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Field Collection and Geochemical Characterization of Potential Mesozoic Source Rocks on Northern Vancouver Island and the Queen Charlotte Islands

Report prepared for

University of Victoria (UVic) –
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Partnership Program

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Introduction

The Tertiary Queen Charlotte Basin (QCB) is located immediately inboard of the Pacific - North American plate boundary and comprises Dixon Entrance, Hecate Strait, and Queen Charlotte Sound from north to south (Figure 3). A network of fault-bound sub-basins in Hecate Strait and Queen Charlotte Sound contain up to 5 km of sandstones, siltstones and conglomerates with some coals, which are known as the Skonun Formation (Figure 1). Based on reflection seismic and well data the Skonun Formation has been divided into syn-rift and post-rift successions. Fossils indicate Miocene and Pliocene ages. At many locations, the basal sediments either interfinger or overly extensional basaltic rocks of the Masset Formation (Hickson, 1992; Hyndman & Hamilton, 1993). Masset rocks on Graham Island have yielded ages of 35-12 Ma; most fall between 25-20 Ma (Figure 1). Unfortunately no reliable dates are available from basalts drilled in the wells.

Upper Triassic / Lower Jurassic potential source rocks, mainly in the Peril, Sandilands and Ghost Creek formations from the Kunga and Maude groups as well as Cretaceous formations, are exposed on the Queen Charlotte Islands (QCI). Both the Sandilands and Ghost Creek formations comprise significant organic-rich petroleum source rocks in the region, which reach up to 600m in thickness with Total Organic Carbon (TOC) up to 6.1%, comprising oil-prone Type I and oil and gas-prone Type II kerogens with Hydrogen Index (HI) values ranging up to 589 mg HC/g C_{org} (Bustin & Mastalerz, 1995; Macauley, 1983; Snowdon etal., 2002, see also Figure 2). Organic-rich shales with 5 to 10% TOC occur in beds up to 10m thick (Dietrich, 1995). At least the Sandilands Formation is likely to occur in most parts of Hecate Strait and Queen Charlotte Sound (Cameron & Tipper, 1985, Woodsworth, 1988, Thompson et al., 1991, and Bustin & Mastalerz, 1995).

Most of the oil occurrences so far encountered in the region appear as surface seeps in Tertiary volcanic rocks of the Masset Formation on Graham Island (Hamilton & Cameron, 1989), but oil stains have also been encountered in Tertiary sandstones within the Sockeye B-10 well. Chemical compositions of these oils appear related to a Lower Jurassic source (Fowler et al., 1988, Snowdon et al., 1988, Hamilton and Cameron, 1989, Bustin and Mastalerz, 1995), which underlines the necessity to include Mesozoic strata into hydrocarbon assessment of the QCB.

Previous basin modeling studies of the hydrocarbon potential within the region of the Queen Charlotte Basin have shown the importance of the distribution and characterization of source rocks (e.g., Macauley, 1983, Vellutini and Bustin, 1991, Bustin, 1997, Whiticar et. al., 2003). Especially determination of type and kinetics of kerogen (constrain how it reacts to heating over time) dominant in the various source rocks has been proven to be crucial to generation and timing of hydrocarbons in the QCB (Whiticar et al., 2004). To establish better knowledge of such kerogen kinetics in the Mesozoic section source rock intervals have been sampled onshore during two field campaigns in 2004.

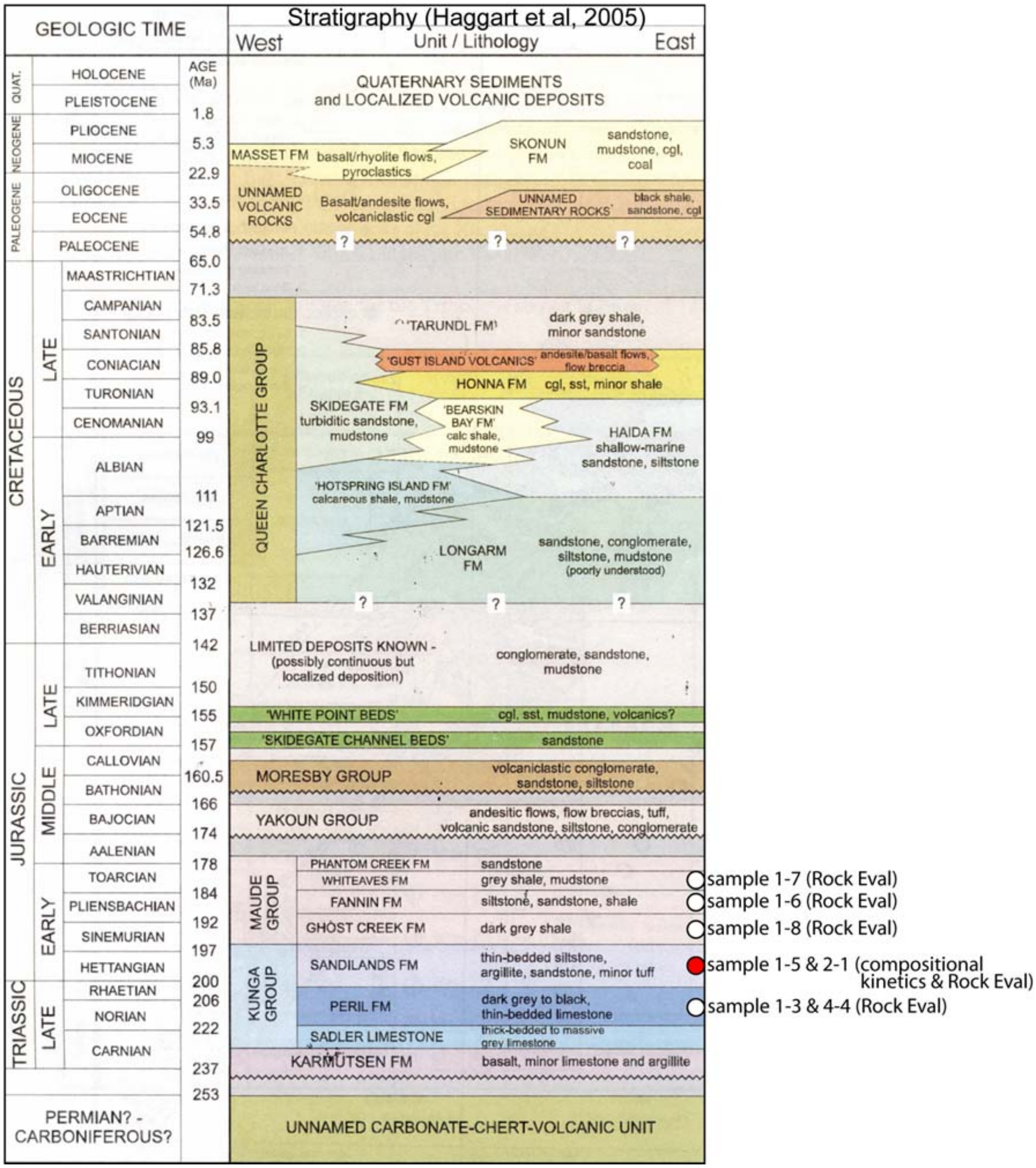

Figure 1. Generalized stratigraphy of Mesozoic (Triassic, Jurassic and Cretaceous) and Cenozoic (Tertiary) of the QCB (after Haggart etal., 2005).

Motivation for sampling campaign

It is important to note that the offshore wells are largely limited in depth to Tertiary units. It is anticipated that deeper in the basin there are Mesozoic (Triassic / Jurassic) units that have oil and gas prone Type II kerogens. Indirect evidence for this comes from:

1. Latest Triassic and Early Jurassic marine mud rocks of the Sandilands and Ghost Creek formations from the Kunga and Maude groups are found on the Queen Charlotte Islands. The Sandilands Formation is likely to occur in Hecate Strait and Queen Charlotte Sound (Cameron & Tipper, 1985, Woodsworth, 1988, Thompson et al., 1991)
2. Both Sandilands and Ghost Creek formations have high %TOC and have evidence of Type I and II kerogens with HI values ranging up to 589 mg HC/g C_{org} (Macauley, 1983; Bustin & Mastalerz, 1995; Dietrich, 1995, Snowdon etal., 2002).
3. Onshore oil shows have chemical compositions that appear related to a Lower Jurassic source (Fowler et al., 1988, Snowdon et al., 1988, Hamilton and Cameron, 1989, Bustin and Mastalerz, 1995).

Sediments of the Kunga and Maude groups comprise Latest Triassic and Early Jurassic organic-rich marine mud rocks (Peril, Sandilands, and Ghost Creek Fms.) which reach up to 600m in thickness, containing up to 10% TOC in some cases (Dietrich, 1995). The amount of organic matter present is critical to determine if sufficient generation will occur to make economic accumulations of petroleum, provided migration, trapping and preservation criteria are also met.

The compositional quality of the organic matter is critical to determine the type of petroleum formed, e.g., oil vs. gas. The proportion of hydrogen in the kerogen is an excellent measure of this proneness. Hydrogen-rich kerogen (Type I or II), as found in aqueous source rocks, forms oil more abundantly than low hydrogen or oxygen rich kerogens (Type III). The hydrogen index is frequently used to quantify the relative amount of hydrogen in the organic matter, and hence determine the kerogen type.

Data published for some source rock intervals reported from the QCI (Macauley, 1983 and Snowdon et al., 2002) reveal HI values in the range of 200 to 600, which clearly places them on typical trends for Type I/II kerogen (Figure 2).

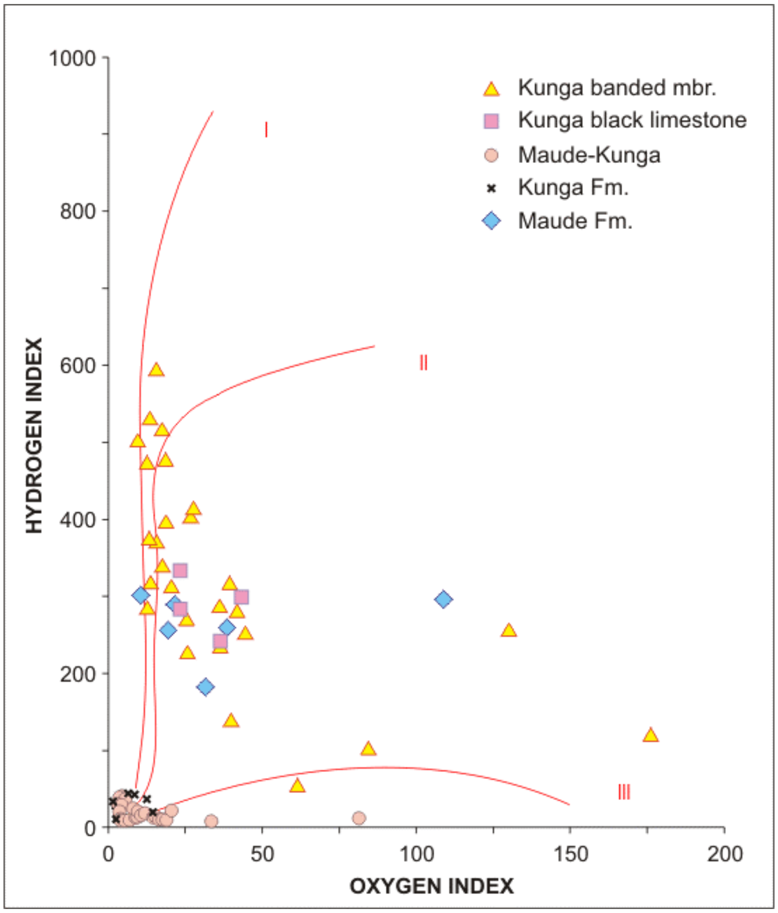

Figure 2. Published data for the source rock intervals reported from the Queen Charlotte Islands (Macauley, 1983 and Snowdon et al., 2002) reveal that the Mesozoic Kunga and Maude source rocks contain marine, Type II-dominated kerogens.

To furthermore characterize kerogen multi-compositional kinetics can be used, which enable to describe generated hydrocarbons as a function of activation energy (temperature). Such kinetic models allow an improved prediction of petroleum phases and composition, leading to better estimates for volumes and qualities (i.e. API gravity) of generated products, as calculated by Petroleum Systems Modeling (PSM).

Previous Petroleum Systems Modeling by UVic

Whiticar etal. (2003, 2004) have shown that younger sediments of the Skonun Formation are not likely to have produced extensive amounts of hydrocarbon, mainly due to insufficient burial and based on the assumed type of organic matter which requires higher activation energies (Type III, as determined by Bustin, 1997).

Older Mesozoic strata has only been encountered as bottom formation in one of the 8 offshore wells, which are largely limited in depth to Tertiary units. However, it is anticipated that deeper in the basin Mesozoic (Triassic/Jurassic) source rock intervals are present.

Whiticar etal. (2004) have recognized that older units in the basin, such as the late Triassic and Jurassic, may have suitable marine source rocks (Type II kerogen) for the substantial generation of oil and gas. As such, they are important to the petroleum situation of the QCB and therefore have been included their Petroleum Systems Model.

The lack of well control, coupled with poor seismic imaging of the older units, are serious constraints on the interpretation of Jurassic and Cretaceous sequences. Although the information base on Mesozoic sediments is much more limited than for the younger units Whiticar etal. (2004) have shown potential for hydrocarbon plays fed from Mesozoic sources.

As no source rock material from those older units has been available for detailed analysis previously, available characteristics from similar source around the world had to be used in accordance to data summarized in Bustin and Masterlerz (1995). Source rocks of the Ghost Creek and Sandilands formations were considered to be marine and their organic material has been assumed to be primarily type II kerogen (Whiticar etal., 2004). Distribution of activation energies was derived from well established comparable “literature kerogens” (see Whiticar etal., 2004 for details). While such an approach is common for frontier exploration areas, it is preferable to use kinetics tailored specifically to the investigated area, based on samples from the area.

Sampling campaigns in 2004

To improve understanding of hydrocarbon generation from Mesozoic sources two sampling campaigns were conducted in 2004. Apart from sampling locations on the Queen Charlotte Islands (QCI), locations on Northern Vancouver Island (NVI), Parson Island (PI), Harbledown Island (HI), and Swanson Island (SI) have been sampled. Late Triassic/Early Jurassic organic rich rocks from these areas have been correlated to known Kunga/Maude source rock sequence on Queen Charlotte Islands (e.g. Tipper, 1977).

The two investigated areas are shown in Figure 3:

1. Queen Charlotte Islands – predominantly on Graham Island, but with local sampling on Moresby and adjacent islands. Samples were taken in September 2004 from the Kunga and Maude Group (Late Triassic / Early Jurassic).
2. North Vancouver Island as defined in this study – includes Parson, Harbledown, and Swanson Island east of Port McNeill (Figure 3). Organic rich sediments of the Parson Bay and Harbledown Fms., equivalent to Late Triassic/Early Jurassic source rocks occurring on the QCI (Tipper, 1977) and inferred to underlay the QCB have been sampled in May 2004.

Table 1. Queen Charlotte islands Rock Eval 6 sampling locations. Sample QCI 1-5 was further analyzed to establish multi-component kinetics.

sample	Location	Formation	UTM (zone 08N)		Figure
1-7	Moresby Island	Whiteaves	698984E	5897966N	
1-6	Graham Island	Fannin	679386E	5920527N	
1-8	Graham Island	Ghost Creek	679476E	5920996N	
1-5	**Graham Island**	**Sandilands**	**679070E**	**5921449N**	**Figure 6**
2-1	Sandilands Island		693813E	5895144N	
1-3	Graham Island	Peril	671519E	5913326N	
4-4	Maude Island		696097E	5897942N	Figure 10

Rock Eval-6 analysis (subcontracted to GSC-Calgary) provides the essential geochemical source rock parameters to characterize the investigated potential Mesozoic source rocks (e.g., TOC, Tmax, S1, S2, S3, HI, OI, PI). Detailed multi-component kinetic studies on one suitable sample from the Sandilands formation was also performed by the GSC-Calgary. This analysis provides valuable input parameters towards future basin modeling at the School of Earth and Ocean Sciences, University of Victoria.

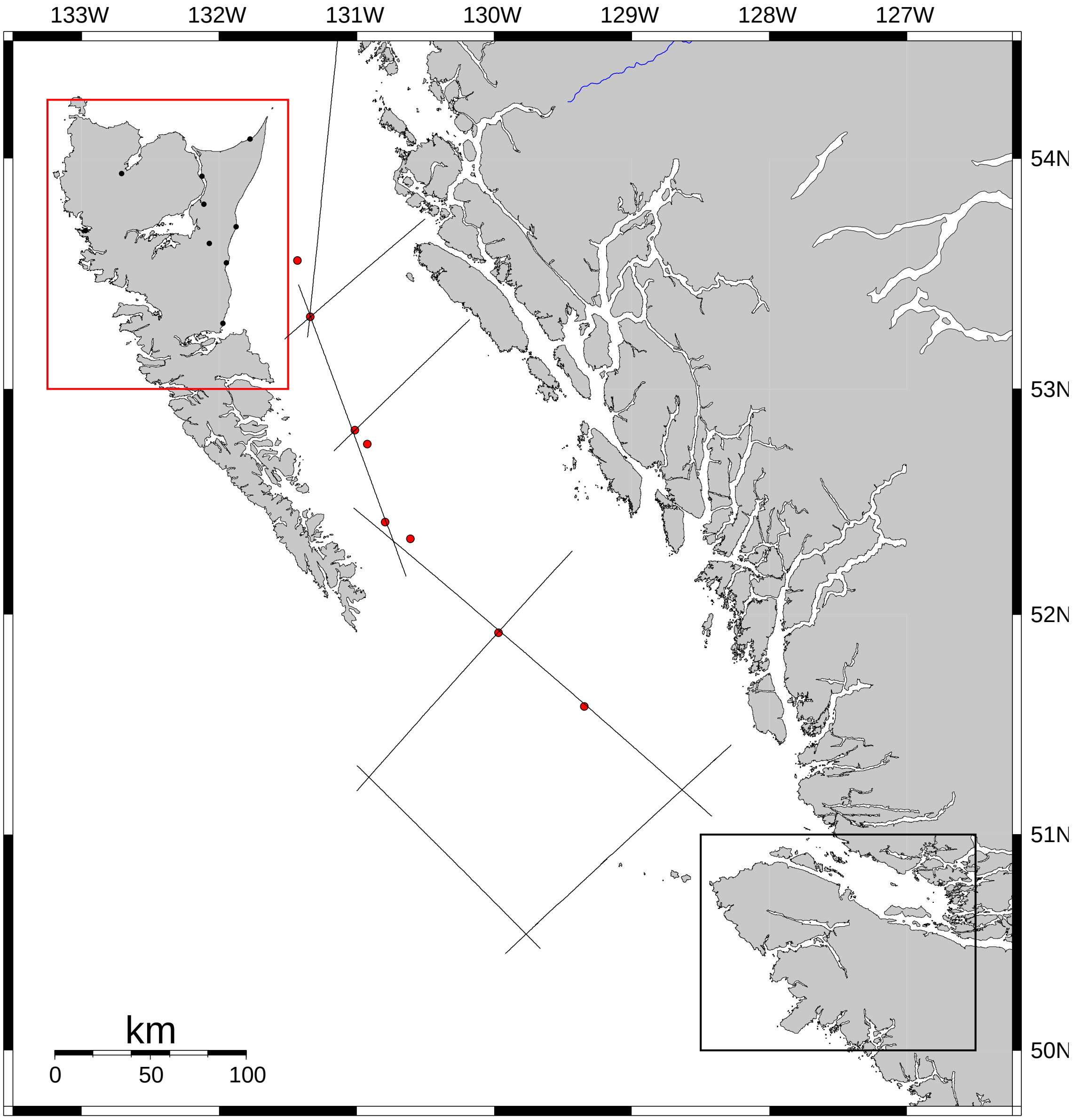

Figure 3. Map of Queen Charlotte Basin with regions of the Queen Charlotte Islands (red box, see also Figure 4) and north Vancouver Island (black box, see also Figure 11) covered by sampling campaigns in 2004. Red dots mark offshore, black dots mark onshore wells.

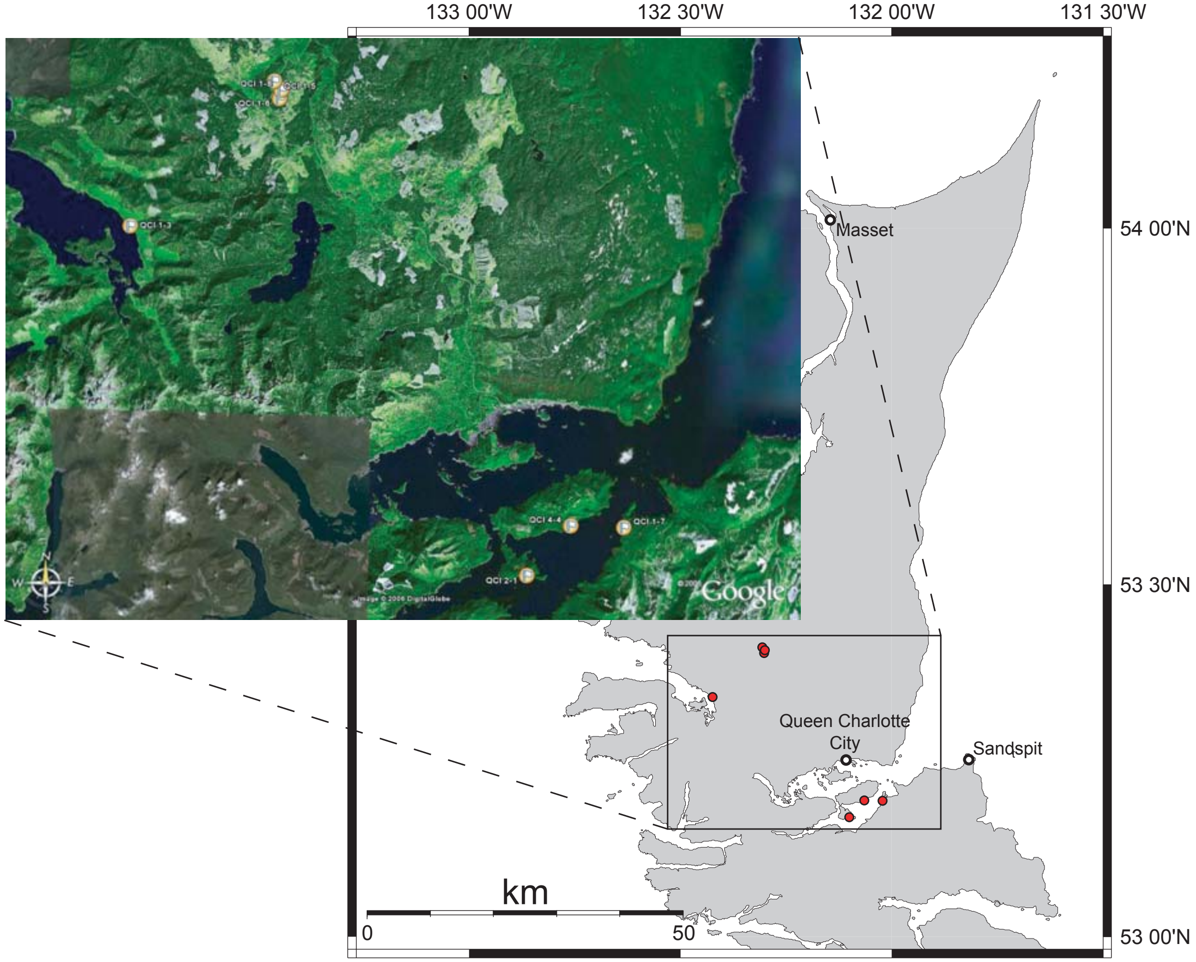

Figure 4. Sampling locations for Rock Eval 6 analysis on the Queen Charlotte islands. Inset shows relief map of sampling locations (Google Earth).

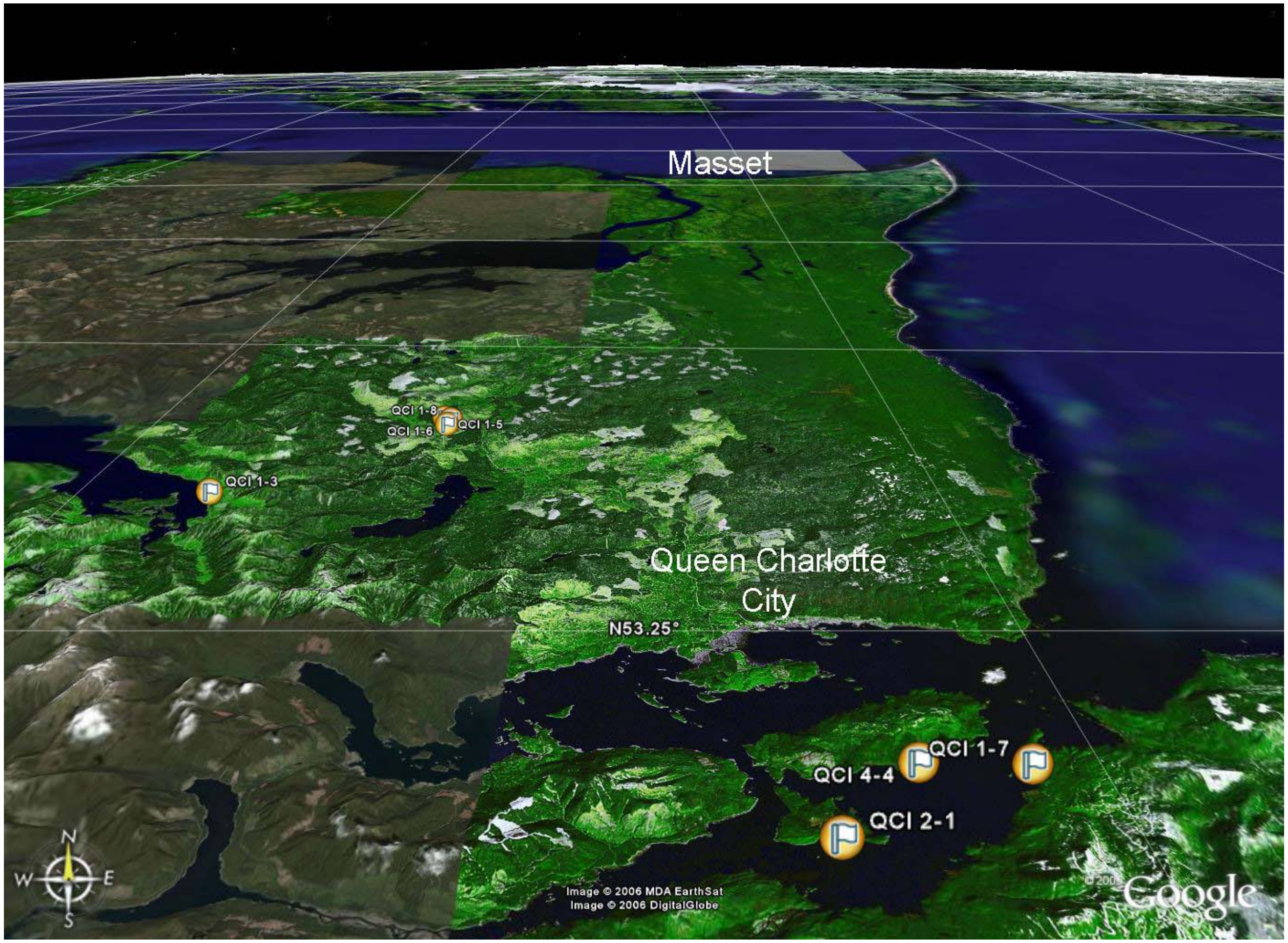

Figure 5. 3D view looking north of Queen Charlotte sampling locations (Google Earth).

Figure 6. Sandilands Fm. (QCI 1-5) in Flagstone Quarry (south central Graham Island).

Figure 7. Peril Fm. (QCI 1-3) in Shields Bay (south western Graham Island).

Figure 8. Fannin Fm. (QCI 1-6) in Fannin Formation Quarry (south central Graham Island).

Figure 9. Sandilands Fm. (QCI 2-1) at beach on south Sandilands Island.

Figure 10. Peril Fm.(QCI 4-4) at shoreline on south Maude Island.

Table 2. North Vancouver Island sampling locations. Samples marked in bold were analyzed using Rock Eval 6.

Location	Formation	Sample	UTM (zone 09N)		Figure
Rainier Creek	Parson Bay (*equivalent to Peril Fm.*)	NVI-1	625350E	5577745N	
		NVI-2	625370E	5577740N	
		NVI-3	625380E	5577735N	
		NVI-4	**625397E**	**5577730N**	**Figure 13**
		NVI-5	625422E	5577726N	
		NVI-6	625478E	5577714N	
		NVI-7	625495E	5577700N	
		NVI-8	625500E	5577695N	
		NVI-9	625507E	5577692N	
		NVI-10	**625350E**	**5577745N**	**Figure 14**
		NVI-11	625350E	5577745N	
		NVI-12	625350E	5577745N	
		NVI-13	625350E	5577745N	
		NVI-14	625350E	5577745N	
		NVI-15	625350E	5577745N	
		NVI-16	625350E	5577745N	
		NVI-17	625350E	5577745N	
		NVI-18	625350E	5577745N	
		NVI-19	625350E	5577745N	
		NVI-20	625350E	5577745N	
		NVI-21	625350E	5577745N	
		NVI-22	625350E	5577745N	
		NVI-23	625350E	5577745N	
Harbledown Island	Harbledown (*equivalent to Ghost Creek Fm.*)	HI-1	664192E	5606344N	Figure 15
		HI-2	664256E	5606320N	Figure 16
		HI-3	664732E	5606187N	Figure 17
		HI-4	665225E	5606266N	
Parson Island	Parson Bay (*equivalent to Peril Fm.*)	PI-1	664466E	5605320N	Figure 18
		PI-2	664560E	5604932N	
		PI-3	664600E	5604936N	
		PI-4	664643E	5604940N	
		PI-5	664653E	5604940N	
		PI-6	664858E	5604898N	Figure 19
Swanson Island	Parson Bay (*equivalent to Peril Fm.*)	SI-1	661192E	5608608N	
		SI-2	661192E	5608608N	
		SI-3	661192E	5608608N	
		SI-4	661192E	5608608N	

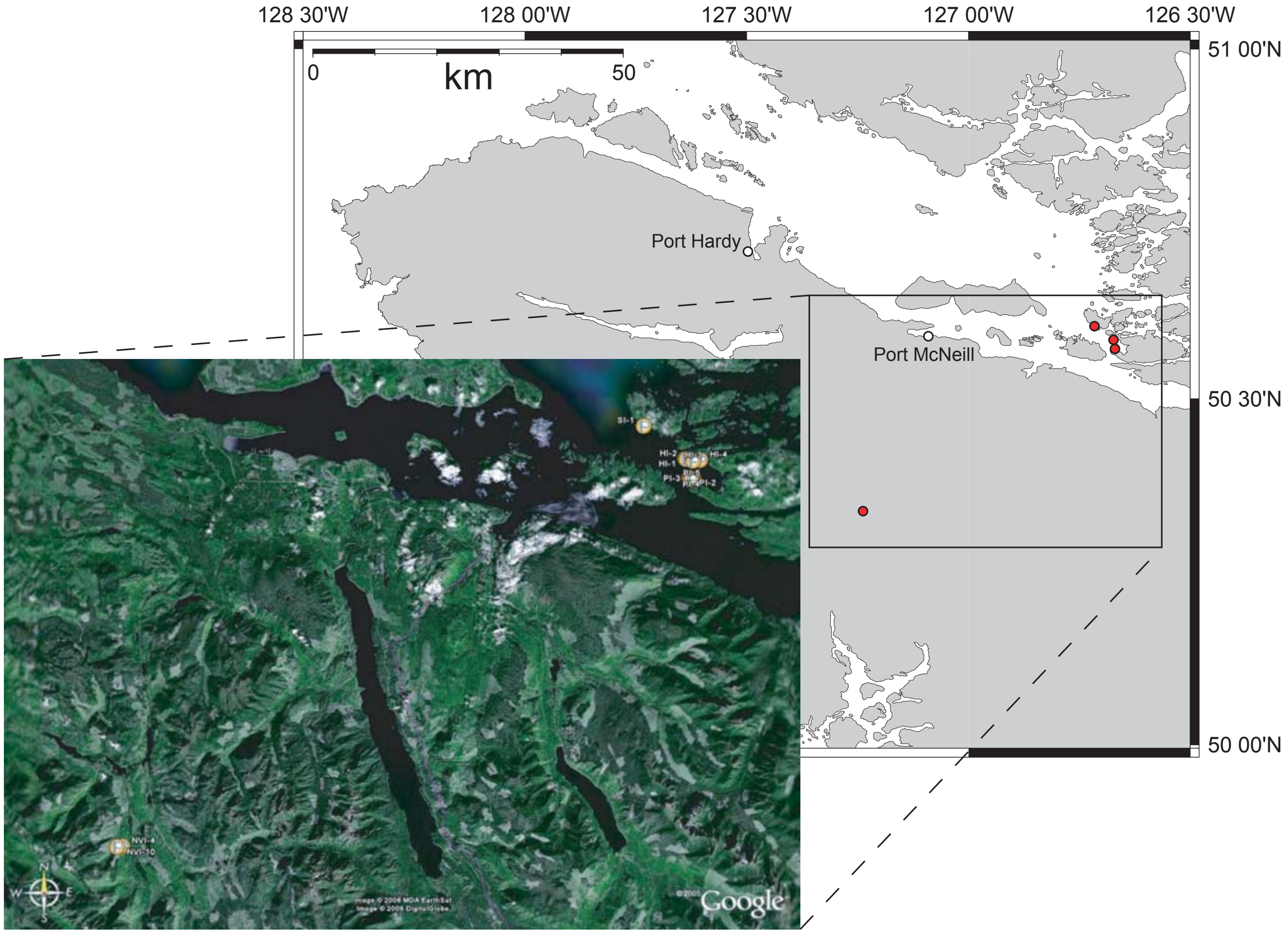

Figure 11. North Vancouver island sampling locations for Rock Eval 6 analysis. Inset shows relief map of sampling locations (Google Earth). sample locations. Figure 12 shows a more detailed representation of Harbledown, Parson, and Swanson Island sampling locations in a 3D view.

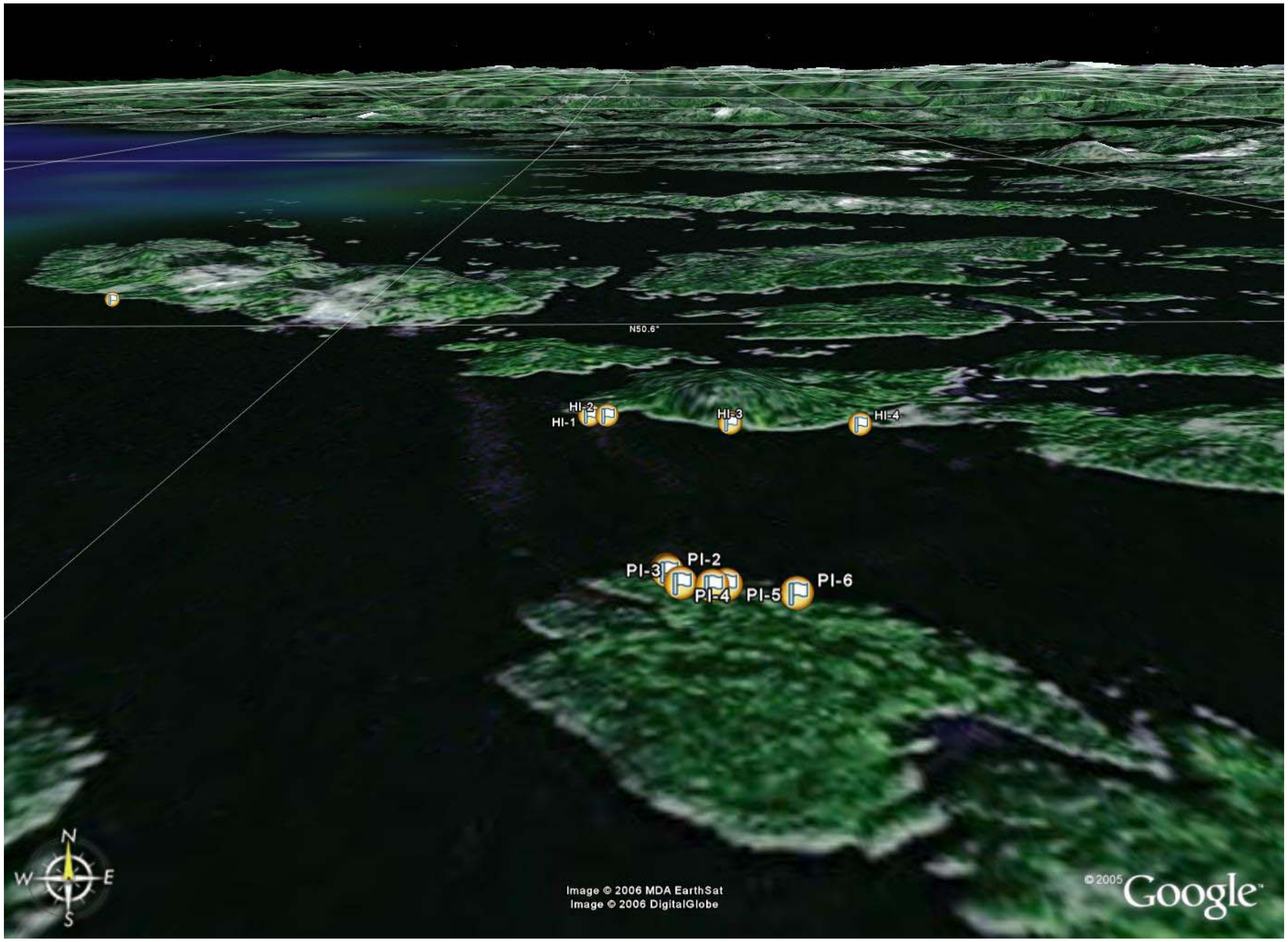

Figure 12. 3D view looking north over Parson (foreground), Harbledown(middle), and Swanson Island (upper left) sampling locations (Google Earth).

Figure 13. Parson Bay Fm. (NVI-4) at Rainier Creek (central northern Vancouver Island).

Figure 15. Harbledown Fm. (HI-1) on south shore of north west Harbledown Island.

Figure 14. Parson Bay Fm. (NVI-10) at Rainier Creek (central northern Vancouver Island).

Figure 16. Harbledown Fm. (HI-2) on south shore of north west Harbledown Island

Figure 17. Harbledown Fm. (HI-31) on south shore of north west Harbledown Island.

Figure 18. Parson Bay Fm. (PI-1) on north shore of Parson Island.

Figure 19. Parson Bay Fm. (PI-6) on north shore of Parson Island.Results of the analytical work.

Rock-Eval/TOC analysis was contracted to by GSC Calgary. It provides fast and reliable characterization of the quantity and quality of sedimentary organic matter, as well as its thermal maturity.

Method

A typical Rock-Eval experiment is initiated with heating of a pulverized rock sample at 300ºC for 3 min in helium atmosphere, when naturally occurring hydrocarbons (free and adsorbed) are volatilized.During the next stage, the oven temperature is steadily increased to 600ºC at a rate of 25ºC/min and decomposition of kerogen occurs. The final stage involves oxidation and combustion of the residual organic matter at 600ºC.

The amount of hydrocarbons volatilized at 300ºC and evolved from kerogen at 300ºC to 600ºC is quantitatively determined by a flame ionization detector, and recorded as the S1 and S2 peaks, respectively. The temperature measured at the maximum of the S2 peak is referred to as Tmax. The quantity of organic CO2 generated from 300ºC to 390ºC, determined by a thermal conductivity detector, comprises the S3 peak. The percentage of carbon in CO2 formed during oxidation at 600ºC and in the hydrocarbon peaks S1 and S2 is used to define the total organic carbon content (TOC), expressed as a weight percentage.

The determination of the quality of organic matter is based upon the calculation of Hydrogen (HI) and Oxygen (OI) indices (HI=S2/TOCx100, OI=S3/TOCx100) which are related to the atomic H/C and O/C ratios (Espitalie et al., 1977). The OI versus HI cross plots ("pseudo van Krevelen diagrams") can be used as an organic matter type indicator at low and moderate maturities.

The Tmax is an indicator of relative thermal maturity. According to Espitalie et al. (1985) the oil window is defined by the following Tmax ranges: 440º-448ºC (Type I), 430º-455ºC (Type II) and 430º-470ºC (Type III). A cross plot of Tmax versus HI is used to constrain estimations of organic matter type and its thermal maturity, while the Production Index PI=S1/[S1+S2]) is used to indicate staining of a sample or as an additional maturity parameter.

Data

Although high, maturation level at the locations visited on the QCI allowed to analyze source rocks spanning the Peril to the Whiteaves Fm. (Norian – Pliensbachian, see also Figure 1). Maturation of samples derived form North Vancouver Island locations were generally too high (hornfels facies) to reveal valuable Rock Eval analysis and only two samples from the Rainier Creek location (Parson Bay Fm.) were analysed. Due to the high maturation level only one source rock sample was chosen for multi component kinetic analysis (Sandilands Fm., QCI 1-5)

Table 4 in the appendix shows the results of the Rock Eval 6 analysis. Tmax values vary between 297 and 486°C, PI between 0.09 and 0.67, and TOC between 0.40 and 4.33wt% for the QCI samples. HI and OI are recorded to lie between 3 - 396 and 5 - 40, respectively. Note: Parson Bay Fm. Samples from Rainier Creek seem unrealistic, most likely due to weathering and / or high maturation.

Figure 20 shows the classification of the investigated source rocks according to type of kerogen and maturation level using a pseudo van Krevelen diagram. Sandilands and Fannin Fm. source rocks mainly contain type I/II kerogen, while type III kerogen seems to outweigh in Peril and Ghost Creek sources, which generally confirms findings by Macauley (1983) and Snodwon etal. (2002) presented in Figure 2. Low values for OI confirm the generally high maturation level.

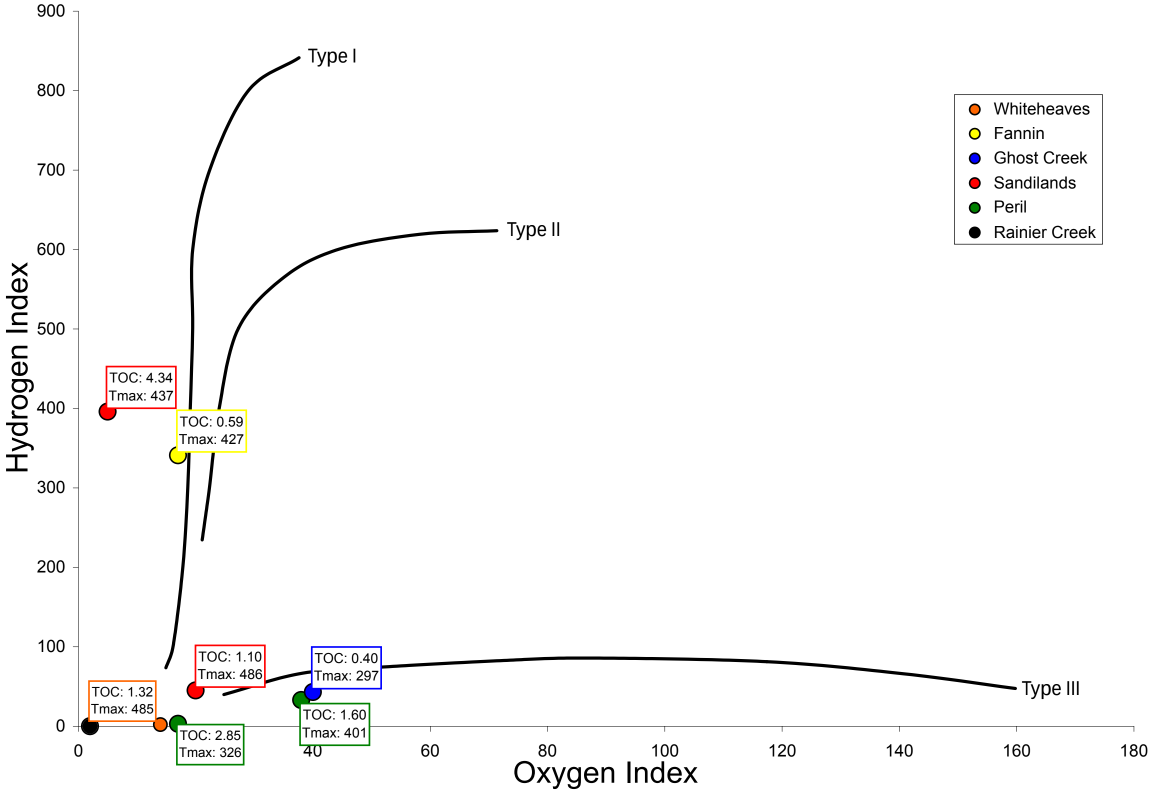

Figure 20. Pseudo van Krevelen diagram for investigated Queen Charlotte Island samples. (Note: Characterization of Rainier Creek (Parson Bay Fm.) samples from North Vancouver Island is impossible, due to heavy weathering and / or high levels of maturation,, which inhibits correct Rock Eval measurements.)

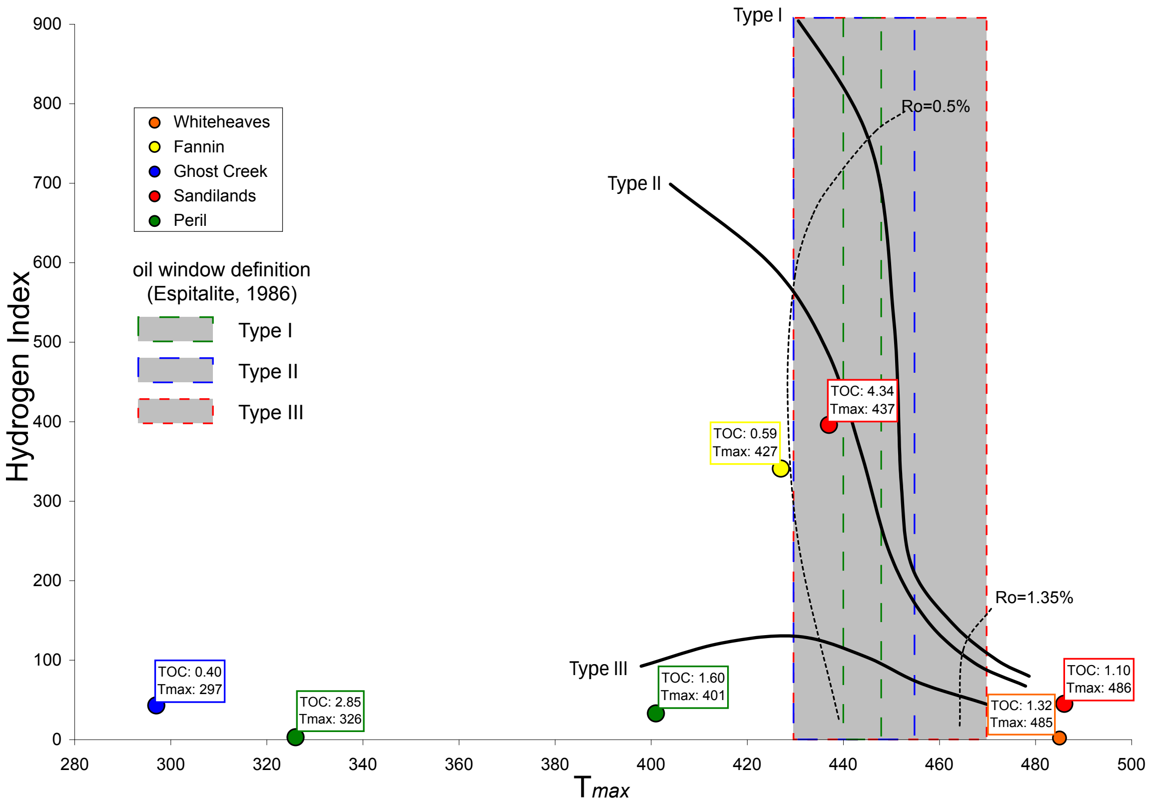

Figure 21. HI versus Tmax diagram of QCI samples. Sandilands and Fannin Fm. samples show type II kerogen characteristics, whereas Peril and Ghost Creek Fm. samples resemble type III kerogen. Oil window definition for different kerogen types according to Espitalité (1986) is represented by gray shaded areas. Stippled lines represent iso-maturity levels.

Figure 21 shows the classification of the investigated source rocks according to type of kerogen and maturation level using a Hydrogen Index versus Tmax temperature diagram. Sandilands and Fannin Fm. source rocks repesent type II kerogen evolution. As already seen in Figure 20 Peril and Ghost Creek source rocks are mainly comprised of type III kerogen. Stippled lines represent iso-maturation levels of 0.5 and 1.35%Ro. Definition of oil window dependant on type of kerogen according to Espitalité (1986) is given.

Due to the limited quality or high stages of maturation only sample (QCI 1-5) showing lower maturation levels (Tmax: 437°C) combined with high oranic content (TOC: 4.34wt%) was further investigated to establish multi-component kinetics for hydrocarbon maturation (Table 3 and Figure 22).

The multi-component analysis reveals similarities to the type II kerogen used in Whiticar etal. (2003, 2004). However, due to maturation level the profile only reveals the remaining reactions to higher activation energies (Figure 22).

Table 3. Multicomponent kinetics of sample QCI 1-5 (Sandilands Fm.).

Activation Energy [cal / mol]	**44**	**46**	**48**	**50**	**52**	**54**	**56**	**58**	**60**	**62**	**64**
Percent	0.02	0.14	0.20	0.00	0.00	68.83	22.15	8.00	0.85	0.43	0.00

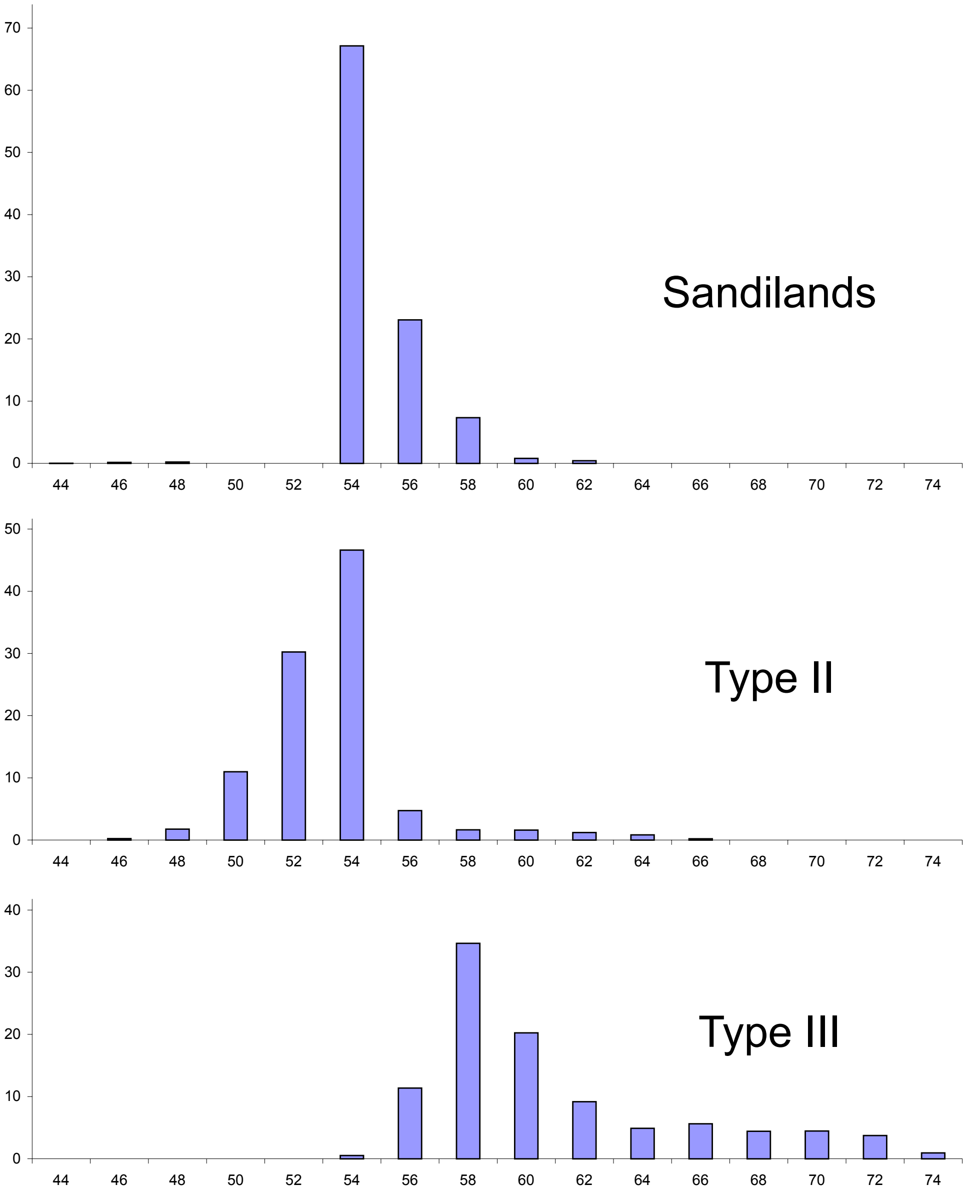

Figure 22. Comparison of kinetic characteristics of investigated Sandilands kerogen (top panel) and Type II and Type III kerogens used in previous basin modeling (Whiticar etal, 2003 & 2004). Sandilands organics as measured here resemble a matured type II kerogen.

Implications for basin modeling

Multicomponent kinetic analysis of the available kerogen enable more precise calculations of amount and quality of generated hydrocarbon and time of generation as well as behavior during migration. For prediction of hydrocarbon accumulation such information is essential.

Analysis of Mesozoic source rocks presented here, confirm the choice of kerogen employed during previous petroleum systems modeling of the Queen Charlotte Basin area (Whiticar etal., 2003, 2004). Due to maturation levels of Mesozoic source rocks outcropping on the Queen Charlotte Islands and Vancouver Island an exact determination of the kinetic behavior during lower stages of maturation could not easily be determined and follow up work on less mature samples would be desirable, if such samples became available.

Outlook

Apart from oil prone Mesozoic (type I/II) gas prone Tertiary (type III) source rocks are reported from the Skonun Formation in the Queen Charlotte Basin area. To better define potential gas plays in the Queen Charlotte area multi-component kinetic analysis of Skonun source rocks should be undertaken. Petroleum systems modeling so far has employed literature values for these gas-prone type III kerogens. With respect to the known high variability of various type III kerogen establishing a kinetic profile specifically tailored to the Queen Charlotte Basin seems essential to any future petroleum systems modeling work addressing potential gas plays in the area.

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Appendix

Table 4. Rock Eval 6 data for Queen Charlotte Islands (QCI) and North Vancouver Island (NVI) samples. (Note unrealistic S1, S2, and S3 values for NVI samples. Most likely due to either overmaturation or heavy weathering of samples. These samples do therefore plot not correctly in the modified van Krevelen diagram, see Figure 20).

Queen Charlotte Islands

Sample	Formation	Qty	S1	S2	S'2	PI	S3CO2	Tmax	Tpeak	S3CO	PC(%)	TOC	RC%	HI	OICO	OICO2	OIRE6	MINC%	S4CO	S4CO2	RCCO(%)	S4CO2	S5aCO2	S5bCO2	KFID	RCCO2(%)
QCI 1-3	Peril	70.0	0.06	0.09	0.00	0.41	0.62	326	366	0.01	0.01	2.58	2.57	3	0	24	17	2.1	13.3	73.3	0.570	72.8	18.7	52.3	1520.275	2.00
QCI 4-4		71.0	0.11	0.51	0.01	0.18	0.69	401	441	0.19	0.06	1.60	1.54	33	12	43	38	0.5	11.3	38.6	0.484	36.9	3.0	13.2	1520.275	1.05
QCI 1-5	Sandilands	69.8	1.64	17.16	0.04	0.09	0.23	437	477	0.15	1.57	4.34	2.77	396	3	5	5	2.0	14.3	78.9	0.613	71.9	15.0	54.2	1382.449	2.15
QCI 2-1		70.8	0.18	0.48	0.01	0.27	0.18	486	526	0.15	0.06	1.10	1.04	45	14	16	20	0.1	7.5	26.5	0.321	25.3	0.8	0.7	1520.275	0.72
QCI 1-8	Ghost Creek	70.9	0.35	0.17	0.00	0.67	0.17	297	337	0.06	0.05	0.40	0.35	43	15	43	40	0.7	1.7	10.2	0.073	9.6	8.2	16.4	1520.275	0.28
QCI 1-6	Fannin	70.0	0.95	2.01	0.00	0.32	0.12	427	467	0.03	0.25	0.59	0.34	341	5	20	17	4.6	2.0	9.2	0.086	8.1	14.6	148.5	1520.275	0.25
QCI 1-7	Whiteheaves	70.4	0.02	0.02	0.00	0.53	0.19	485	525	0.09	0.01	1.32	1.31	2	7	14	14	0.1	8.4	34.8	0.360	33.1	1.1	1.0	1520.275	0.95

North Vancouver Island

Sample	Formation	Qty	S1	S2	S'2	PI	S3CO2	Tmax	Tpeak	S3CO	PC(%)	TOC	RC%	HI	OICO	OICO2	OIRE6	MINC%	S4CO	S4CO2	RCCO(%)	S4CO2	S5aCO2	S5bCO2	KFID	RCCO2(%)
NVI-4	Parson Bay	70.3	0.00	0.00	0.00	0.00	0.15	607	647	0.02	0.00	4.33	4.33	0	0	3	2	4.5	30.3	111.0	1.299	110.4	12.0	143.3	1520.275	3.03
NVI-10		70.0	0.00	0.00	0.00	1.00	0.03	-40	0	0.01	0.00	1.80	1.80	0	1	2	2	0.0	12.5	46.5	0.536	46.2	0.2	0.2	1520.275	1.27