Analysis of Petroleum Generation Potential in Queen Charlotte Basin

Phase I Report: Broad-Scale Basin Characterization

1. Executive Summary

This 2-phase project, commissioned by the B.C. Ministry of Energy and Mines, creates a unified assessment using our Petroleum Systems Modeling of available geophysical, geologic and geochemical information for the Queen Charlotte Basin (QCB). The primary objective is to refine the definition of the most probable sectors of petroleum formation in the region. The report evaluates available data and reviews processes and important parameters, which influence hydrocarbon generation in the area. Due to the restriction of data coverage, this report encompasses ca. 23,000 km^2 of the approximately 65,000 km^2 area of the Queen Charlotte and Hecate Basins.

1.1 Approach

In this Phase I report we present our initial Petroleum Systems Modeling results and the assessment based on them. This represents the culmination of our efforts to

1. Identify the relevant existing information base, review and update
   a) the stratigraphic record based on well and outcrop reports
   b) the geologic-structural record based on seismic survey data and well samples

2. Apply the existing geophysical and tectonic framework using the available reflection seismic data, especially the 1988 MCS surveys by the Geological Survey of Canada (GSC)

3. Reconstruct the QCB burial history using a backstripping method based on the sediment stratigraphy established from the 8 offshore exploration wells and the regional seismic survey data

4. Input data into Petroleum System Model, including previously available information and that generated in this report on:
   a) QCB basin formation (structural-tectonic timing)
   b) sedimentary unit thicknesses and ages
   c) available sedimentologic parameters, e.g., sediment type (shale, sandstone, volcanic, etc.)
   d) source rock information (%TOC, kerogen types, maturity)
   e) heat flow history

5. Create 1D Petroleum Systems Models using IES PetroMod 8.0, with input data from the 8 offshore well, to estimate:

a) maturation history of source rocks
b) petroleum product formation thresholds and timing
c) spatial extent of oil and gas formation and occurrence

6. Regional (basin-wide) assessment of petroleum generation concept based on 1D Petroleum Systems Model results and 2D interpretations.

1.2 Primary Outcomes

The major outcomes of Phase I of this project are as follows:

1. Sufficient drill well, seismic data and outcrop information are available to make a reasonable, initial assessment of the conditions of the Cenozoic (Paleogene, Neogene) sedimentary package in Queen Charlotte Basin with respect to petroleum formation. This means that a rough mapping of the maturity of Tertiary-age rocks in the basin is possible, for today and over the past 60 Ma.

2. Considerable structural and sedimentological variability is recorded in the QCB. For example considerable differences are noted for the thickness of specific lithologic unit. In addition, important lateral facies changes are known for sediments of similar age. Some of this is recognized in the multi-channel seismic and drill well data.

   This heterogeneity severely limits the identification and definition of specific exploration plays. However, the available data permit a regional overview to be made, especially for the Cenozoic.

3. The information base on Mesozoic sediments is much more limited than for the younger units. The lack of drill well control, coupled with the poor seismic information on the older units, are serious constraints on the interpretation of the Jurassic and Cretaceous sequences. The estimations of petroleum formation for these older units are significantly less reliable.

4. There is some uncertainty in the heat flow history of the QCB, however, a reasonable estimation can be made and constrained by a) recent measurements of heat flow (Lewis, 1991), and b) the measurements of vitrinite reflectance on cuttings from the 8 offshore drill wells (Vellutini and Bustin, 1991a, b). In concert with burial history and timing, the heat flow history for the basin is critical for accurate prediction of maturation and generation. Fortunately, our studies have demonstrated that only the more recent heat flow (last ~10 Ma) is important for the maturation of Cenozoic sediments. This is due to the limited burial of early Tertiary sediments before the latest Oligocene/early Miocene.

5. Based on our models, we have defined 6 maturity stages for the QCB:
    a) Immature – no generation expected
    b) Marginally Mature – very limited and special generation, i.e., resinites
    c) Mature oil – generation of oil if appropriate source rocks present
    d) Mature oil + gas – generation of oil and gas if appropriate source rocks present
    e) Late mature – predominantly dry gas (methane) or condensate
    f) Overmature – overcooked source rocks, no generative potential remaining today

    The QCB Cenozoic package typically enters the top of the petroleum window today at or just deeper than 2,100 m (0.5 %Ro, Type II). Restricted, if any, production will result in the shallower Marginally Mature zone (1,200 to 2,100 m). The oil window (Mature, oil) today extends to depths of approximately 2,800 m (0.8 %Ro, Type II), while the Mature oil + gas window currently brackets 2,800 to 4,100 m. The bottom of this zone is deeper than most of the wells drilled in the QCB. Most of the offshore QCB wells encountered Cenozoic sediments which have a maturity of less than 0.8 %Ro, i.e., are in the formation stage of early petroleum window or younger. The Sockeye B-10 well is an exception in that at TD (4,773 m) the measured maturity of the sediments is ca. 2 %Ro.

    Based on the measured %Ro profiles for the wells, the Late Mature (gas window) in the QCB today is between 4,100 m and 4,800 m (1.2 – 2.0 %Ro, Type II). At greater depths any source rocks are overmature today, but may have generated hydrocarbons in the past. Only the Sockeye B-10 approaches the base of the gas generation zone.

    Any sedimentary units currently deeper than 4,800 m are likely Overmature. They have little, if any, generative potential remaining, but may have generated hydrocarbons in the past.

Table 1 Summary of expected present day Cenozoic maturity zonation depths

Maturity Zone	VR range (% Ro)	Minimum Depth (m)	Maximum Depth (m)
Immature	< 0.3	0	< 1,200
Marginally Mature	0.3 – 0.5	1,200	2,100
Mature (oil)	0.5 – 0.8	2,100	2,800
Mature (oil + gas)	0.8 – 1.2	2,800	4,100
Late mature (gas)	1.2 – 2.0	4,100	4,800
Overmature	> 2.0	>4,800	

Notes: 1) due to insufficient coverage, these maturity depths are calibrated for the Cenozoic units only. Mesozoic sequences may display different maturation profiles, but this is not known.
2) generally valid only for oil prone Type II kerogens. Humic Type III kerogens show different kinetic behavior.

6. Our modeling demonstrates that the maturation depth profiles of the Cenozoic units are relatively uniform across the basin, i.e., at any particular depth, the maturity will be approximately the same for different locations in the QCB. This reflects the more or less consistent, recent subsidence and heating history.

7. Variations in unit sediment thickness remain important to assess the amount of hydrocarbons generated. The maturation does not account for the volume or quality of the oil and gas – this is made by %Total Organic Carbon and Hydrogen Index.

8. By combining geochemical parameters with the stratigraphic history, we produce initial models for the formation of Cenozoic -sourced oil and gas for the QCB. It is important to note that this assessment is for the Cenozoic only, the Mesozoic will be addressed in Phase II of this project.

9. Based on the interpretation of existing information, extensive generation of oil and gas from Cenozoic units of the QCB is not basin-wide, rather it is more restricted to specific sections of the basin. The Neogene-age areas expected to be most productive in forming oil and gas is in a fairway approximately 75 km wide and 380 km long that extends northwest to southeast roughly parallel to the axis of Hecate Strait (Figure 1). This corresponds to an approximate area of 23,000 km^2. Our initial assessment indicates that region more to the western side of the Strait is rated more favourably than the

eastern side, including the mainland coast. This is consistent with other reports, including evaluations by the GSC (e.g., Hannigan et al. 2001)

It is important to note that this stage of our assessment does not address the migration or trapping histories in the QCB, and thus makes no prediction as to potential reservoir locations, frequency or sizes.

10. Our assessment of the present day region of interest for hydrocarbon generation from Cenozoic strata in the QCB is restricted to sectors with existing seismic and drill well coverage (study area). This represents only ca. 23,000 km^2 (dotted blue outline in Figure 1) of the approximately 65,000 km^2 area of the Queen Charlotte and Hecate Basins (dotted red outline in Figure 1), or ca. 60,000 km^2 area of the offshore region (Dixon Entrance, Hecate Strait and part of Queen Charlotte Sound, orange line in Figure 1).

    Our initial evaluation of the maturation of the Cenozoic strata in the study area suggests that ca. 72 % of these source rocks (ca. 16,700 km^2) presently have the maturity range for the generation of oil and/or gas. Approximately 4 % (ca. 770 km^2) are overmature and 24 % (ca. 5, 500 km^2) are undermature. These estimates are summarized in Table 2.

Table 2. Comparison of maturation zone areas in Cenozoic source rocks of Queen Charlotte Basin.

Present Day Cenozoic Source Rocks of Study Area of Queen Charlotte Basin	Approximate Area Neogene Strata in Study Area (km^2)	% of Neogene Strata in Study Area
Undermature (immature and marginally mature)	5,500	24
Mature (oil, gas and oil/gas)	16,700	72
Overmature	770	4

11. In this phase of the project, no detailed predictions of the Mesozoic are made. Although sediments deeper than 4,800 m today are likely overmature, there are periods of time in the history of the Mesozoic when they generated oil and gas. A complete treatment of the QCB requires careful consideration of source rocks and potential reservoirs from this era.

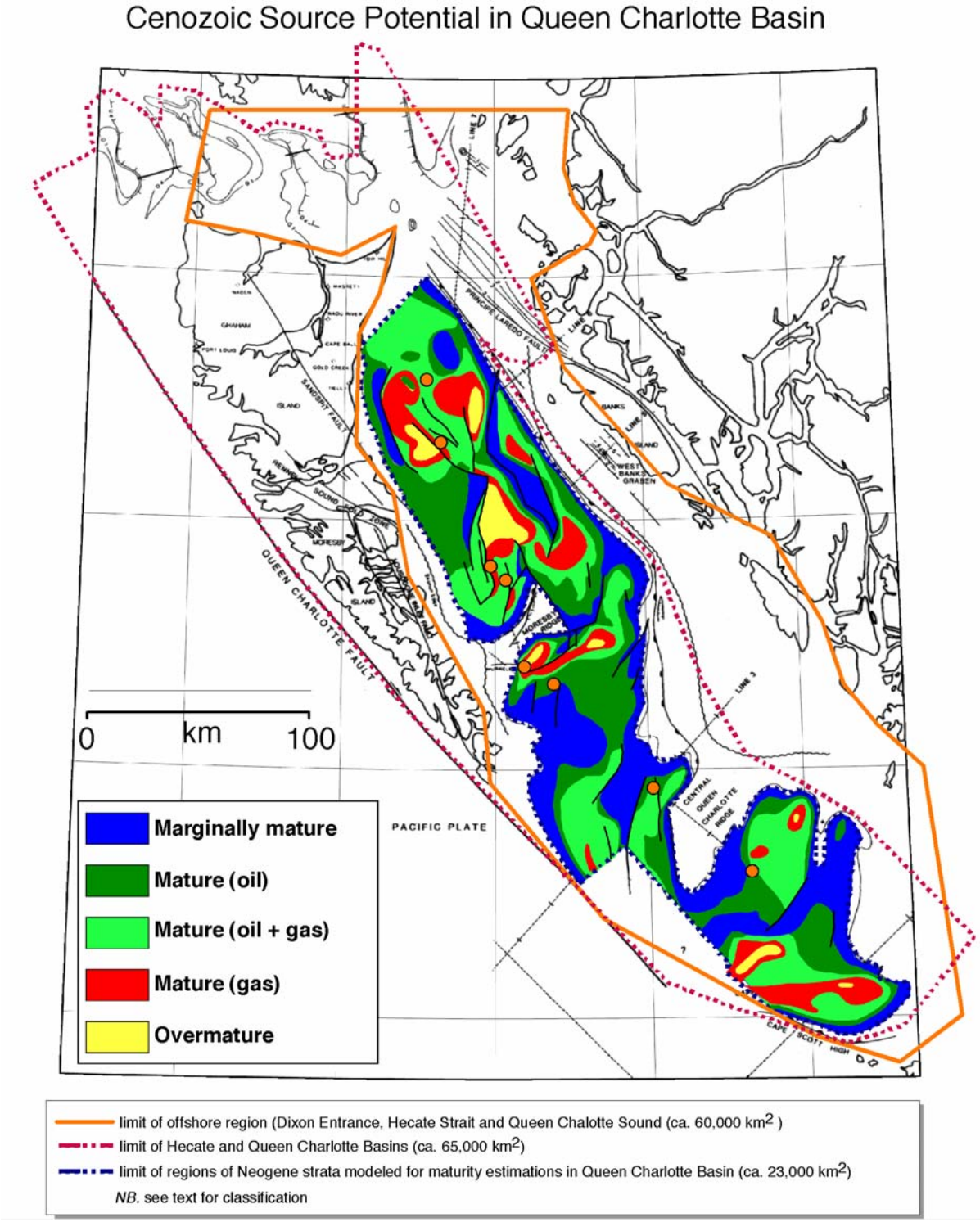

Figure 1. Map of Queen Charlotte Basin region showing the present day maturity zones of the Neogene sediment package and the outlines of the offshore region and the Hecate + Queen Charlotte Basin. The structural information is from Rohr and Dietrich (1992).

1.3 Constraints, Concerns and Challenges

1. Coverage of seismic reflection data for the QCB is essentially limited to 1000 km of multichannel seismic shot on 8 lines by the GSC in 1988. For a basin the size of the QCB and with its higher level of geologic complexity, this degree of coverage is inadequate.

2. Only 8 wells have been drilled offshore in the QCB, spaced over an approximate 300 km distance, roughly parallel to the axis of the basin. Some of these wells were drilled for stratigraphic reasons and not necessarily placed in locations elucidate the most information.

3. Offshore wells mostly terminate in Cenozoic (lower Tertiary) or uppermost Cretaceous units. No information or samples on the anticipated and important Jurassic marine source rocks (oil prone) is available.

4. Mesozoic tectonic and basin history, critical for the estimation of oil, is difficult to assess with existing information and data, including paleo-heat flow.

5. Timing of the Tertiary Rifting event is poorly constrained (early Miocene?). The basalts at this time have not been adequately dated and the fossil coverage is extremely poor at that time. The timing is important to define the start of the Paleogene subsidence and the onset of elevated heat flows. Fortunately, this timing is less of an issue for the assessment of the Tertiary package, than for the Mesozoic oil-prone source rocks.

6. The dating of the Skonun Fm, a critical sedimentary unit, needs updating.

1.4 Recommendations

At the end of Phase I we have identified several components that could definitely or potentially enhance the interpretation and assessment of the petroleum formation in the QCB. Most of these recommendations exceed the scope of this project, but are expressed here as positive steps that could be taken to improve the understanding of the basin. Generally these recommendations fall into three categories, A) Geophysics, B) Stratigraphy, and C) Geochemistry as follows:

A) Geophysics

1. Re-interpret the existing geophysical and tectonic framework using reflection seismic data, especially the 1988 MCS surveys by the Geological Survey of Canada (GSC) and possibly the recent UVic data (R. Chapman), to:

a) Provide the best resolution within the Tertiary and the Cretaceous sediments

b) Transfer the interpretation into a seismic interpretation system

This seismic information enhancement could involve a professional reprocessing of the reflection data, including improved velocity picks.

2. Attempt to re-evaluate the 1988 MCS seismic survey data using a refraction seismic mode to better delineate the basement and possibly Mesozoic intervals.

3. Incorporate additional seismic data shot in the QCB, such as the Chevron Texaco and Shell Canada seismic data. This data could provide critical infilling of information for the basin.

B) Stratigraphy

1. Reliable chronologies and age control is essential to interpret the basin evolution, including groundtruthing the geophysical information. Several attempts have been made to generate a chronostratigraphic framework for the basin using cuttings from the 8 offshore wells, albeit for the Cenozoic and latest Mesozoic only. There are significant inconsistencies between these various interpretations and findings that need to be resolved. This may involve re-analysis of specific horizons using the original cuttings and well logs.

2. A major deficiency in the petroleum assessment for the basin is the lack of reliable information on Mesozoic units. These are particularly important for the generation of oil, especially the Jurassic Kunga and Maude groups. source rocks. Recently, it has come to our attention that outcrops of these units may exist on land on the northern tip of Vancouver Island. It is highly recommended that these possible outcrops be visited, sampled and analysed.

C) Geochemistry

1. Pockmarks and petroleum seepages are well known, or suspected, on land and in the Hecate Strait of the QCB. These overt expressions of hydrocarbons can provide key information on the character of the petroleum deeper in the basin. Many of the seeps based on the Queen Charlotte Islands (QCI) have been examined and characterized, but little work has been performed on the seafloor indicators. These pockmarks have been mapped previously, including the extensive work by V. Barrie, GSC-Victoria. It is recommended that these pockmark sites be visited and sampled to analyse the character of any hydrocarbons emanating or residing in these features.

2. As part of this study of surface seepages, it is recommended that a hydrocarbon gas "sniffer" study be conducted in Hecate Strait. The instrumentation for this activity is substantial. The Australian AGSO have such a system, and we have been in contact with them to possibly arrange use of their system.

3. If Mesozoic source rocks are found on northern Vancouver Island, these should be analysed for their conventional geochemical source rock parameters (%TOC, RockEval-6, %Ro, etc.) If appropriate good samples should be used for kinetic maturation studies to characterize the generation profile of these source rocks.

4. Surface Geochemistry using sorbed gas characterization of surficial sediments of the Hecate Strait. This is a common exploration approach to map the geochemical expression of the subsurface, and to make predictions on the type and maturity of generated hydrocarbons. Such surveys potentially have the additional bonus of providing samples for environmental assessment work in the Hecate Strait. The primary limitation on this work is the poor surficial sediment quality. The regions of interest typically have sandy sediments at the surface, which are not suited to surface geochemistry. This places strong restrictions on the sampling locations, and needs to be considered beforehand.