Lower Jurassic carbonate and clastic strata are widespread and approximately 1 kilometre in thickness. They include good to excellent petroleum source rocks with abundant Type I and Type II organic matter, with TOC values up to 11% locally. Middle Jurassic volcanic and sedimentary strata are widespread, but Upper Jurassic volcanics and clastics are much more restricted; neither of these units contains high-quality source or reservoir rocks. The Cretaceous succession is approximately 3 km thick but contains only poor-quality source rocks with Type III organic matter and TOC values around 1% or less. In contrast, Tertiary clastic deposits, lying principally offshore, contain Type III and II organic matter, with TOC values averaging 1 to 1.5% (and locally much higher in coal-bearing zones). Carbonaceous mudstones with good source rock potential have been identified in the Tertiary succession in almost all wells in the basin.

Triassic-Jurassic source rocks range from thermally mature to overmature onshore, whereas Tertiary source rocks tend to be immature to mature (*Fig. 3*), depending on local proximity to Jurassic and Tertiary igneous plutons. Stratigraphic correlations, as well as gravity and seismic geophysical evidence, suggest that the Mesozoic source rocks continue offshore under western QC Sound. Oil expulsion and migration from the Mesozoic source rocks is known to have taken place during the Tertiary. Considering the apparent burial depths, and making realistic geothermal-gradient assumptions, around 40% of the offshore Tertiary basin fill is thus estimated to be within the oil window; the underlying Mesozoic source rocks are expected to vary from mature to overmature, depending on local burial depth and proximity to igneous plutons.

Potential reservoir strata are found in both the Cretaceous and Tertiary packages. Cretaceous marine sandstones include lithic arenites with secondary-porosity values of up to 15% locally, and fair to good permeability. Tertiary sandstones include both marine and non-marine facies and consist of arkoses and lithic arkoses, with very high primary porosity (up to 35% at some localities) and fair to good permeability. Cretaceous and Tertiary reservoir strata are interstratified with shales, clayey mudstones, and volcanic rocks which provide effective seals. The QC Basin's Tertiary succession is not over-pressured. Some Tertiary traps may have been breached by faults that are particularly abundant in Hecate Strait.

Late-1980s-vintage seismic data from QC Sound and Hecate Strait allow basin structures to be delineated, and provide control on Tertiary stratigraphy and basin geometry (*Fig. 4*). Jurassic-Cretaceous structural history onshore was dominated by block-faulting and associated large-scale folding and thrusting. Geological data suggest that Tertiary deformation onshore is dominated by block-faulting as well. Tertiary structures offshore appear to be characterized by

block-faulting and strike-slip faulting with large dip-slip components. These displacements, evident from seismic, gravity and geologic field evidence, account for the block-like structure of the Tertiary basin, with many depocenters of varying sizes and depths, and intervening structural ridges. These depocenters are small in Hecate Strait, but are up to some tens of kilometers across in western QC Sound, where caprock-cutting Neogene faults are correspondingly much sparser.

Hydrocarbon traps of both structural and stratigraphic varieties are expected in the offshore basin with large closures on some block structures. Regional magnetic data and geological correlations suggest that large Miocene plutons might exist in the subsurface of eastern QC Sound, potentially degrading the hydrocarbon potential. Thus, the prime exploration areas of QC basin are in Hecate Strait and western Queen Charlotte Sound. Regional stratigraphic correlations and gravity and seismic data suggest the latter area contains a favorable stack of Mesozoic and Cenozoic source, reservoir, and seal rock units, with comparatively little fault breaching. Tertiary reservoirs have the advantage of being shallow, and they may occur in many parts of the basin.

The Georgia basin is a thick Tertiary and Upper Cretaceous succession deformed in a Late Cretaceous to Tertiary thrust regime. Possible gas-prone source rocks are limited to rather poor intervals within the Cretaceous and Tertiary package, and subsurface strata are immature to mature. Potential reservoir strata abound in Cretaceous and Tertiary clastic-rich, marine and non-marine rocks, and folds associated with thrusts form structural traps. To date, only limited gas production has come from the basin.

The Winona (8 km-thick) and Tofino (>3 km-thick) basins also have limited gas potential. Source rocks in the Tofino basin contain Type III organic matter and, although good-quality reservoir rocks occur locally, diagenetic clays appear to limit porosity and permeability. Reservoir and source rock characteristics of the Winona basin are unknown. Underlying crust in these basins seems to be continental and transitional, some of the deeper rocks might be similar to the Mesozoic and older rocks on Vancouver Island, and deep burial provides for favorable to too-high levels of thermal maturation. Water depth and the precarious open-ocean setting of these basins limit their attractiveness as exploration targets.

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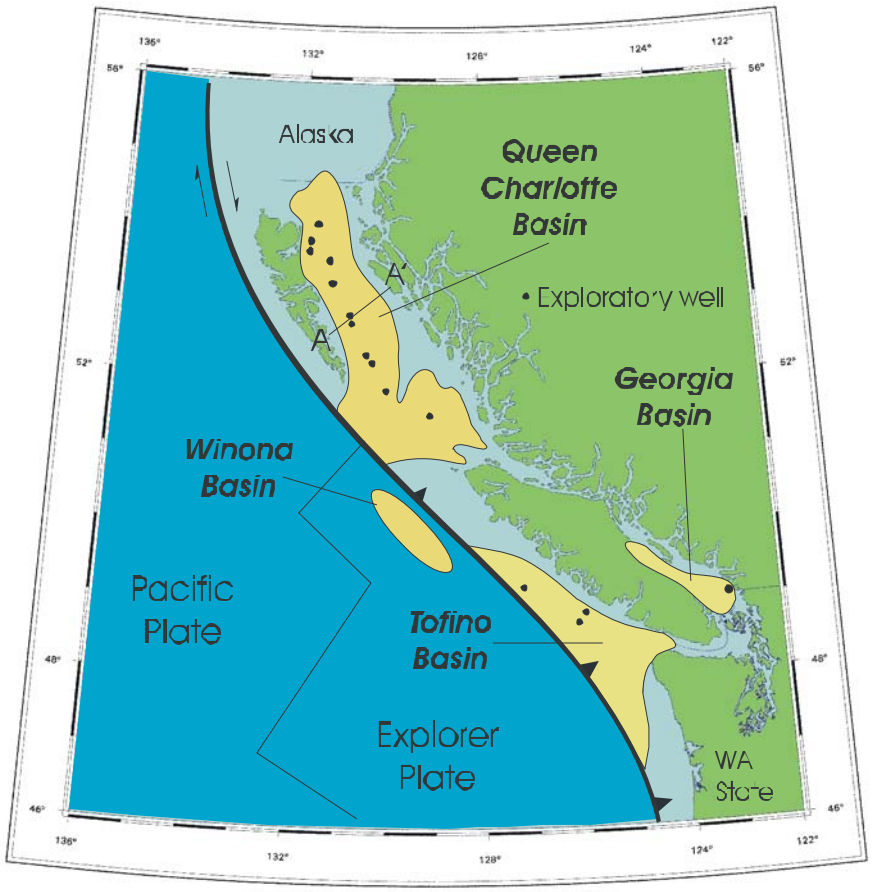

Fig. 1. Location map of hydrocarbon basins along the west coast of Canada.

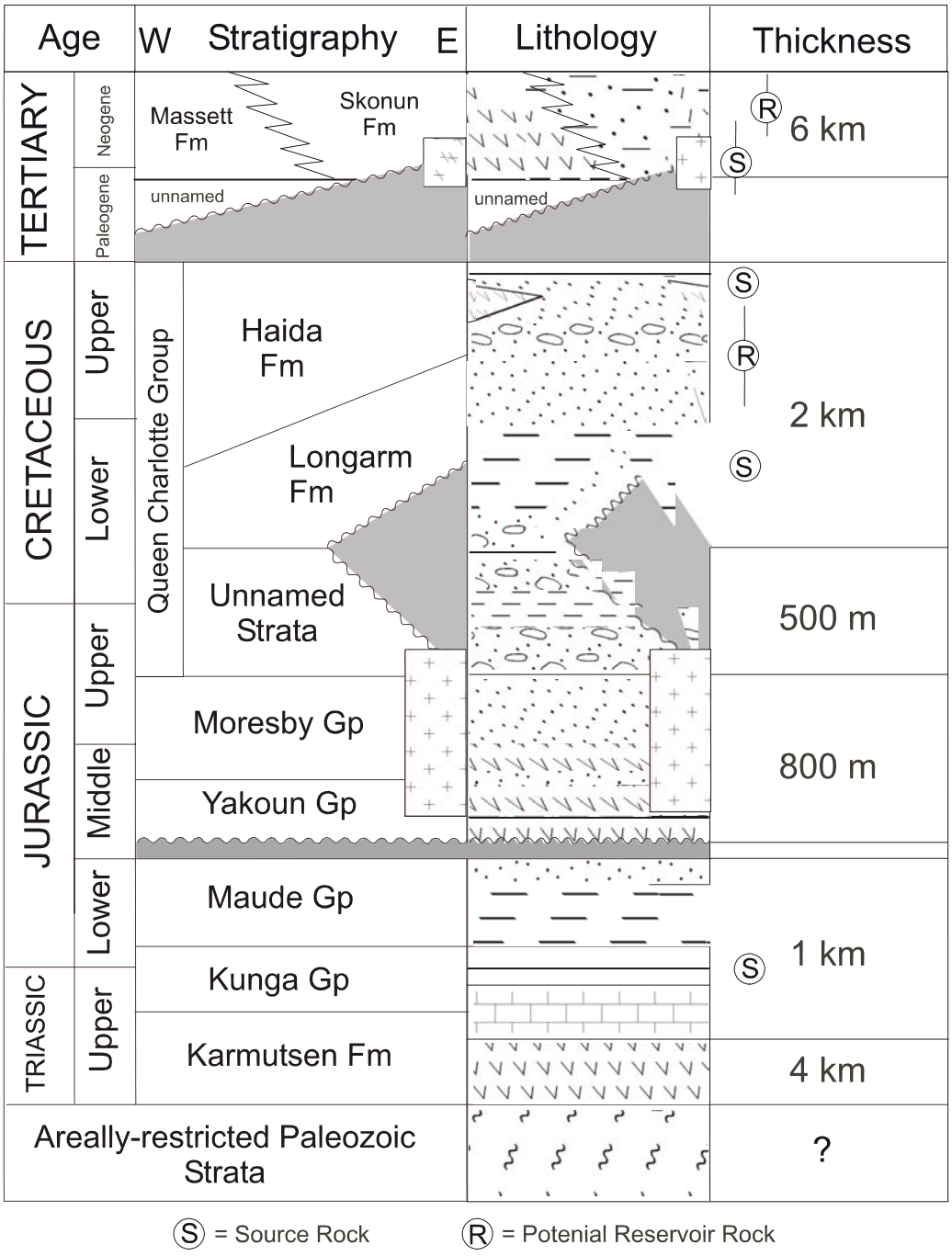

Fig. 2. Mesozoic-Tertiary stratigraphy of Queen Charlotte Islands and adjacent offshore region, British Columbia; modified after Dietrich (1995).

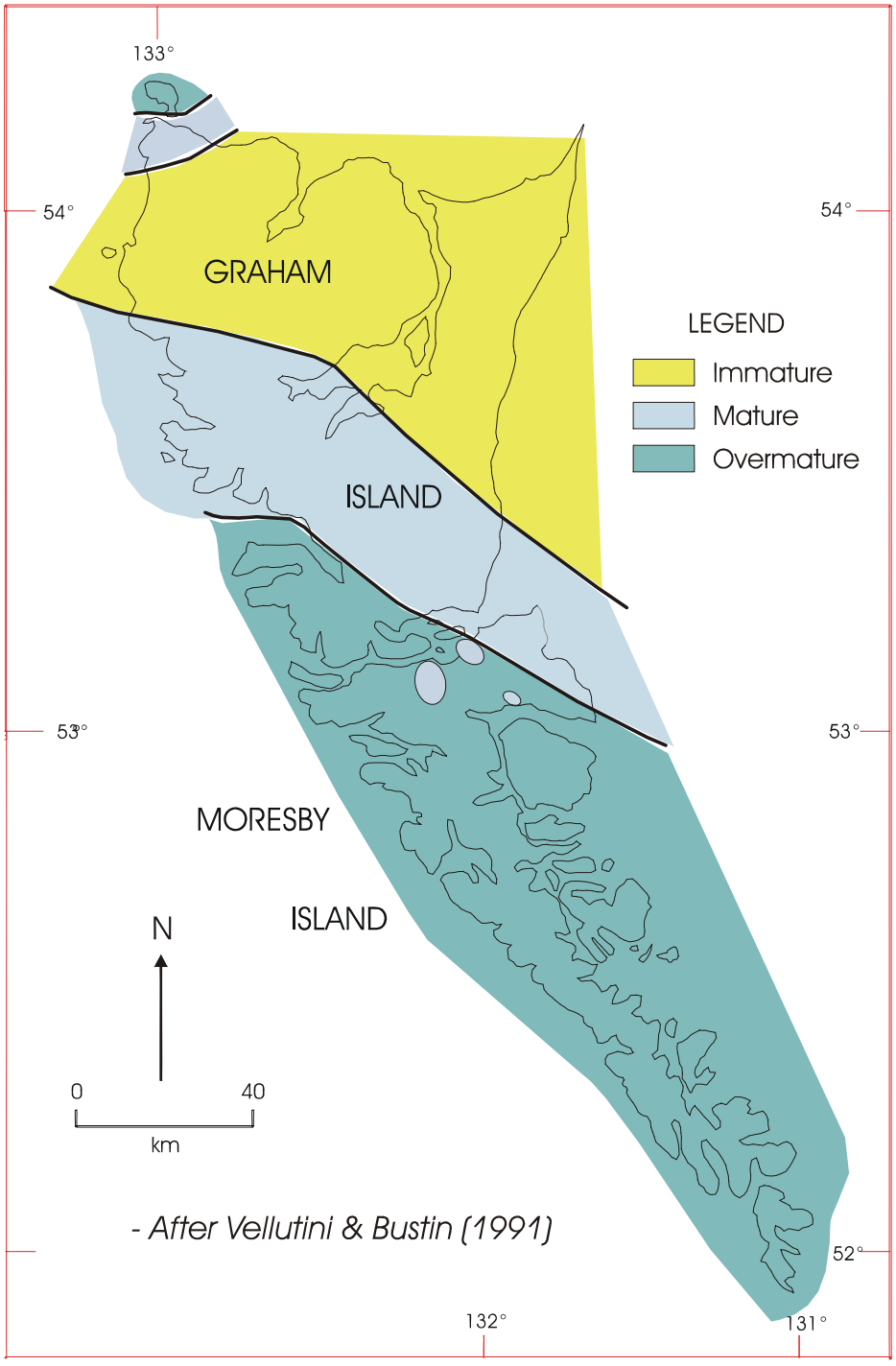

Fig. 3. Maturation trends for Mesozoic and Tertiary strata, Queen Charlotte Islands.

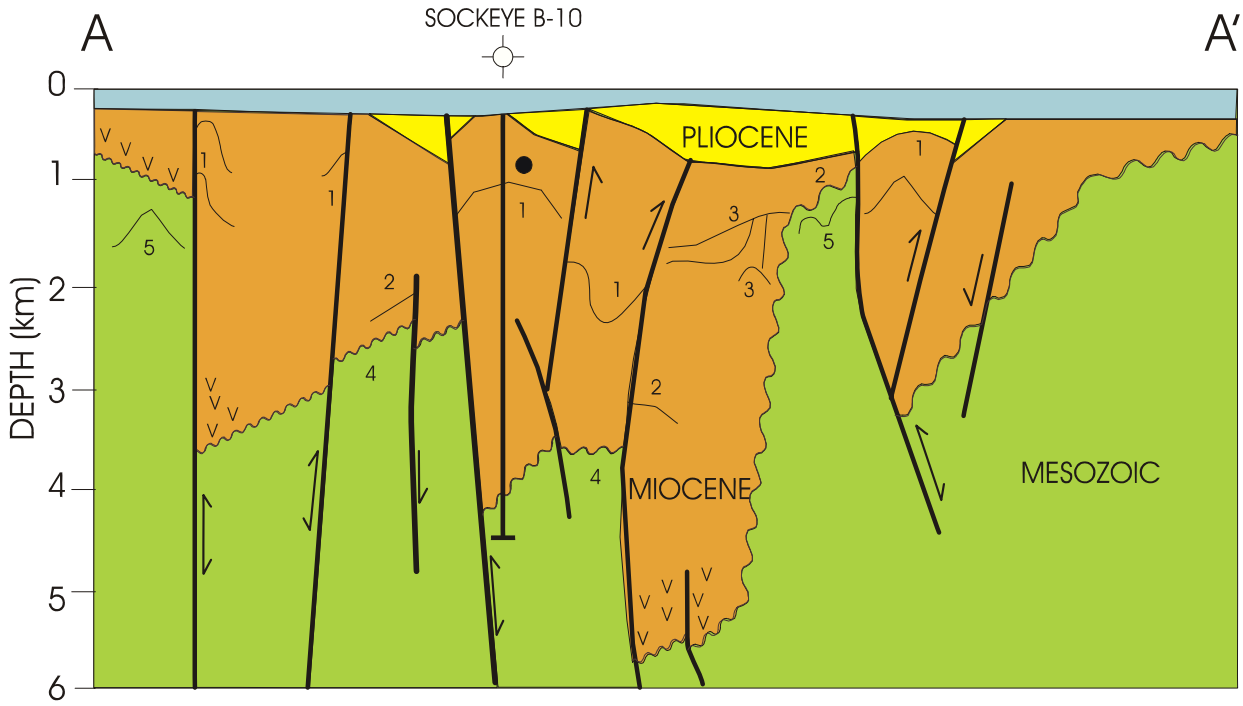

Fig. 4. Simplified structural cross-section for offshore region of Hecate Strait; from Hannigan et al. (1998), modified after Dietrich (1995). Location of line of cross-section shown on Fig. 1.