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Dispersed organic matter reflectance and thermal maturation in four hydrocarbon exploration wells in the Hudson Bay Basin: regional implications

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INTRODUCTION

The Hudson Bay Basin is the largest Phanerozoic intracratonic sedimentary basin in North America, the waters of Hudson Bay cover most of the basin but a sizable onshore component is also present in Northeastern Manitoba and Northern Ontario. However, the Hudson Bay Basins is definitively a frontier basin for our knowledge of its geological history and its hydrocarbon potential.

Hydrocarbon exploration was initiated in the 1960s and this first round of exploration was terminated in the mid-80s following a major depression in oil price. During that period of time, five offshore dry wells have been drilled: 1) Aquitaine et al. Hudson Walrus A-71 in 1969, 2) Aquitaine et al. Narwhal South O-58 in 1974, 3) Aquitaine et al. Polar Bear C-11 in 1974, 4) Trillium Soquip Onexco et al. Beluga O-25 in 1985, and 5) ICG Sogepet et al. Netsiq N- 01 in 1985.

In the following years, these wells have been subject of various studies including, mineralogy, palynology, geochemistry (total organic carbon, carbon ratios, Rock Eval and organic extracts), organic matter petrography (reflectance, spores and conodonts color alteration) in order to determine the thermal maturation of the successions (Penigel *et al*., 1975a, b; Fallgatter 1984; Dolby, 1986; Zhang and Barnes, 2007).

As part of the Geological Survey of Canada Geomapping for Energy and Minerals program, the Hudson Bay Basin and its smaller satellite Foxe Basin, at the northern margin of the former, are subjects of a complete re-evaluation of their geological evolution and a new reappraisal of their hydrocarbon potential.

PROBLEMATIC

A vintage database of Rock Eval data, conodonts color alteration index (CAI) and limited reflectance data was later enhanced with addition of new Rock Eval data. The CAI used in previous works has limited precisions in low thermal conditions with increments of 0.5. From CAI of 1 (immature) to 1.5 (oil window), the upper 1.5 limit indicative of roughly 90°C, the onset of oil window (e.g., 60-65°C) goes unnoticed. Vitrinite reflectance values and spore coloration reported in previous studies, although with some inconsistencies, suggest low thermal conditions. Moreover, the Rock Eval maximum pyrolysis temperatures (T_{max}) have been considered to be too low to indicate the oil window (threshold of 435°C). However, if this evaluation holds well for the Devonian successions, close to 40% of T_{max} values for Ordovician samples have reached that threshold in recent analyses (Zhang and Dewing, 2008) and some CAI of 1.5, the lower part of the Polar Bear and Narwhal wells would have reached temperatures of about 90°C (Zhang and Barnes, 2007).

A preliminary study of organic matter reflectance on 65 cutting samples of four offshore wells was recently completed (Bertrand *et al.*, 2011). The old Paleozoic successions are largely devoid of vitrinite, the standard terrestrial maceral for reporting reflectance values. However, marine organoclasts abound and reflectance measurements were taken on scolecodonts, chitinozoans and graptolites. That approach has been successfully used in regional maturation studies in lower Paleozoic successions (Bertrand, 1990a, b; Bertrand, 1991; Bertrand and Malo, 2001, 2005, 2010; Roy 2004, 2008; Wilson *et al.*, 2004). The preliminary research concluded that the Ordovician and Silurian successions have reached the thermal stage of oil generation whereas the Devonian successions are immature (Bertrand *et al.*, 2011).

PROPOSED RESEARCH

For many years, the industry has considered the Hudson Bay basin to be thermally immature. This conclusion was largely based on low-resolution color alteration indexes of conodonts and spores and limited organic matter reflectance (Penigel *et al*. 1975a, b; Dolby, 1986). This report aims at re-evaluating the vintage thermal indicators in the context of new reflectance data on organoclasts and recent Rock Eval data

A revised stratigraphic framework based on new well log correlation and biostratigraphic data has recently been released (Hu *et al*., 2011), this new framework is used here. The current study aims to: 1) precise the preliminary results of organic matter reflectance on organoclasts in offshore wells, 2) re-evaluate the recent Rock Eval 6 data in order to qualify potential source rocks and address eventual hydrocarbon migration events, 3) propose regional thermal maturation patterns and 4) generate hypotheses on the burial history of the basin.

REGIONAL GEOLOGY

Geological setting and well locations

The Hudson Bay Basin is a Phanerozoic intracratonic basin surrounded on all sides by Precambrian basement (Fig. 1). Based on limited well information and poor quality seismic, the preserved sedimentary succession is close to 2500 m (Sanford, 1987; Hamblin, 2008; Hu *et al.*, 2011).

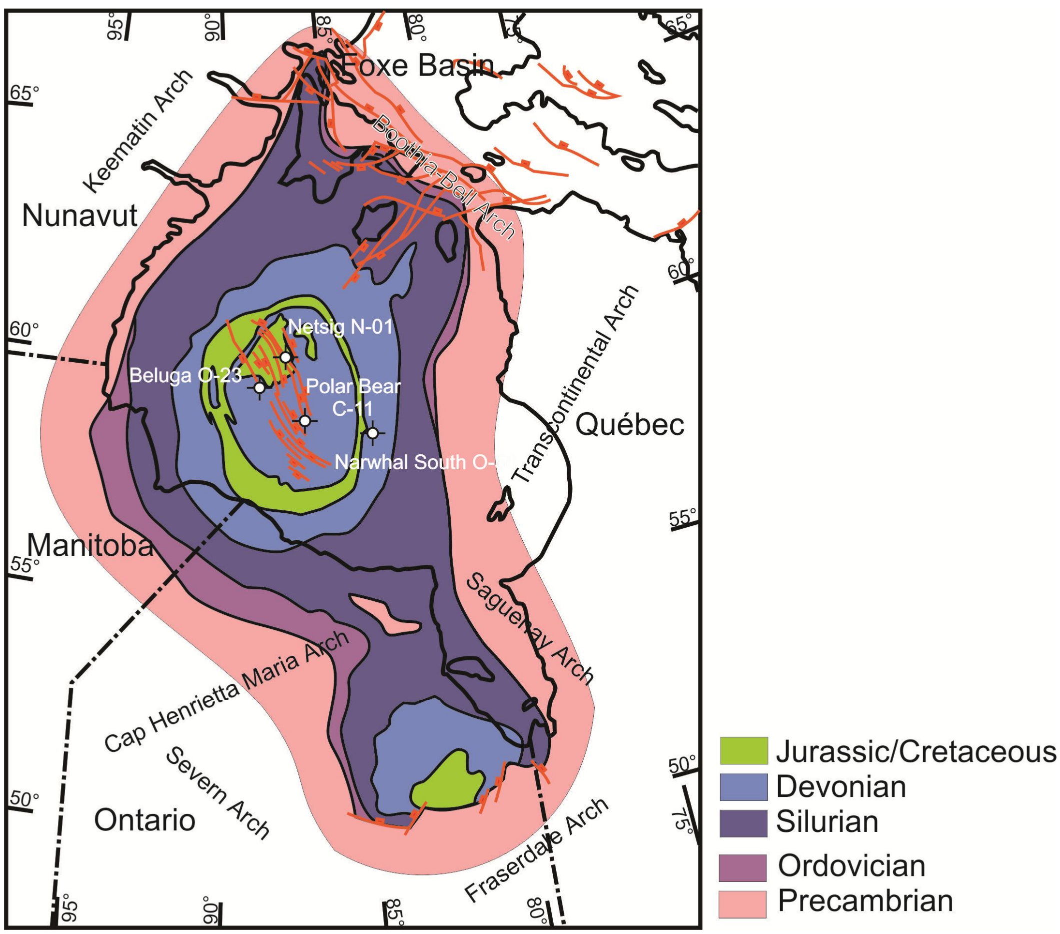

Figure 1. Simplified regional geology of Hudson Bay Basin. Modified from Sanford and Grant (1998) and Hamblin (2008).

Compared to other intracratonic basins in North America, the preserved sedimentary succession is thinner and recent palynology data suggests at least intermittent sediment accumulations in the Cretaceous and Tertiary (Galloway, 2011). The oldest deposits unconformably overly the Precambrian basement and are Late Ordovician in age whereas Upper Devonian units are found at the top of the wells with however, Mesozoic and Cenozoic sediments reported in the Narwhal South well (Williams and Barss, 1976).

The Hudson Bay Basin is almost entirely isolated by interpreted Precambrian highs or « arches » (Fig. 1) (Sanford and Grant, 1990, 1998; Hamblin, 2008). To the south, the Cap Henrietta Maria Arch separates the Hudson Bay Basin from the smaller Moose River Basin (Fig. 1) whereas the Boothia-Bell Arch separates the Hudson Bay Basin from the smaller Foxe Basin of the Southeast Arctic Platform (Zhang, 2010).

Away from its heavily faulted northern margin, the sedimentary rocks of the Hudson Bay Basin are little deformed, although a tectonic high characterises its central domain. This "Central High" was tectonically active during the Silurian to earliest Devonian (Lavoie *et al.*, 2011; Hu *et al.*, 2011). The wells included in this study were located on or immediately adjacent to this "Central High" (Fig. 1).

Stratigraphy and basin evolution

The stratigraphy of the Hudson Bay Basin has recently been revised based on well logs re-evaluation and new biostratigraphic data (Hu *et al.*, 2011). The new chitinozoans age data, in sections largely devoid of other biostratigraphically useful organoclasts has resulted in 1) a significant displacement of the Silurian-Devonian boundary, 2) the reassignment to the Lower Devonian of most of the thick evaporite/salt succession previously included in the Late Silurian in the Beluga well and 3) the identification of a significant unconformity during the Late Silurian – Early Devonian time interval. The sedimentation history in the Hudson Bay basin covers most of the Late Ordovician to Late Devonian. Three major sedimentary packages are recognized in the studied wells (Zhang, 2010; Hu *et *al*., 2011) (Fig. 2), 1) an Upper Ordovician to Lower Silurian shallow subtidal to peritidal carbonate-dominated intervals with various small and large reefs and good Type I-II hydrocarbon source rocks (Bad Cache Rapids Formation, Churchill River Group and the Red Head Rapids, Severn River, Ekwan River and Attawapiskat formations), 2) a thin early Upper Silurian siltstone, carbonates and evaporites (Kenogami River Formation) and 3) a late Lower Devonian to Upper Devonian interval of mixed evaporite - carbonate with interpreted reefs and minor clastics (Stooping River, Kwataboahegan, Moose River, Murray Island, Williams Island and Long Rapid formations).

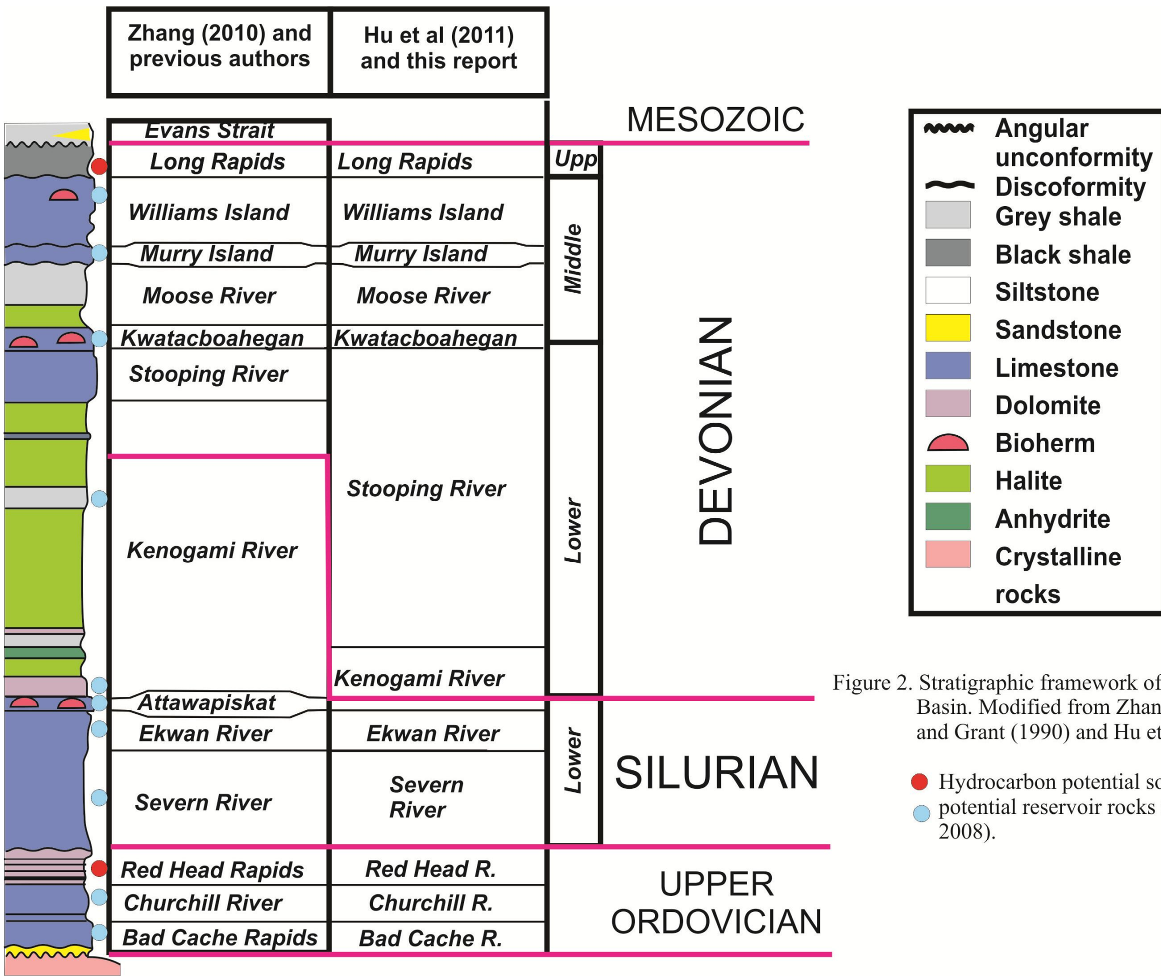

Figure 2. Stratigraphic framework of the Hudson Bay Basin. Modified from Zhang (2010), Sandford and Grant (1990) and Hu et al. (2011).

● Hydrocarbon potential source rocks; ● potential reservoir rocks (Hamblin, 2008).

In the Hudson Bay, all wells except Beluga O-25 have been drilled on the "Central High"; the Beluga well has been drilled west of it. The Beluga well displays some significant increase thickness compared to the other wells (Hu *et al*., 2011; Fig. 3) and if some subtle thickness differences in the Ordovician units are indicative of an active faulting environment, major fault movement occurred along the "Central High" in Late Silurian – Early Devonian resulting in major (local?) unconformity coeval with marine sedimentation (Kenogami River and Stooping River formations stratigraphic lateral equivalence; Fig. 3).

A late Early Devonian marine transgression covered the locally exposed platform and led to mixed shallow marine to nearshore Middle to Upper Devonian mixed (carbonate-evaporite-clastic) succession. Based on seismic reflection data, Middle Devonian reefs have been postulated in the

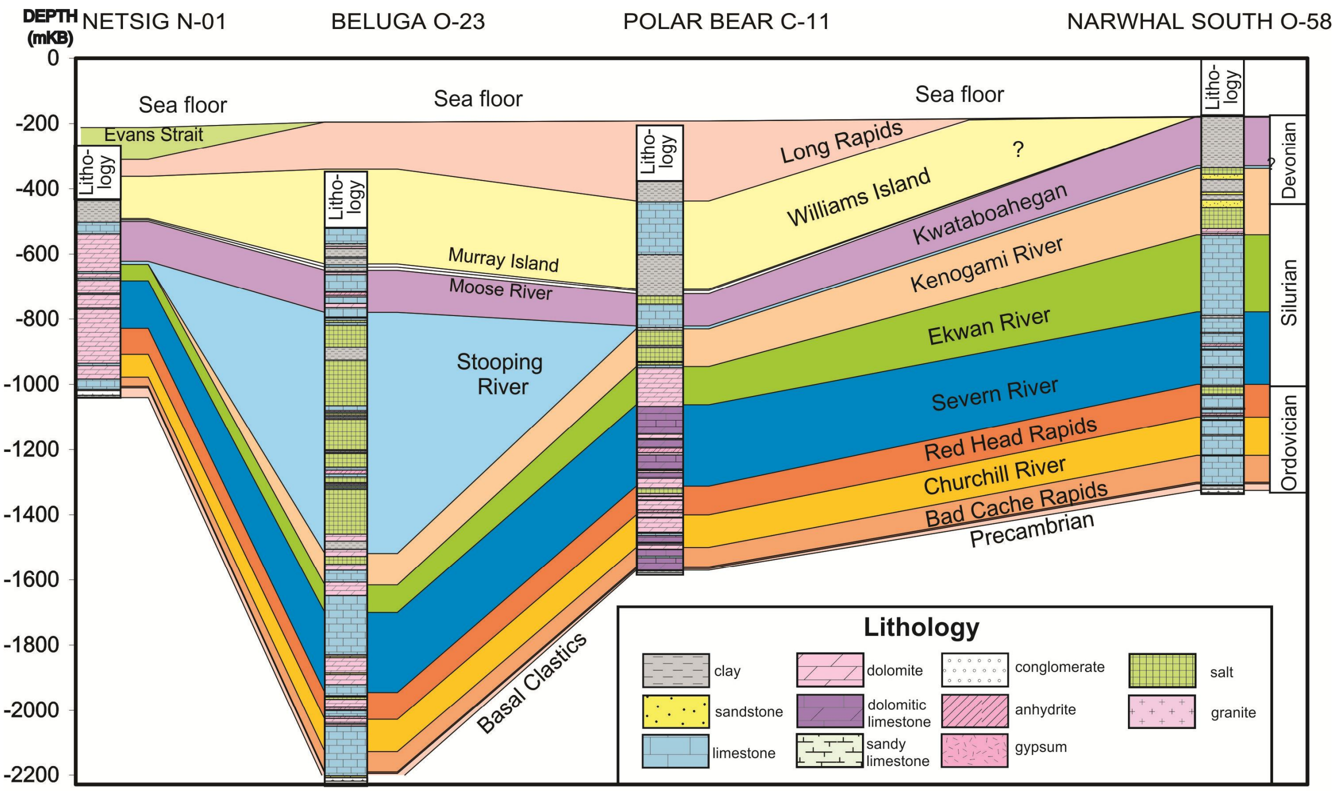

Figure 3. Fence diagram and lithostratigraphy of the four studied wells in the Hudson Bay Basin. Modified from Hu et al. (2011).

Kwataboahegan and Williams Island formations (Hamblin, 2008). The Devonian succession is capped by the nearshore clastics of the Long Rapids Formation, which in the Moose River Basin is an organic-rich immature black shale succession (Hamblin, 2008). Some Carboniferous (Pennsylvanian) sediments have been interpreted in the Narwhal well (Tillement *et al.*, 1976), although the possibility of microfossil contamination of samples has been proposed.

Interpreted Cretaceous fauna have been reported in the Netsiq Well (Fig. 3) whereas Williams and Barss (1976) reported the presence of mixed Cretaceous and Tertiary fauna in a poorly consolidated clastic succession in the uppermost part of the Narwhal well. Elsewhere, Sanford and Grant (1998), based on their interpretation of industry and high-resolution GSC seismic data have mapped more or less continuous patches of interpreted post-Paleozoic sediments they assigned to the Mesozoic Evans Strait Formation (Figs. 2 and 3).

A significant number of the carbonate units are characterized by interpreted or documented bioconstructions of various sizes (a few meters up to hundreds of meters in lateral and vertical extension). In field outcrops (Zhang, 2010), many of the Ordovician and Silurian reefs are highly porous and petrophysical log analyses confirm the high porosity of these Ordovician-Silurian cases as well as that of the non-outcropping Devonian reefs, they could form good potential reservoirs (Hamblin, 2008) (Fig. 2). Recently, field work and core examination supplemented by petrography and geochemistry works have confirmed the presence of porous hydrothermal dolomites in the Ordovician and possibly in the Silurian carbonates (Nicolas and Lavoie, 2009, 2010; Lavoie *et al*., 2011a); these dolomites form major reservoirs in the Michigan and Illinois intracratonic basins (Davies and Smith, 2006). Good cap rocks such as shales and evaporites are present at multiple intervals, tectonic (fault) and sedimentary (pinch out, unconformity) traps are visible on the seismic data (Lavoie *et al.*, 2011b).

Method

The new interpretation presented here is based on: 1) measurements of reflectance of all types of dispersed organic matter (DOM) in the kerogen-concentrated thin sections, 2) the equation-based transfer of DOM reflection values into vitrinite-equivalent reflectance values and 3) the comparison of the vitrinite-equivalent reflectance values with the various Rock Eval values and indices taken from public domain reports. All these stages lead to a new interpretation of the thermal maturation of the Paleozoic successions of the Hudson Bay Basin.

Reflectance of dispersed organic matter (DOM)

Sixty-five composite cutting samples from offshore wells have been used for determination of the reflectance of dispersed organic matter (DOM). The composite samples consist of equal-weight sub-samples from two to three consecutive cutting bags that cover 10 meters or 15 feet. The complete list of samples is found in Annex 1. Eight (8) samples are from the Netsiq well (450 – 1000 m), eighteen (18) samples are from the Beluga well (580 – 2185 m), twenty (20) samples are from the Polar Bear well (2515 – 5140 feet) and nineteen (19) samples are from the Narwhal well (1130 – 4275 feet). Cuttings from the Walrus well were not available for sampling.

The organic matter concentrate (kerogen) form these samples was generated following the procedure described in Bertrand and Héroux (1987) whereas the glass thin section preparation was prepared and polished following a procedure modified from Bertrand *et al*. (1985).

A Zeiss II reflectometry photomicroscope with transmitted and incident light has been used for organic matter reflectance measurements at a specific wavelength of 546 nanometres with a 40X lens under oil immersion (oil indices of 1.515%). The width of the polished kerogen surface is approximately 3 micrometres in diameter. The organic matter reflectance is measured on random-oriented particles with non-polarized incident light. In order to correct the drift of reflectance measurements, a glass standard with an under immersion indices of 1.025% is measured at the beginning and after the last measurement of any single sample. If the variance of the data is too important, the sample is re-measured entirely. If acceptable, the data are proportionally corrected by the computer assuming that the draft was a linear time function. Based on the size of the particle, one or more reflectance measurements are taken to account for the intra-particular reflectance variation.

Conversion into vitrinite equivalent ($R_{o\text{-}evi}$)

The particles are identified at the time of measurements: graptolite, chitinozoan, scolecodont, hydroid, vitrinite, semifusinite, liptinite (alginite, acritarch and spore), protobitumen, migrabitumen and pyrobitumen. The identification of particles in the kerogen preparation is based on their morphology and their optical properties as proposed and described by the *International Commission of Coal Petrology* (Taylor *et al,* 1998). The reflectance value of many of these organoclasts is then converted in the equivalent reflectance of the standard vitrinite using equations of Bertrand (1990a, 1993), Bertrand and Malo (2001) and Tricker *et al*. (1992). These equations are:

$R_{o\text{-}evi} = 0.8873{*}R_{o\text{-}chitinozoan} + 0.0124$

$R_{o\text{-}evi} = 0.9376{*}R_{o\ graptolite} + 0.0278$ or $R_{o\text{-}evi} = 0.9686{*}R_{o\ graptolite}{}^{0.9819}$

$R_{o\text{-}evi} = 0.6493{*}R_{o\ hydroid} + 0.2126$

$R_{o\text{-}evi} = 1.2038{*}R_{o\text{-}scolecodont}{}^{0.6824}$

$R_{o\text{-}evi} = 0.8113{*}R_{o\text{-}migrabitumen\ (shale\text{-}marl)}{}^{1.2438}$

$R_{o\text{-}evi} = 1.2503{*}R_{o\text{-}migrabitumen\ (limestones)}{}^{0.904}$

Figure 4 illustrates the resulting conversion framework from DOM reflectance to equivalent-vitrinite reflectance ($R_{o\text{-}evi}$). For example, reflectance values from scolecodonts of 0.5%, 1.0%, 1.5%, and 2.0% are equivalent to vitrinite reflectance of 0.75%, 1.2%, 1.9%, and 2.5%, respectively. However, if reflectance values are taken from migrabitumen particles, the nature of the encasing lithology has to be taken into account and a range of $R_{o\text{-}evi}$ is possible. From Figure 4, a reflectance value of 1.0% from a migrabitumen particle in a limestone unit translates to a $R_{o\text{-}evi}$ comprised between 0.95% and 1.25%.

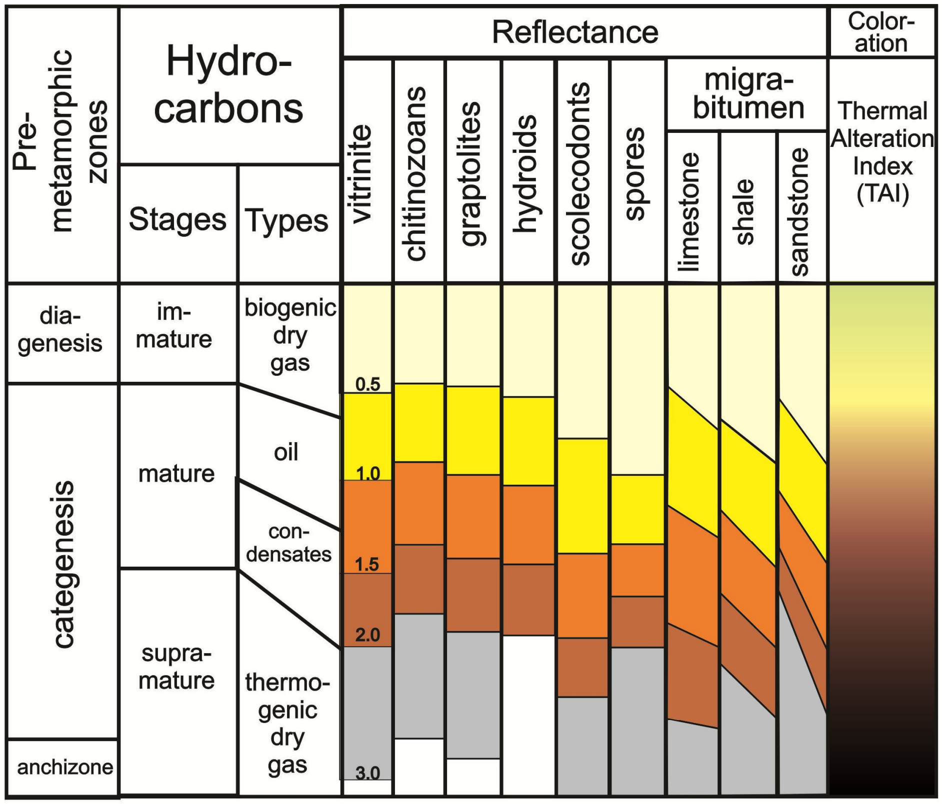

Figure 4. Calibration scales between the reflectance of vitrinite (collotelinite), zooclasts (chitinozoans, graptolites, hydroids and scolecodonts), spores and migrabitumen as a function of lithology. Modified from Bertrand (1993).

Correlation between Rock Eval and $R_{o\text{-}evi}$ data

Rock Eval 6 data (Zhang and Dewing, 2008 and unpublished data) comprise more than 250 analyses for the Beluga, Polar Bear and Narwhal wells. There is no Rock Eval data for the Netsiq well. Moreover, the data for the 3 analysed wells do not cover the entire succession; the Beluga well has data between 1580 and 2210 m, the Polar Bear well is covered between 2660 and 5110 feet and the Narwhal well is analysed between 1550 and 4280 feet. The intervals from which Rock Eval data are available correspond to those we studied for organic matter reflectance except for the Beluga well. For the latter, approximately 1000 m of strata have been petrographically examined for organic matter reflectance. Moreover, sampling for DOM reflectance was not as systematic as that for Rock Eval analyses and there are few direct correlations between a specific DOM reflectance value and a Rock Eval data. Ultimately, the $R_{o\text{-}evi}$ value was correlated to fifty-one (51) Rock Eval analyses. Because of the composite nature of our sampling for DOM, only twenty-nine (29) reflectance values are directly correlated with only one Rock Eval analysis. Moreover, we have removed samples with Rock Eval data having total organic carbon (TOC) lower than 0.1%. At the end, we have fifty-one (51) Rock Eval analyses that correlate with twenty-seven (27) reflectance values (Annex 2).

RESULTS

Petrography of dispersed organic matter (DOM)

The detailed semi-quantitative summary of petrographic study of the dispersed organic matter is presented in Annex 2. A large number of particles have been observed and are divided in four groups: 1) amorphinite, 2) zooclasts, 3) humic maceral and 4) solid bitumen. The amorphinite could be included with liptinite but because it does not have specific shape and given its abundance in all kerogen types (humic maceral, liptinite, zooclasts or bitumen), its origin is uncertain. Zooclasts include chitinozoans, graptolites, scolecodonts and hydroids.

The process to extract kerogen material from the sample includes soaking in concentrated chloridric followed by fluoridric acids. The phosphatic tests of conodonts are totally dissolved and therefore cannot be present on the petrographic preparation used for reflectance analyses. However, scolecodonts that are essentially composed of organic matter are preserved. These zooclasts have been illustrated many times in previous organic matter reflectance studies in nearby Paleozoic basins (Bertrand *et al*, 1985; Bertrand, 1987, 1991, 1993); but for comparison, a few examples are still illustrated in this report (Plates 1 and 2).

Solid bitumen comprises a variety of migrabitumen that can be distinguished on their petrographic habit or anisotropy. In the following discussion, the migrabitumens are regrouped whereas bitumen droplets and natural coke are presented independently.

The average composition of DOM in the stratigraphic unit is presented in Table 1 and illustrated in Figure 5. However, for most stratigraphic units, the nature of DOM relies on limited number of samples and only preliminary considerations can be made. From the limited dataset, the distribution suggest that: 1) amorphous organic matter (amorphinite) dominates, 2) most of stratigraphic units contain more or less abundant protobitumen-bituminite and liptinite (sporinite, alginite, acritarchs), 3) most stratigraphic units contain more or less abundant chitinozoans and more abundant scolecodonts, 4) hydroids are mostly found in the Ordovician Churchill River Group and Bad Cache Rapids Formation, 5) cookified organic matter is rare but present in a few stratigraphic intervals and 6) the organic matter in the Netsiq well has been entirely contaminated by lignite used in the drilling mud for this specific well. In all the other wells, the humic maceral (inertinite and vitrinite) are only observed in Upper Silurian to Devonian units (Kenogami River Formation and younger).

Organoclasts used to evaluate thermal maturation

The thermal maturation of the sedimentary successions of the Hudson Bay Basin is here evaluated from the reflectance of marine organoclasts including scolecodonts, chitinozoans, graptolites and hydroids. Plates 1 and 2 illustrate the lack of ambiguity in the identification of these specific organoclasts. In the hydrocarbon literature, vitrinite is the standard maceral used in reflectance analyses to evaluate the thermal rank of a sedimentary succession (Taylor *et al*., 1998). Vitrinite is derived from

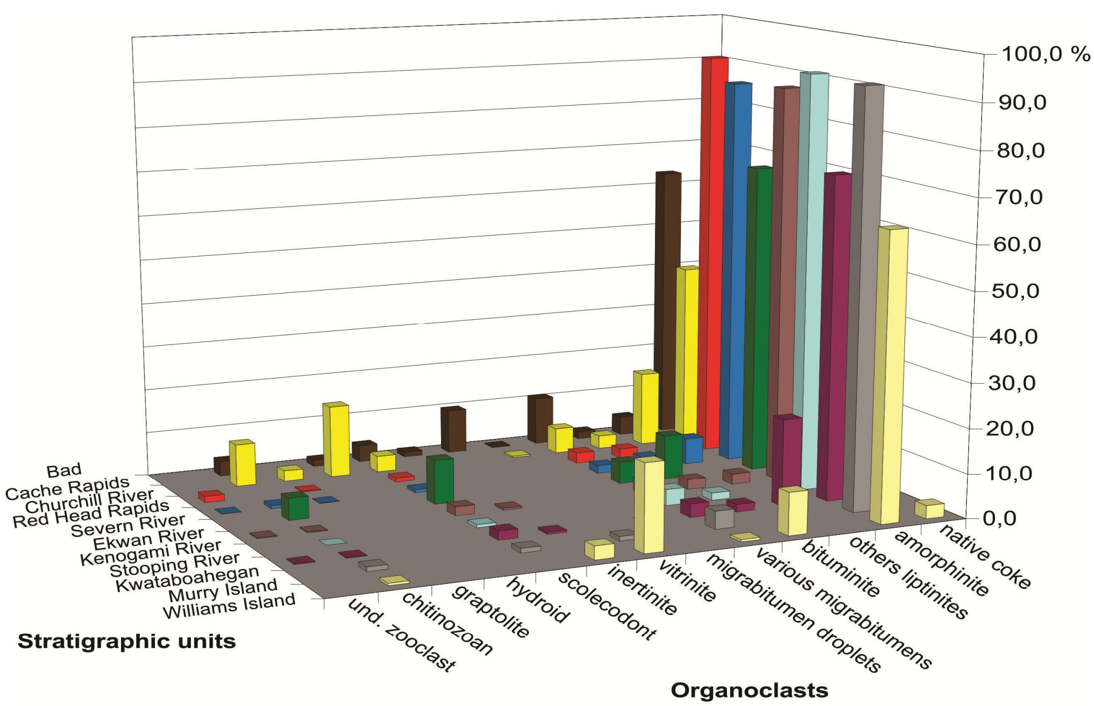

Figure 5. Petrography of dispersed organic matter from stratigraphic units in Hudson Bay Basin.

continental coal and is formed through humification of vascular plants in a periodically inundated and oxygenated paralic environment. Vitrinite is only abundant in Devonian and younger rocks, even though some vitrinite has been reported in Upper Silurian sedimentary successions and controversial traces have been interpreted in older rocks.

The sedimentary succession of the Hudson Bay Basin consists of both pre-, syn- and some post-Devonian units. These are mostly shallow marine carbonate units with subordinate clastics and locally significant evaporites and salt units. These types of non-continental units are either poor or devoid of vitrinite. This is corroborated by the nature of dispersed organic matter observed under the microscope (Fig. 5). Therefore, zooclasts and solid bitumen are the only available type of particles for the reflectance analysis to precise the thermal maturation of the Hudson Bay Basin.

Reflectance analysis and interpretation of thermal maturation

Particles

The detailed results of the DOM reflectance of all cutting samples with sufficient kerogen are summarized in Annex 3. For each sedimentary unit, the annex presents for individual sample: 1) the average value, 2) the standard deviation and 3) the number of measurements, all these for the main types of identified zooclasts (undetermined, chitinozoans, graptolites, hydroids, scolecodonts) and other particles (liptinite, inertinite, vitrinite, migrabitumen droplets, migrabitumen and natural coke). At the extreme right end of the annex, our interpretation of 1) the vitrinite-equivalent reflectance value ($R_{o\text{-}evi}$), 2) the correspondent pre-metamorphic diagenetic domain and 3) the assumed hydrocarbon generation window. The estimated vitrinite-reflectance values ($R_{o\text{-}evi}$) are based on mathematic formula with results shown in Figure 4. The thermal maturation domains are based on scales suggested by Héroux *et al.* (1979) and Hunt (1995).

Most of the organoclasts comprise material unambiguously identified and material most likely related to a specific organoclasts. Measurements on chitinozoans are taken from walls and opercula.

Graptolite data are from measurements taken on the theca and spines but exclude any particle devoid of the fusellar structure. Liptinite data include measurements taken on bituminite, alginite, spores and acritarchs. Inertinite data comprise fusinite, semi-fusinite and pseudo-vitrinite. The vitrinite group includes measurements from telinite, collinite and undifferentiated vitrinite. Data for migrabitumen include values on diverse type of solid bitumen that are close to measurements on the isotropic form of this particle. Natural coke and migrabitumen droplets are both excluded for the migrabitumen statistical data.

Results as frequency distribution

Examples of frequency distribution of individual reflectance values are shown in Figure 6 for the Beluga O-23 well. This is the raw data used to calculate statistical parameters (average, standard deviation) in Annex 3. This figure offers reflectance data histograms for six (6) of the seventeen (17) samples analysed for that well and displays the analysed materials reflectance values for six Ordovician to Devonian stratigraphic units. The nature of DOM on which measurements were taken changes

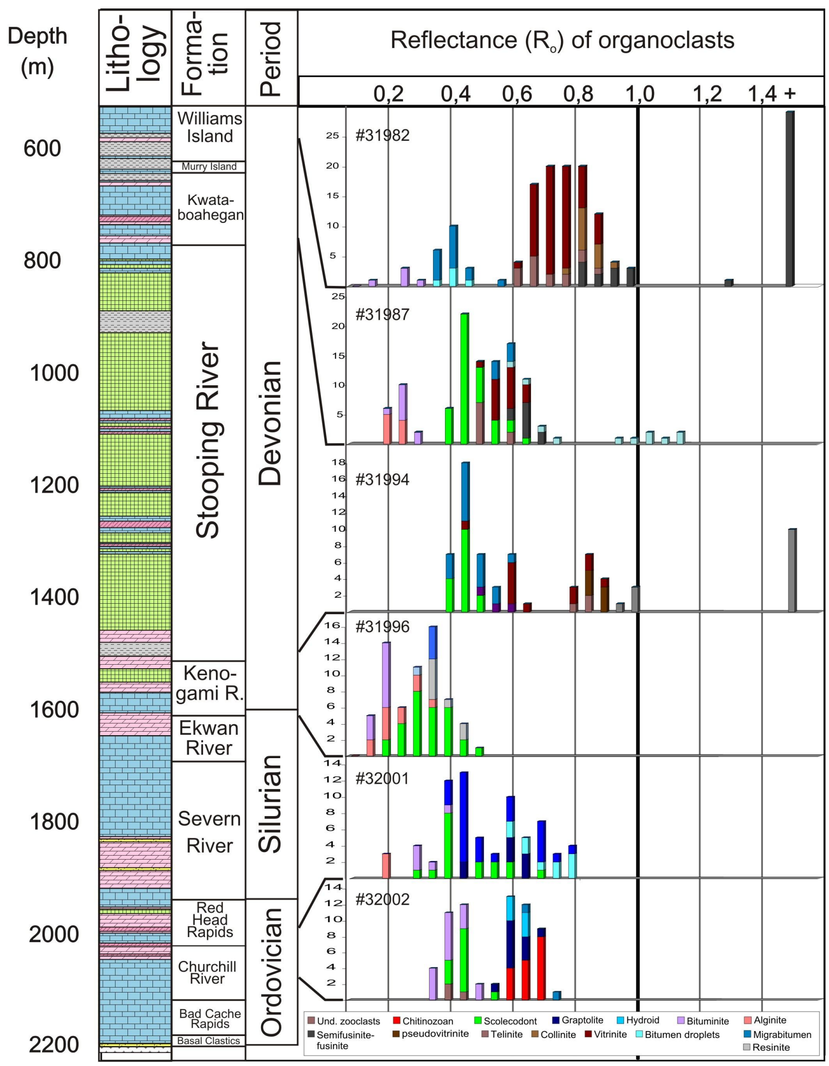

Figure 6. Reflectance analysis of the Beluga O-23 well, frequency distribution of individual reflectance (R_o) values for selected samples.

significantly to stratigraphic top to bottom. For the Devonian units, the reflectance measurements were mostly taken from macerals that belong to the vitrinite and inertinite groups. For the Ordovician-Silurian units, reflectance data come largely on zooclasts (chitinozoans, graptolites, hydroids and scolecodonts) and migrabitumen. This figure also shows that scolecodonts and bituminite are present in all Ordovician to Devonian stratigraphic units. However, if the reflectance of bituminite increases from top to bottom of the well, the downward evolution of scolecodonts reflectance data is less precise.

Beluga O-23 well – reflectance profile as a function of depth

Figure 7 presents the entire results of the reflectance of DOM for the Beluga O-23 well. This figure offers the interpretation of thermal maturation evolution with depth. Each coloured symbol represents the average of reflectance values for specific type of DOM. All the average data points are plotted against the organoclasts reflectance (R_o) scale on top. Thirteen (13) stratigraphic intervals have been sampled in that specific well and a total of eleven (11) types of DOM have been identified.

It is from the average values of the most pertinent organoclasts that the vitrinite-equivalent reflectance ($R_{o\text{-}evi}$) is calculated for each of the 13 intervals based on equations presented before. A $R_{o\text{-}evi}$ data (black square) is obtained whether or not vitrinite macerals are present. The coloured background represents various hydrocarbon generation zones (immature, oil, condensate, dry gas, sterile) correlated with $R_{o\text{-}evi}$ thresholds (top of the diagram). The vertical trend built with $R_{o\text{-}evi}$ data suggests that the onset of oil window ($R_{o\text{-}evi}$ of 0.6%) occurs near the base of the Devonian – top of the Silurian, almost exactly at the position where the significant biostratigraphic time hiatus / unconformity has recently been documented (Hu *et al.*, 2011). The Devonian units are immature with respect to thermogenic hydrocarbon generation whereas the Silurian and Ordovician units have reached

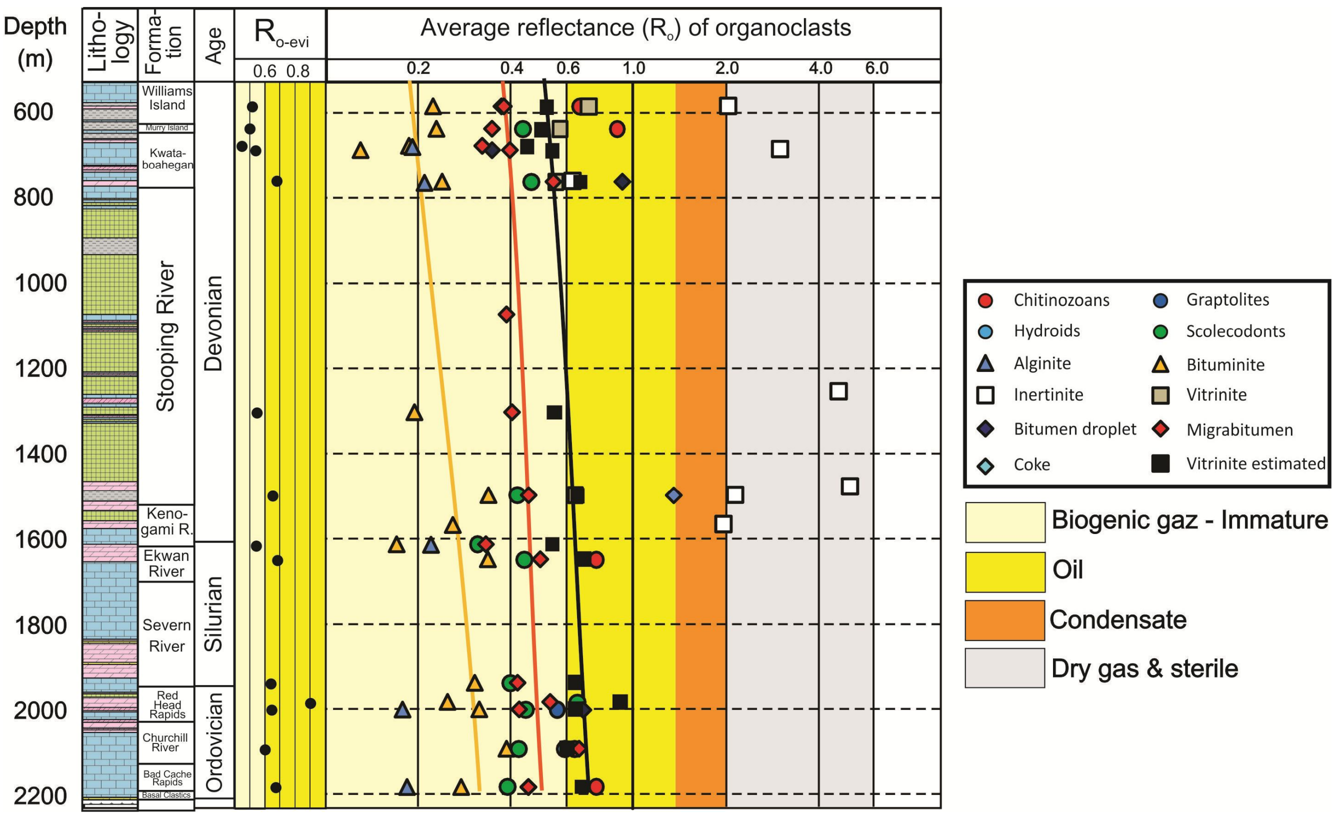

Figure 7. Organoclasts average reflectance values (R_o) in the Beluga O-23 well and estimated reflectance of vitrinite ($R_{o\text{-}evi}$)

oil window conditions. The highest $R_{o\text{-}evi}$ value is below 1%; the succession does not have potential to have generated thermogenic gas (Fig. 7).

Estimated reflectance ($R_{o\text{-}evi}$*) values for the other wells*

The same approach is applied to the 3 other studied wells and allows generating the regional synthesis of $R_{o\text{-}evi}$ values for the 4 wells that is shown on Figure 8. The results are presented in the context of the new regional stratigraphic correlation (Hu *et al.*, 2011) (Fig. 3).

Only one significant result is derived from the Netsiq well. In the 450-455 m interval, the cutting sample contains a unique type of kerogen not seen in other wells, the migrabitumen is strongly anisotropic and reflectant (R_o of 0.74; oil window); natural coke, with R_o of close to 7%, is also common. These results indicate that this type of organic matter is most likely derived from the old Proterozoic successions that are present at various places on the Canadian Shield. The kerogen of the

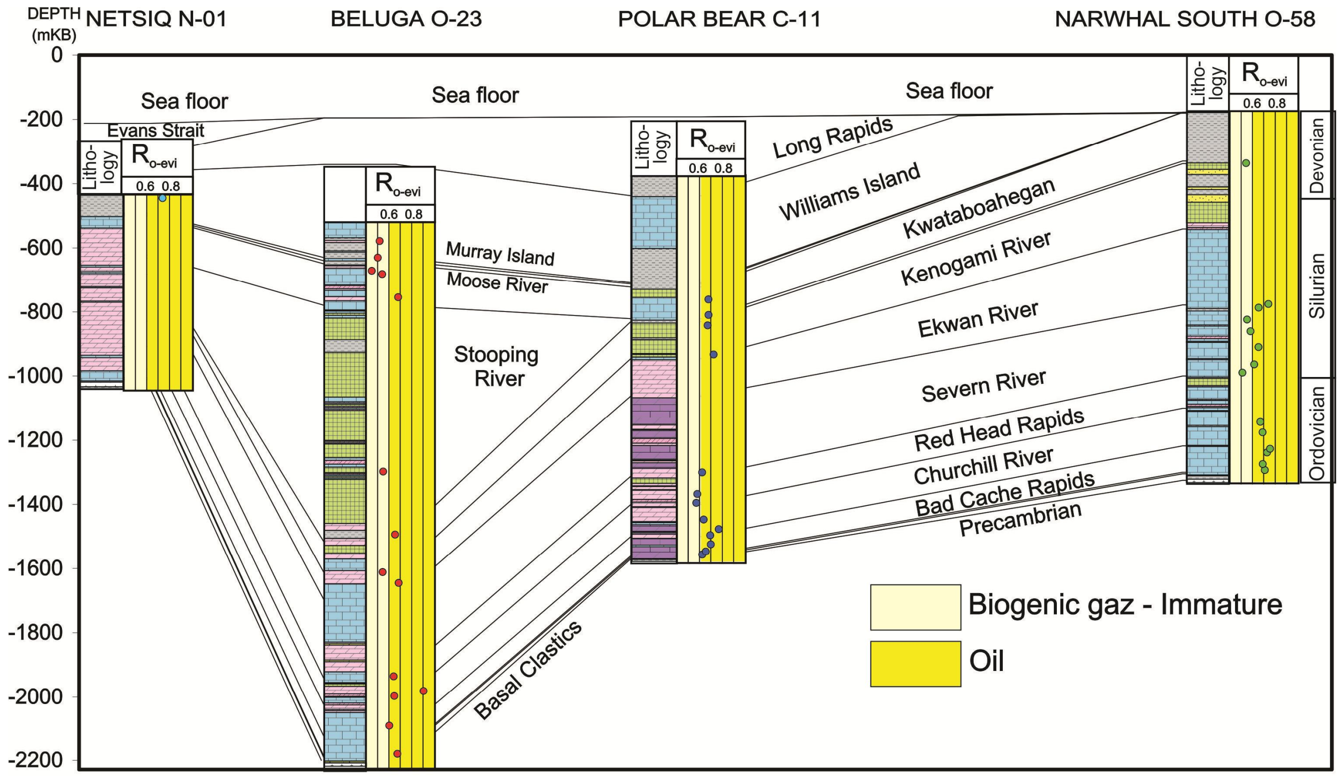

Figure 8. Estimated vitrinite reflectance ($R_{o\text{-}evi}$) and hydrocarbon stages in four studied wells of Hudson Bay Basin.

remaining seven (7) samples of this well is completely contaminated by major amounts of lignite. The final drilling report (Cantera Energy Ltd, 1986) indicates that diverse varieties of lignite were added to the drilling mud from 840 m down to total depth. Beside the sample at 450-455 m, only one other cutting sample (535-540 m) is above the 840 m depth; this sample is largely devoid of organoclasts (4 measurements on liptinite: Annexe 3).

The other three wells display $R_{o\text{-}evi}$ values that increase more or less clearly with depth. This trend is best represented in the Beluga well (Figs. 7 and 8). The evolution is less obvious for the Narwhal South well and seemingly absent in the Polar Bear well (Fig. 8). The lack of obvious trends for the last two wells relies on the presence of some abnormal $R_{o\text{-}evi}$ values that are either significantly above or below the overall trend defined by the other data (Fig. 8). This pattern of abnormal $R_{o\text{-}evi}$ values with depth is not unique to Hudson Bay Basin as it was also noted for material from wells drilled on Anticosti Island and on the St. Lawrence Lowlands. The latter two areas comprise lower Paleozoic sedimentary successions dominated by shallow marine depositional environments in the Ordovician to

Early Silurian. However, these seemingly random variations are of lower magnitude in the Anticosti Island and St. Lawrence Lowlands basins and vertical profiles of $R_{o\text{-}evi}$ are less equivocal (Bertrand et Héroux, 1987; Bertrand, 1990b; Héroux et Bertrand 1991).

For the Beluga and Narwhal wells, the Devonian successions are in the immature / biogenic gas window with $R_{o\text{-}evi}$ values below 0.6% (Fig. 8). In the Beluga well, between 700 and 1600 m, from the Kwataboahegan to the Kenogami River formations, the $R_{o\text{-}evi}$ values fluctuate between 0.55 to 0.67% (4 points) even with widely separated samples (Fig. 8), an interval that spans the threshold of the oil window at 0.6%. Below the Silurian Kenogami River Formation down to the Ordovician Bad Cache Rapids Formation, the entire succession has reached thermal conditions favourable for generation of oil.

For the Polar Bear well, the uppermost $R_{o\text{-}evi}$ data are from the Kwataboahegan Formation. The values and those of the underlying units are generally over 0.6% and up to 0.7%, all indicative of the oil window. However, two samples (Red Head Rapids Formation; 1372 and 1399 m depth) have $R_{o\text{-}evi}$ values of 0.58 and 0.57%, respectively, at the margin of oil window (Fig. 8).

For the Narwhal South well, one sample from the Kenogami River Formation suggests that the Devonian successions are immature (Fig. 8). Seven (7) samples from the Lower Silurian Severn River Formation have $R_{o\text{-}evi}$ data ranging between 0.51 and 0.78% that indicates immature to oil window conditions. The following six (6) samples from the Ordovician Churchill River Group and Bad Cache Rapids Formation have $R_{o\text{-}evi}$ values over 0.7%, this suggests that these units have reached the oil window.

In summary, the DOM reflectance data indicate that for the Beluga, Polar Bear and Narwhal South wells, the Devonian succession are thermally immature (Fig. 8). The oil window conditions are first reached in the Kenogami River or in the Severn River formations depending on specific wells. Moreover, besides few samples, the Ordovician interval is well within the oil window as $R_{o\text{-}evi}$ data are fluctuating in a narrow range close to 0.7%.

Correlation between dispersed organic matter reflectance and Rock Eval data

Pyrolysis potential of rock kerogen

Zhang (2008, 2010) and Armstrong and Lavoie (2010, 2011) have documented the presence of excellent Upper Ordovician hydrocarbon source rocks in Southampton Island and Northern Ontario, respectively. TOC values of the oil shale on Southampton Island are up to 35% and up to 15% for the Northern Ontario exposures. In both cases, hydrogen index can be as high as 650 kg HC/ t TOC. In her detailed work on cuttings, Zhang (2008) was able to identify a few organic matter or bitumen-rich grains in the cuttings associated with high gamma-ray kicks on the offshore wells logs.

Figures 9 and 10 integrate 1) $R_{o-evi,}$ 2) hydrogen index (HI) and 3) total organic carbon (TOC). The estimated-vitrinite reflectance (R_{o-evi}) is the indicator of the thermal maturation, the hydrogen index (HI) is the indicator of the nature of the dispersed organic matter and the total organic carbon (TOC) reflects the quantity of organic matter present in the rock.

The integration of these three elements allows classifying the nature of the dispersed organic matter of a potential source rock in one of the three major geochemical types: I - algal; II - planktonic and III - humic. The integration of the data allow the determination of the actual pyrolysis potential of a source rock as a function of potential weight (kg) of hydrocarbons for a ton of rock and lead to hypothesis about the hydrocarbon potential of a source rock prior to maturation.

All data shown on figures 9 and 10 are listed in the Annex 4. These figures aim at characterizing the source rock potential of the samples, therefore all samples with TOC values lower than 0.1% are excluded. Moreover, Rock Eval data on such lean material is considered not reliable (Hunt, 1995).

Figure 9 displays the correlation between the hydrogen index (HI) and the reflectance of organic matter (R_{o-evi}) for specific sedimentary units. The Devonian formations are represented by the

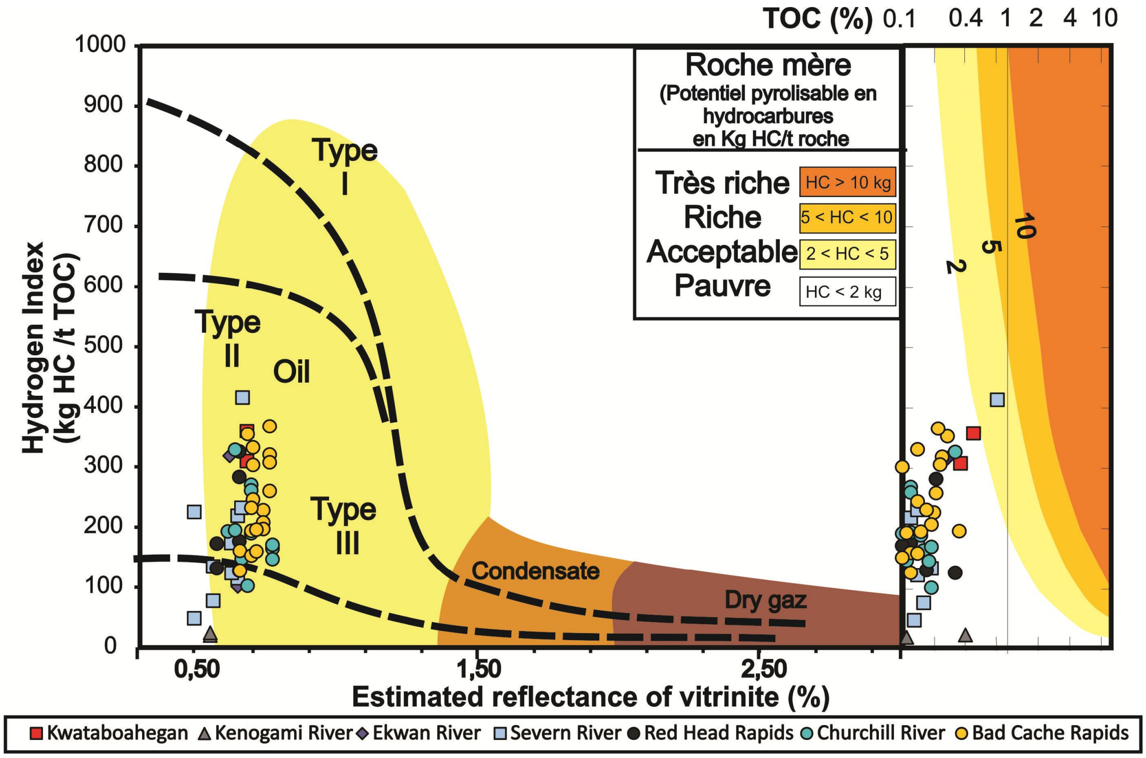

Figure 9. Geochemical nature, maturity domains, estimated vitrinite reflectance (%) and pyrolysis potential in hydrocarbons (HC) of the organic matter in three Hudson Bay wells based on stratigraphic units (TOC >0.1%).

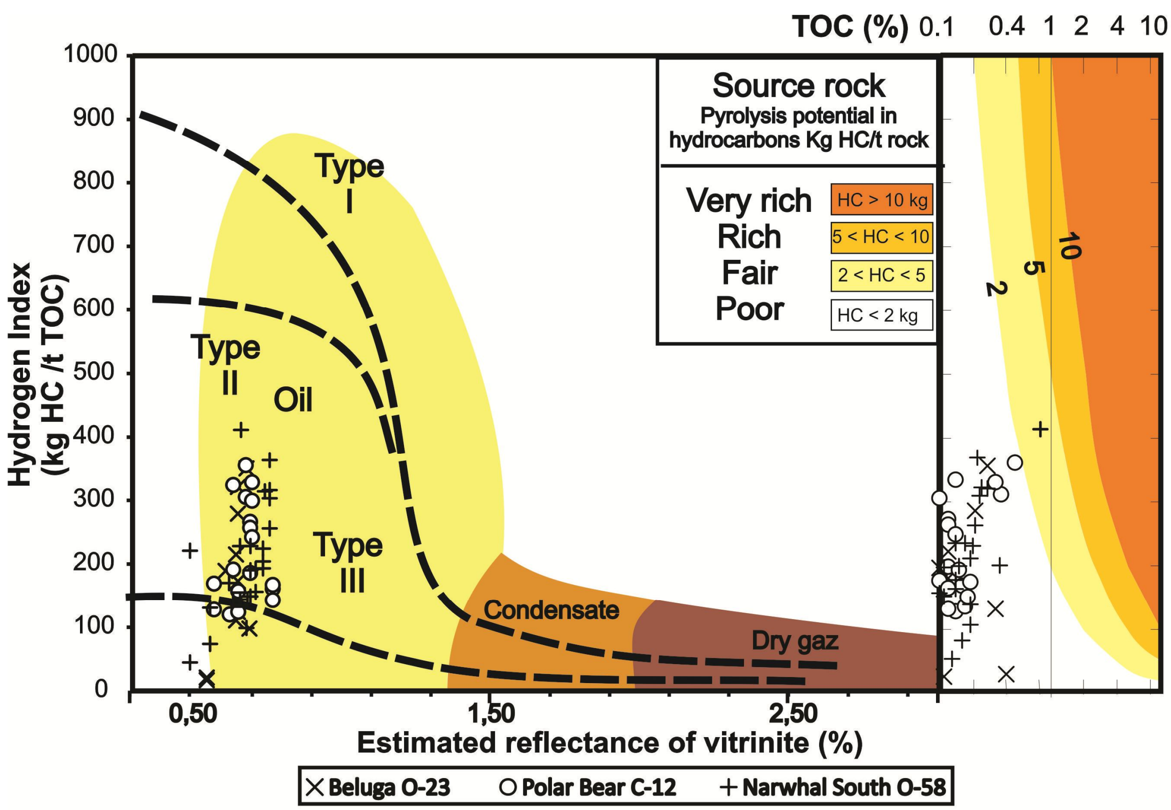

Figure 10. Geochemical nature, maturity domains, estimated vitrinite reflectance (%) and pyrolysis potential in hydrocarbons (HC) of the organic matter in three Hudson Bay wells (TOC >0.1%).

Kenogami River and Kwataboahegan formations; Rock Eval data are not available for the other units. The Silurian-Ordovician Ekwan River, Severn River, Red Head Rapids, Churchill River and Bad Cache Rapids formations or group have been analysed.

The left-hand side of Figure 9 displays the evolution of HI with respect to the thermal evolution ($R_{o\text{-}evi}$) of the sampled units. The dispersed organic matter is relatively similar in all units, the kerogen being of a mixed Type II and III origin. The most hydrogen-depleted kerogen is from the Kenogami River Formation, the most varied types of kerogens are found in the Severn River Formation whereas the Kwataboahegan Formation offers the kerogen with the highest hydrogen content (Fig. 9).

The right-hand side of Figure 9 compares the HI with the TOC. The relationship allows estimating the eventual hydrocarbon production from pyrolysis. Besides one value from the Severn River Formation, which can be considered as a fair source rock for oil (3.3 kg HC/ t), all samples are poor source rocks. This conclusion is not surprising given the fact that TOC values are all below 0.5% and the HI are lower than 400 kg HC/t TOC.

Figure 6 to 9 illustrate that these rocks are close or slightly above the threshold of oil window ($R_{o\text{-}evi}$ between 0.5% and 0.75%). Therefore, the actual composition of the kerogen is close to that prior to thermal maturation. The diagram suggests that the analyzed samples are poor hydrocarbon source rocks.

Figure 10 displays the same dataset as Figure 9 with however data being presented on a well basis. The HI vs $R_{o\text{-}evi}$ plot shows that the kerogen is similar for the three wells whereas from the TOC vs kg HC/t rock, only the Severn Formation from the Narwhal South well has a fair source rock potential. The Polar Bear well has the next three best source rock units whereas the Beluga well has the lowest potential source rock units.

Hydrocarbon migration

Figures 11 and 12 compare the production index (PI) values as a function of thermal maturation

($R_{o\text{-}evi}$). The coloured fields illustrate the variations of PI during the various stages of hydrocarbon generation. For a source rock, values in the coloured field indicate that even if hydrocarbons were generated, the products would not have been expelled from the source rock. The limits of the various hydrocarbon domains are based on the vitrinite reflectance as presented on Figure 4.

Values of PI higher than the coloured domain are indicative of hydrocarbon charge in the rock unit, whereas lower PI values suggest expulsion of hydrocarbons out of the rock unit. Figure 11 displays the relationship for the stratigraphic units. Forty-one (41) samples are found in the coloured fields (immature and oil window), therefore, any hydrocarbon generated by these units is still trapped in the rock whatever their maturation. Ten (10) samples from four (4) stratigraphic units have PI values higher than the expected values at specific thermal rank.

Four samples of the Upper Ordovician Read Head Rapids Formation are in that group; this unit

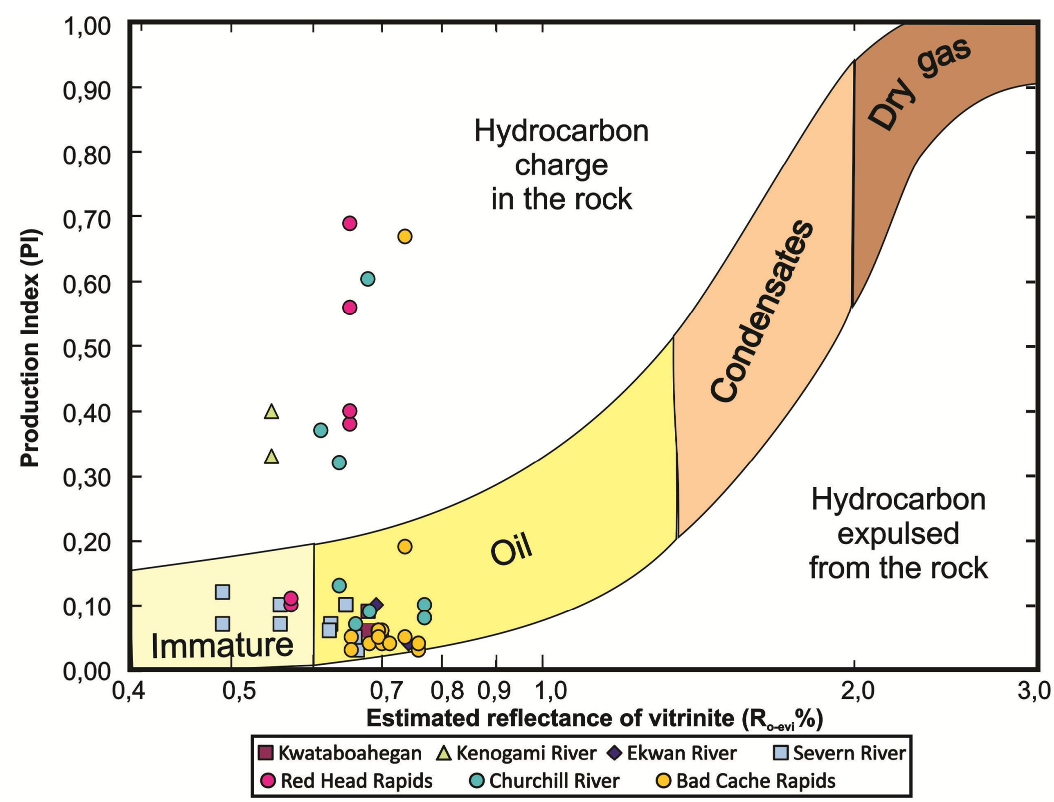

Figure 11. Relationship between the estimated vitrinite reflectance **($R_{o\text{-}evi}$%)** and the production index (PI), in three wells of the Hudson Bay Basin based on stratigrahic units. Diagram modified from Tissot and Welte (1984) and Hunt (1995).

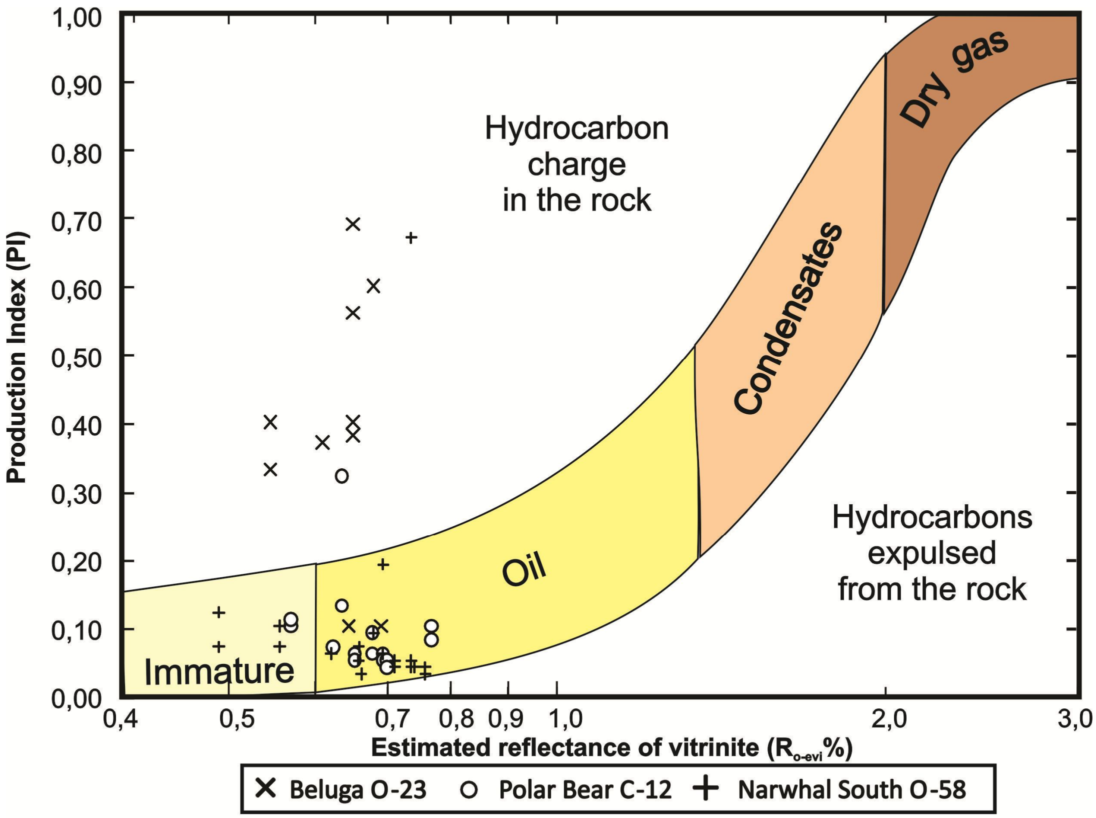

Figure 12. Relationship between the estimated vitrinite reflectance **(R_{o-evi}%)** and the production index (PI), in three wells of the Hudson Bay Basin. Diagram modified from Tissot and Welte (1984) and Hunt (1995).

is the host of the oil shale intervals on Southampton Island (Zhang, 2008, 2010). Four (4) more Ordovician samples also have higher PI values, and include three (3) samples from the Churchill River Group and one from the Bad Cache Rapids Formation. Two (2) samples from the Kenogami River Formation also have higher PI values at their thermal rank. These results indicate that these analysed samples have been the site of a hydrocarbon charge event. Some of the Ordovician units can therefore being considered as potential reservoirs.

Figure 12 presents the same data set on a well basis. It is obvious that most of evidence of hydrocarbon charge is found in the Ordovician and Silurian units of the Beluga well. Limited evidence of charge in Ordovician units is found in the other two wells.

DISCUSSION

The first reports of organic matter reflectance for the Hudson Bay Basin have generated a long period of controversies on the thermal maturation of the successions. Reflectance measurements were reported to be made on vitrinite, although the presence of vitrinite in pre-Devonian rocks is equivocal. In order to evaluate the thermal history of the successions Penigel *et al.* (1975a and b) and Fallgatter (1984) used standard techniques and preparations applied to the petrography of vitrinite in coals which cannot discriminate the marine organoclasts, in particular, the zooclasts that constitute the main fraction of the pre-Devonian kerogens (Tissot et Welte, 1984).

The reflectance analyses of the Penigel *et al* (1975a and b) and Fallgatter (1984) suggested that the entire Hudson Bay basin succession was immature. However, the work by Dolby (1986) on conodont colour alteration indicated oil window conditions for the lower part of the wells, a conclusion rejected by Zhang and Barnes (2007). The latter concluded that based on the colour alteration of hundreds of conodonts, the sedimentary succession is immature. The same authors also indicated that the on-shore stratigraphic equivalents are less mature than that of the offshore.

Rock Eval data is considered to provide unequivocal data to address the thermal rank of sedimentary successions. In the case of the Hudson Bay Basin, the main thermal indicator, the maximum temperature for pyrolysis (T_{max}) is slightly over the oil window threshold (435°C) in the Ordovician Churchill River Group and Bad Cache Rapids Formation in the Narwhal South well. However, this threshold is surpassed in the Silurian Severn River Formation in the Polar Bear well (Zhang and Dewing, 2008). For the onshore wells and outcrop samples, the T_{max} values are even lower and these authors concluded that the onshore extension of the Hudson Bay Basin is immature.

The herein reported R_{o-evi} values are in good agreement with the Rock Eval T_{max} data. The Devonian successions are immature and the transition into the oil window is roughly coincident with the Silurian-Devonian boundary for the Polar Bear and Beluga wells. For all three wells, the entire Ordovician succession is definitively in the oil window (Fig. 8). Therefore, the study of organic matter reflectance supports a significantly thicker oil window zone compared to previous Rock Eval and conodonts colour alteration data.

A recent reflectance study on 2 onshore wells in Northern Ontario (INCO-Winisk Core #49212 and INCO-Winisk Core #49204) has generated $R_{o\text{-}evi}$ ranging between 0.74 and 0.82% (Armstrong et Lavoie, 2010, 2011; Reyes *et al.*, 2011). This study focussed on Ordovician successions that are equivalent to the base of the offshore wells (Boas River Formation, Churchill River Group and Bad Cache Rapids Formation). These values indicate that the Ordovician successions in Northern Ontario are well within the oil window.

The petrographic preparation allowed the identification of chitinozoans but not graptolites or scolecodonts, the latter possibly included with phosphatic conodonts. The $R_{o\text{-}evi}$ is based on bitumen reflectance (Reyes *et al.*, 2011). When the reflectance of chitinozoans is transformed in $R_{o\text{-}evi}$ (Fig. 4), there is a good correlation between the chitinozoans and the bitumen reflectance. In the following discussion, the $R_{o\text{-}evi}$ values are based on both the solid bitumen and chitinozoan data.

It is possible to correlate the reflectance of vitrinite-equivalent from the three offshore wells with that of the two onshore wells in Northern Ontario. Figure 13 shows the average $Ro_{\text{-}evi}$ of the Ordovician succession in all five wells. This correlation represents the first preliminary regional thermal maturation map for the Hudson Bay basin. However, given the size of this sedimentary basin, obviously, significant caution and care are needed when one tries to extrapolate.

Figure 13 shows that the $R_{o\text{-}evi}$ values for the Upper Ordovician are essentially similar for offshore and onshore wells. This is a critical observation to suggest that the thermal maturity is not related to the actual depth of the successions. In the deepest part of the sedimentary basin, up to 2.5 km of preserved strata are recognized. However, the presence of a major unconformity / hiatus has been documented at the Silurian-Devonian boundary (Hu *et al*., 2011) and it is possible that an interval of unknown thickness has been eroded at that time. With similar $R_{o\text{-}evi}$ data, it is necessary, at maximum burial, to have a succession as thicker over the current erosional margin of the basin, as the one present in the central part of the basin. From these evidence, it follows that the actual basin morphology is certainly different from the situation in Paleozoic time.

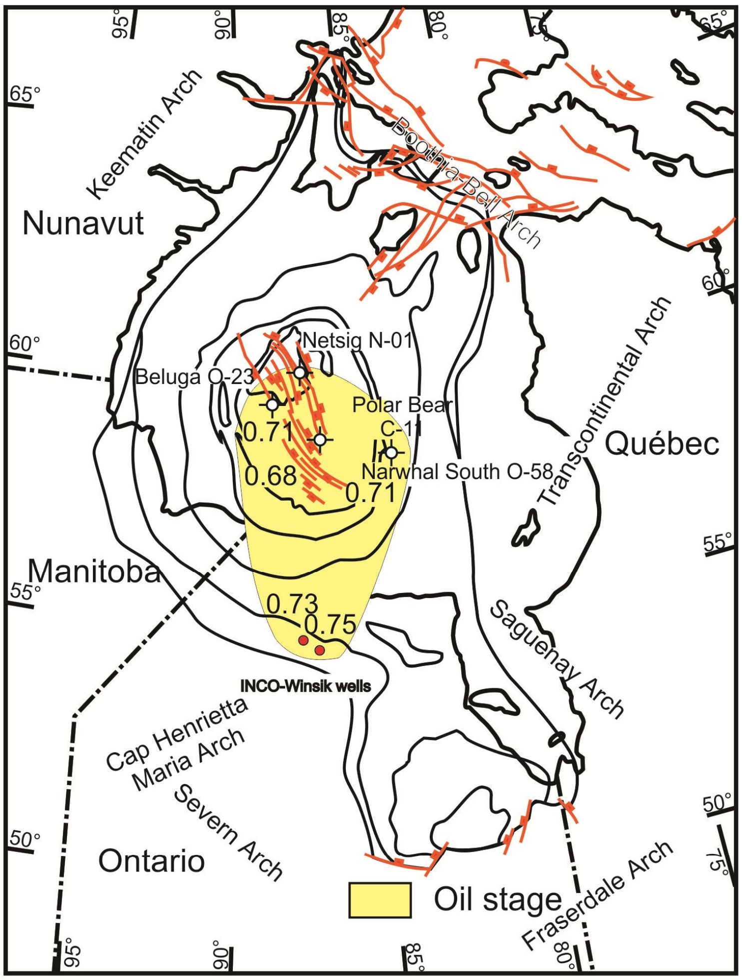

Figure 13. Isovalues zones of the estimated reflectance of vitrinite ($R_{o\text{-}evi}$) in the Ordovician strata of the studied area of the Hudson Bay basin. Data from three offshore wells are in this report and data for the two onshore Ontario wells are in Armstrong and Lavoie (2011) and Reyes et al. (2011).

The evolution of $R_{o\text{-}evi}$ in the three offshore wells (Fig. 8) is imperfectly defined. Regression correlation coefficients “R” are rather low (R = 0.62 for Beluga well and R= 0.67 for Narwhal South well) to even inexistent for the Polar Bear well. The $R_{o\text{-}evi}$ evolution with depth is more straightforward for the lower Paleozoic successions of the St. Lawrence Platform of Anticosti Island and southern Québec (Bertrand and Héroux, 1987; Bertrand, 1990b; Héroux and Bertrand, 1991).

Differences in lithology, diagenetic evolution or hydrothermalism could be invoked to explain the discrepancies. Clastics are definitively more abundant on the St. Lawrence platform (Lavoie, 2008) compared to the Hudson Bay successions. In the St. Lawrence Platform, porous and permeable facies are restricted to basal clastics and dolomites whereas, in the Hudson Bay Basin, the limestones and dolomites have significant porosity (Hu and Dietrich, in press) and clastics are rare (Fig. 2). Hydrothermal alteration will generate significant secondary porosity and erratic variations of $R_{o\text{-}evi}$ (Bertrand, 1987; Héroux and Tassé, 1990; Bertrand *et al.* 2003; Davies and Smith, 2006). The current well and field observations for the Ordovician and Silurian (?) of the Hudson Bay Basin document significant hydrothermal alteration with important secondary porosity (Nicolas and Lavoie, 2009, 2010; Lavoie *et al.*, 2011a). The erratic $R_{o\text{-}evi}$ variations could be related to hydrothermal effects but more data is needed to back up such preliminary working hypothesis.

Rock Eval data for the three offshore wells indicates that the succession does not contain significant source rock (Zhang et Dewing, 2008). However, Zhang (2008) extended the presence of oil shales on Southampton Island to the central part of the Hudson Bay on detailed examination of cuttings and gamma ray log interpretation. The low TOC values can provide an explanation on the divergence between Rock Eval data and petrographic observations for the nature of the kerogen. From Rock Eval, the organic matter can be interpreted to have a significant humic component (Type III). However, the petrographic study reveals an organic matter rich in amorphinite, algal fragments, acritarchs and other zooclasts, such assemblage is typical of a sapropilic kerogen (Type I – II). Results from the Comeault well, onshore Manitoba, show for equivalent Ordovician units, the presence of type II organic matter (HI over 300 kg HC/t TOC; Zhang and Dewing, 2008). Moreover, the TOC values from the Comeault well are well above 1.0%.

Evidences for hydrocarbon migration are detected from Rock Eval and petrography. The Rock Eval data suggest that the central domain of the Hudson Bay, near or on the « Central High » is an area of hydrocarbon charge. This charge is confirmed by the presence of migrabitumen droplets in number of stratigraphic units: Kwataboahegan, Kenogami River, Severn River, Churchill River and Bad Cache Rapids. The Churchill River Group and the Bad Cache Rapids Formation in the Beluga and Polar Bear wells show the most abundant migrabitumen droplets. However, more data would be needed to precise the relationship between the Rock Eval data and the petrographic observations on dispersed organic matter.

CONCLUSIONS

The thermal evolution of the lower Paleozoic rocks of the Hudson Bay Basin is evaluated through reflectance of diverse organoclasts such as chitinozoans, graptolites, scolecodonts, hydroids and solid bitumens. Vitrinite is the standard reference material for reflectance, although it cannot be used in our study as this maceral from coal-derived terrestrial material is absent from the Ordovician and Silurian successions.

The thermal maturation of the sedimentary successions in three wells in the central part of Hudson Bay indicates that the Devonian interval is immature whereas the Ordovician-Silurian successions are within the oil window. However, the vertical evolution of vitrinite-equivalent reflectance based on available organoclasts (vitrinite, zooclasts and solid bitumen) is not as clear as that of coeval, but more mature, successions of the St. Lawrence Platform in Anticosti Island and in southern Quebec.

From available Rock Eval data, almost all samples examined under the microscope, have too low total organic carbon (TOC) to be considered as a potential hydrocarbon source rock. Moreover, the low TOC values might explain the fact that based on Rock Eval hydrogen index, the Ordovician and Silurian shallow marine units belong to the geochemical Type III terrestrial-derived organic matter. This assumed composition does not agree with the clear marine depositional facies as well as from the petrographic observations that document marine kerogen such as planktonic and benthic organoclasts and algal material.

The integration of organic matter reflectance with Rock Eval data indicates that the Red Head Rapids Formation, which hosts a significant hydrocarbon source rock in the basin (Zhang, 2008; 2010) has been charged with hydrocarbons in the Beluga well. The other Ordovician units (Churchill River Group and Bas Cache Rapids Formation) have also been charged with migrating hydrocarbons. The relative absence of good hydrocarbon source rocks and the presence of hydrocarbon charge event(s) in the lower part of the succession could be related to the fact that these wells are located on a structural high in the basin. It could be hypothesized that away from the structural high, in deeper marine settings, conditions favourable for the sedimentation of Ordovician to even Silurian good hydrocarbon source rocks could have been met. At distance from the central high, very rich Upper Ordovician (Macauley, 1986, 1987; Zhang, 2008, 2010, 2011, Armstrong and Lavoie, 2010, 2011) and fair Lower Silurian (Zhang and Dewing, 2008) source rocks are well known.

The actual shape of the Hudson Bay basin is the results of profound erosion; the thin succession in the onshore extension in Northern Ontario was, based on new organic matter reflectance data, once covered by a succession as thick as the one currently present in the central part of Hudson Bay.

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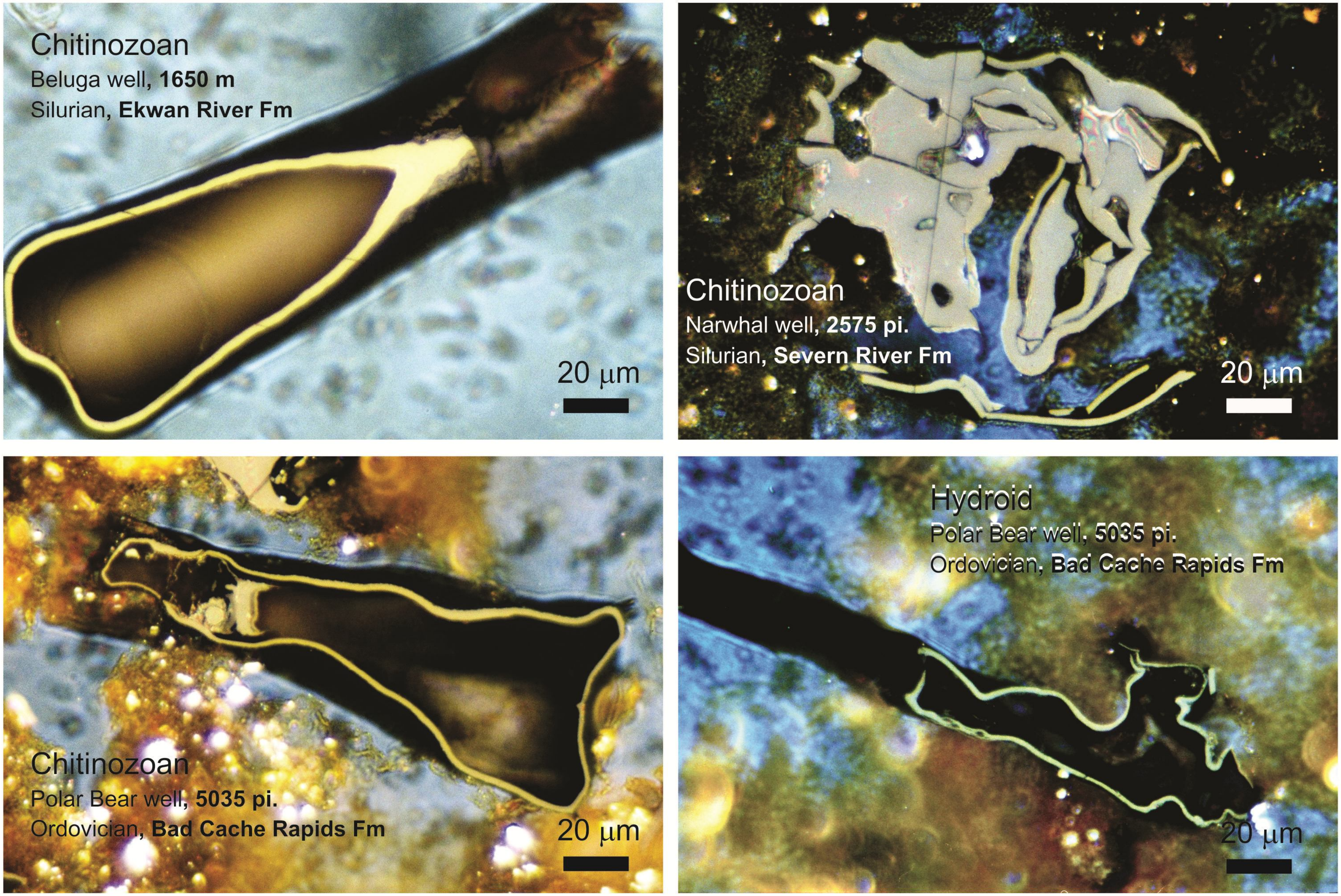
Chitinozoan
Beluga well, 1650 m
Silurian, Ekwan River Fm
20 µm
Chitinozoan
Narwhal well, 2575 pi.
Silurian, Severn River Fm
20 µm
Chitinozoan
Polar Bear well, 5035 pi.
Ordovician, Bad Cache Rapids Fm
20 µm
Hydroid
Polar Bear well, 5035 pi.
Ordovician, Bad Cache Rapids Fm
20 µm

Plate 1

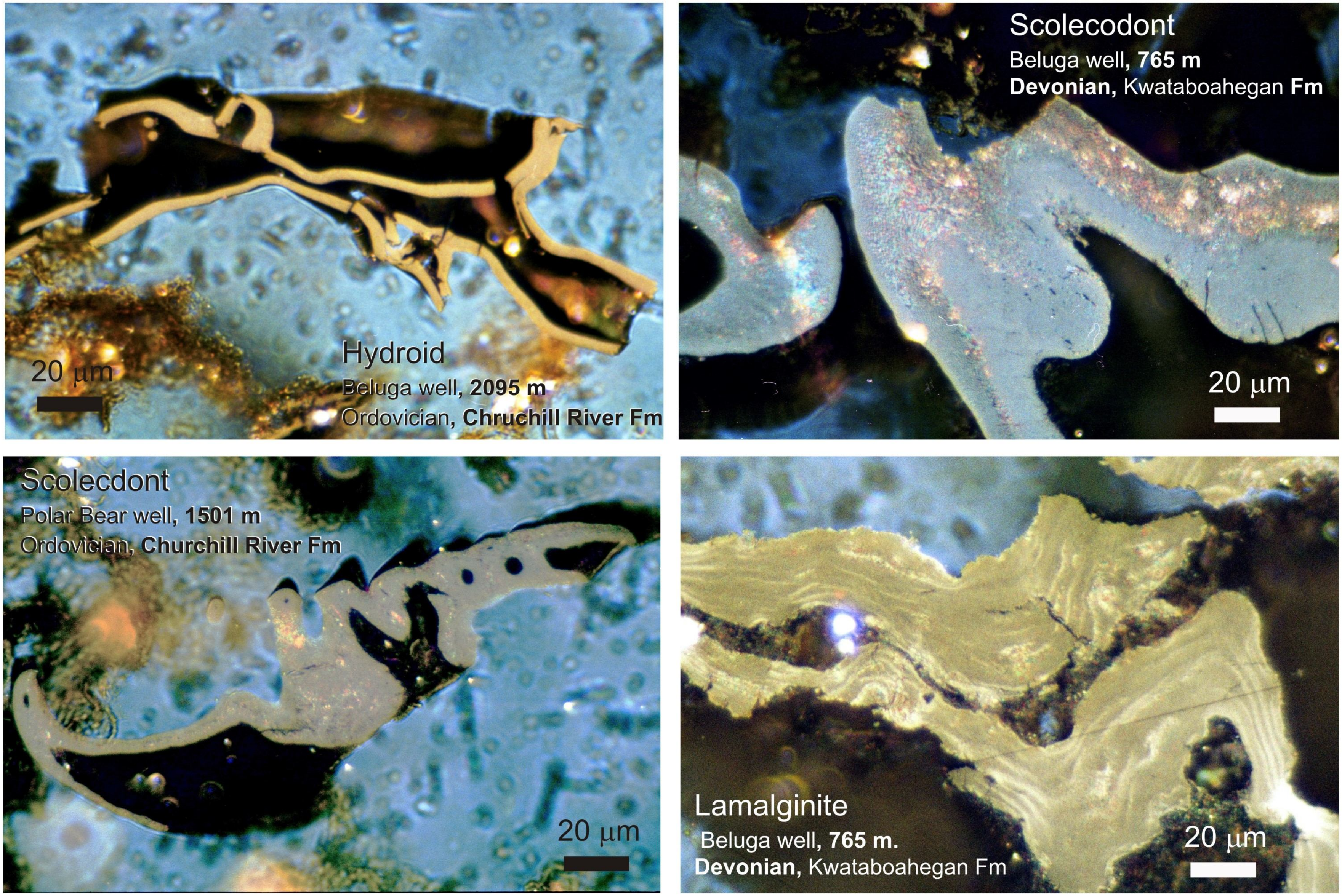
Hydroid
Beluga well, 2095 m
Ordovician, Chruchill River Fm
20 µm
Scolecodont
Beluga well, 765 m
Devonian, Kwataboahegan Fm
20 µm
Scolecdont
Polar Bear well, 1501 m
Ordovician, Churchill River Fm
20 µm
Lamalginite
Beluga well, 765 m.
Devonian, Kwataboahegan Fm
20 µm

Plate 2

Table 1		**Zooclasts**						**Liptinite**				**Humic**			**Migrabitumen**				
Stratigraphic unit	**NB**	**zoo**	**chit**	**grap**	**hyd**	**scol**	**Total**	**am**	**proto**	**lip**	**total**	**inert**	**vitr**	**total**	**Dpt**	**Isotro pic**	**aniso tropic**	**total**	**Coke**
Williams Island	2	0	TR	0	0	0	**1**	64	10	0	**74**	3	20	**23**	0	0	TR	**1**	3
Murry Island	1	0	1	0	0	1	**2**	93	0	0	**93**	0	1	**1**	0	4	0	**4**	0
Kwataboahegan	6	TR	TR	0	0	2	**2**	73	2	20	**94**	TR	0	**1**	TR	3	0	**3**	0
Stooping River	3	0	0	0	0	1	**1**	93	2	0	**95**	0	0	**0**	0	4	0	**4**	1
Kenogami River	7	TR	TR	0	0	2	**2**	89	2	2	**94**	TR	0	**0**	0	3	0	**3**	TR
Ekwan River	1	0	5	0	0	10	**15**	70	10	0	**80**	0	0	**0**	0	5	0	**5**	0
Severn River	11	TR	TR	0	0	TR	**2**	88	3	6	**97**	0	0	**0**	0	2	TR	**2**	0
Red Head Rapids	5	1	0	0	0	1	**3**	93	2	0	**95**	0	0	**0**	0	2	0	**2**	0
Churchill River*	3	0	0	0	0	0	**0**	28	0	5	**33**	29	35	**64**	0	0	0	**0**	3
Bad Cache Rapids*	1	0	0	0	0	0	**0**	0	0	0	**0**	10	90	**100**	0	0	0	**0**	0
Churchill River	6	0	10	3	16	4	**32**	42	3	17	**62**	0	0	**0**	TR	6	0	**6**	0
Bad Cache Rapids	9	0	3	0	1	4	**9**	63	2	4	**69**	1	10	**11**	TR	11	0	**11**	0

Table 1. Semi-quantitative average composition of dispersed organic matter in various stratigraphic units in the Hudson Bay Basin. * Netsiq well data as material was contaminated by lignite incorporated in drilling mud (Cantera Energy, 1986). NB = nomber of samples. TR = less than 1%. Zoo = undetermined zooclasts, chit = chitinozoan, grap = graptolite, hyd = hydroid, scol = scolecodont, am = amorphinite, proto = protobitumen-bituminite, lip = diverse liptinite, inert = inertinite, vitr = vitrinite, Dpt = migrabitumen droplet, coke = natural coke.

Netsiq N-01 (0290) 87°30'59,92" West 30'59,92"59° North

No INRS	Depth (m)		Lithology	Formation	Period	Epoch
	Upper	Lower				
31964	450	455	Shale	Williams Island	Devonian	Middle
31968	535	540	Limestone, shale	Kwataboahegan	Silurian	Upper
31971	715	720	Shale, dolostone	Ekwan River	Silurian	Lower
31974	860	865	Shale, dolostone	Severn River	Silurian	Lower
31975	915	920	Dolostone, shale	Churchill River	Ordovician	Upper
31976	920	925	Dolostone, shale	Churchill River	Ordovician	Upper
31977	940	945	Limestone, shale, dolomite	Churchill River	Ordovician	Upper
31980	995	1000	Limestone shale	Churchill River	Ordovician	Upper

Beluga O-23 (283) 88°33'27,184" West 33'27,184"59° North

No INRS	Depth (m)		Lithology	Formation	Period	Epoch
	Upper	Lower				
31982	580	590	Shale, dolomite	Williams Island	Devonian	Middle
31984	635	640	Shale, dolomite	Murry Island	Devonian	Middle
31985	675	680	Limestone , shale	Kwataboahegan	Devonian	Middle
31986	685	690	Shale, Limestone	Kwataboahegan	Devonian	Middle
31987	760	765	Limestone, shale	Kwataboahegan	Devonian	Middle
31990	1070	1075	Limestone, shale	Stooping River	Silurian	Middle
31991	1300	1305	Limestone, shale	Stooping River	Silurian	Middle
31993	1475	1480	Shale, dolomite	Stooping River	Silurian	Upper
31994	1495	1500	Dolostone, shale	Stooping River	Silurian	Upper
31995	1565	1570	Limestone	Kenogami River	Silurian	Upper
31996	1610	1615	Shale, dolomite	Kenogami River	Silurian	Lower
31997	1645	1650	Limestone, shale	Ekwan River	Silurian	Lower
31998	1800	1805	Limestone, shale	Severn River	Silurian	Upper
31999	1935	1940	Limestone	Severn River	Silurian	Upper
32000	1980	1985	Limestone, dolostone	Red Head Rapids	Ordovician	Upper
32001	1995	2005	Limestone	Red Head Rapids	Ordovician	Upper
32002	2090	2095	Limestone	Churchill River	Ordovician	Upper
32003	2180	2185	Limestone	Bad Cache Rapids	Ordovician	Upper

Polar Bear C-11 (0138) 86°47'18,489" West 47'18,489"58° North

No INRS	Depth (ft.)		Lithology	Formation	Period	Epoch
	Upper	Lower				
32004	1260	1270	Shale	Long Rapids	Devonian	Upper
32006	1520	1530	Shale, Limestone	Williams Island	Devonian	Middle
32009	1880	1895	Limestone, shale	Williams Island	Devonian	Middle
32011	2120	2140	Shale, Limestone	Williams Island	Devonian	Middle
32013	2515	2525	Limestone, shale	Kwataboahegan	Devonian	Lower
32014	2680	2690	Limestone, shale	Kwataboahegan	Devonian	Lower
32016	2780	2800	Evaporite	Stooping River	Devonian	Lower
32017	3085	3095	Limestone, shale	Ekwan River	Silurian	Upper
32018	3560	3570	Limestone, shale	Severn River	Silurian	Lower
32019	3745	3755	Limestone, dolostone	Severn River	Silurian	Lower
32020	4090	4100	Limestone, dolostone	Severn River	Silurian	Lower
32021	4290	4300	Limestone, dolostone	Severn River	Silurian	Lower
32022	4510	4520	Limestone, shale	Churchill River	Ordovician	Upper
32023	4600	4610	Limestone, shale	Churchill River	Ordovician	Upper
32024	4770	4780	Limestone, shale	Churchill River	Ordovician	Upper
32025	4865	4875	Limestone, shale	Churchill River	Ordovician	Upper
32026	4935	4945	Limestone, shale	Bad Cache Rapids	Ordovician	Upper

Polar Bear C-11 (0138) 86°47'18,489" West 47'18,489"58° North (suite)

No INRS	Depth (ft.)		Lithology	Formation	Period	Epoch
	Upper	Lower				
32027	5025	5035	Limestone, shale	Bad Cache Rapids	Ordovician	Upper
32028	5100	5110	Limestone, shale	Bad Cache Rapids	Ordovician	Upper
32029	5130	5140	Shale, Limestone	Basal Clastics	Ordovician	Upper

Narwhal South N-58 (0137) 84°8'2,963" West 58° 8'2,963" North

No INRS	Depth (ft.)		Lithology	Formation	Period	Epoch
	Upper	Lower				
32033	1130	1140	Shale	Kenogami River	Devonian	Lower
32034	1175	1185	Shale, grès	Kenogami River	Devonian	Lower
32037	1350	1370	Shale, grès	Kenogami River	Devonian	Lower r
32040	2565	2575	Limestone	Severn River	Silurian	Lower
32041	2600	2610	Limestone, shale	Severn River	Silurian	Lower
32042	2730	2740	Limestone, shale	Severn River	Silurian	Lower
32043	2845	2855	Limestone, shale	Severn River	Silurian	Lower
32044	3005	3015	Limestone	Severn River	Silurian	Lower
32045	3185	3195	Limestone	Severn River	Silurian	Lower
32046	3270	3280	Limestone	Severn River	Silurian	Lower
32047	3290	3300	Limestone	Red Head Rapids	Ordovician	Upper
32048	3490	3500	Limestone	Red Head Rapids	Ordovician	Upper
32049	3595	3605	Limestone	Red Head Rapids	Ordovician	Upper
32050	3790	3800	Limestone, shale	Churchill River	Ordovician	Upper
32051	3895	3905	Limestone, shale	Churchill River	Ordovician	Upper
32052	4050	4060	Limestone	Bad Cache Rapids	Ordovician	Upper
32053	4085	4095	Limestone	Bad Cache Rapids	Ordovician	Upper
32054	4205	4215	Limestone	Bad Cache Rapids	Ordovician	Upper
32055	4265	4275	Shale, sandstone	Basal sandstone	Ordovician	Upper

Annex 1. Detailed list of well cutting samples for the study of reflectance of dispersed organic matter.

Netsiq N-01 87°30'59,92" West 30'59,92"59° North

No INRS	Depth (m)	Formation	zoo	chit	grap	hyd	scol	Total zoo	am	proto	lip	Total lip	inert	vitr	Total	mig-dpt	iso-mig	res-mig	aniso-mig	Total mig	coke
31964	453	Williams Island	0	0	0	0	0	**0**	89	0	0	**89**	1	4	**5**	0	0	0	1	**1**	5
31968	538	Kwataboahegan	0	0	0	0	0	**0**	0	0	100	**100**	0	0	**0**	0	0	0	0	**0**	0
31975	918	Churchill River	0	0	0	0	0	**0**	0	0	5	**5**	20	70	**90**	0	0	0	0	**0**	5
31976	923	Churchill River	0	0	0	0	0	**0**	83	0	10	**93**	2	5	**7**	0	0	0	0	**0**	0
31977	943	Churchill River	0	0	0	0	0	**0**	0	0	0	**0**	65	30	**95**	0	0	0	0	**0**	5
31980	998	Bad Cache Rapids	0	0	0	0	0	**0**	0	0	0	**0**	10	90	**100**	0	0	0	0	**0**	0

Beluga O-23 88°33'27,184" West 59°33'27,184" North

No INRS	Depth (m)	Formation	zoo	chit	grap	hyd	scol	Total zoo	am	proto	lip	Total lip	inert	vitr	Total	mig-dpt	iso-mig	res-mig	aniso-mig	Total mig	coke
31982	585	Williams Island	0	1	0	0	0	**1**	39	19	0	**58**	5	35	**40**	0	0	0	0	**0**	1
31984	638	Murry Island	0	1	0	0	1	**2**	93	0	0	**93**	0	1	**1**	0	4	0	0	**4**	0
31985	678	Kwataboahegan	0	0	0	0	0	**0**	99	0	1	**100**	0	0	**0**	0	0	0	0	**0**	0
31986	688	Kwataboahegan	0	0	0	0	0	**0**	90	0	0	**90**	2	0	**2**	1	7	0	0	**7**	0
31987	763	Kwataboahegan	0	0	0	0	10	**10**	70	10	5	**85**	0	0	**0**	0	5	0	0	**5**	0
31990	1073	Stooping River	0	0	0	0	0	**0**	100	0	0	**100**	0	0	**0**	0	0	0	0	**0**	0
31991	1303	Stooping River	0	0	0	0	0	**0**	100	0	0	**100**	0	0	**0**	0	0	0	0	**0**	0
31994	1498	Stooping River	0	0	0	0	2	**2**	80	5	0	**85**	0	0	**0**	0	11	0	0	**11**	2
31995	1568	Kenogami River	0	0	0	0	0	**0**	97	1	0	**98**	2	0	**2**	0	0	0	0	**0**	0
31996	1613	Kenogami River	0	0	0	0	10	**10**	68	10	10	**88**	0	0	**0**	0	0	0	2	**2**	0
31997	1648	Ekwan River	0	5	0	0	10	**15**	70	10	0	**80**	0	0	**0**	0	5	0	0	**5**	0
31998	1803	Severn River	0	0	0	0	0	**0**	100	0	0	**100**	0	0	**0**	0	0	0	0	**0**	0
31999	1938	Severn River	0	0	0	0	5	**5**	80	5	0	**85**	0	0	**0**	0	10	0	0	**10**	0
32000	1983	Red Head Rapids	0	0	0	0	1	**1**	97	1	0	**98**	0	0	**0**	0	1	0	0	**1**	0
32001	2000	Red Head Rapids	0	0	0	0	3	**3**	87	5	0	**92**	0	0	**0**	0	5	0	0	**5**	0
32002	2093	Churchill River	0	10	10	38	5	**63**	30	0	5	**35**	0	0	**0**	2	0	0	0	**0**	0
32003	2183	Bad Cache Rapids	0	5	0	0	0	**5**	70	10	5	**85**	0	0	**0**	0	10	0	0	**10**	0

Polar Bear C-11 86°47'18,489" West 47'18,489"58° North

No INRS	Depth (m)	Formation	zoo	chit	grap	hyd	scol	Total zoo	am	proto	lip	Total lip	inert	vitr	Total	mig-dpt	iso-mig	res-mig	aniso-mig	Total mig	coke
32013	766	Kwataboahegan	1	0	0	0	0	**1**	97	0	0	**97**	1	0	**1**	0	1	0	0	**1**	0
32014	816	Kwataboahegan	0	1	0	0	2	**3**	80	0	12	**92**	0	0	**0**	<1	5	0	0	**5**	0
32016	848	Kenogami River	0	1	0	0	15	**16**	64	0	20	**84**	0	0	**0**	0	0	0	0	**0**	0
32020	1248	Severn River	0	0	0	0	0	**0**	100	0	0	**100**	0	0	**0**	0	0	0	0	**0**	0
32021	1305	Severn River	1	1	0	0	1	**3**	95	0	0	**95**	0	0	**0**	0	2	0	0	**2**	0
32022	1372	Red Head Rapids	2	0	1	0	1	**4**	85	5	0	**90**	0	0	**0**	0	6	0	0	**6**	0
32023	1399	Red Head Rapids	5	0	0	0	0	**5**	95	0	0	**95**	0	0	**0**	0	0	0	0	**0**	0
32024	1451	Churchill River	0	3	5	0	2	**10**	45	10	30	**85**	0	0	**0**	0	5	0	0	**5**	0
32025	1480	Churchill River	0	3	0	0	2	**5**	50	0	40	**90**	0	0	**0**	0	5	0	0	**5**	0
32026	1501	Churchill River	0	2	0	0	3	**5**	60	5	10	**75**	0	0	**0**	0	20	0	0	**20**	0
32027	1528	Bad Cache Rapids	0	5	0	3	2	**10**	80	0	0	**80**	0	0	**0**	0	10	0	0	**10**	0
32028	1551	Bad Cache Rapids	0	3	0	0	1	**4**	91	0	0	**91**	0	0	**0**	0	5	0	0	**5**	0
32029	1560	Bad Cache Rapids	0	3	0	2	3	**8**	80	2	3	**85**	0	0	**0**	2	5	0	0	**5**	0

Narwhal South N-58 84°8'2,963" West 58° 8'2,963" North

No INRS	Depth (m)	Formation	zoo	chit	grap	hyd	scol	Total zoo	am	proto	lip	Total lipt	inert	vitr	Total	mig-dpt	iso-mig	res-mig	aniso-mig	Total mig	coke
32033	345	Kenogami River	0	0	0	0	0	**0**	80	0	0	**80**	9	11	**20**	0	0	0	0	**0**	0
32034	358	Kenogami River	0	0	0	0	0	**0**	98	0	0	**98**	0	0	**0**	<1	1	1	0	**2**	0
32040	781	Severn River	0	5	0	0	0	**5**	88	5	0	**93**	0	0	**0**	0	2	0	0	**2**	0
32041	791	Severn River	0	1	1	0	0	**2**	90	8	0	**98**	0	0	**0**	0	0	0	0	**0**	0
32042	831	Severn River	0	0	0	0	0	**0**	97	1	0	**98**	0	0	**0**	0	2	0	0	**2**	0
32043	866	Severn River	0	0	0	0	0	**0**	98	0	0	**98**	0	0	**0**	0	1	0	1	**2**	0
32044	914	Severn River	0	1	0	0	1	**2**	95	0	2	**97**	0	0	**0**	<1	1	0	0	**1**	0
32045	969	Severn River	0	0	0	0	1	**1**	30	10	59	**99**	0	0	**0**	0	0	0	0	**0**	0
32046	995	Severn River	0	0	0	0	0	**0**	95	0	4	**99**	0	0	**0**	0	1	0	0	**1**	0
32049	1094	Red Head Rapids	0	0	0	0	0	**0**	100	0	0	**100**	0	0	**0**	0	0	0	0	**0**	0
32050	1153	Churchill River	0	25	0	35	5	**65**	15	3	17	**35**	0	0	**0**	0	0	0	0	**0**	0
32051	1185	Churchill River	0	15	0	25	5	**45**	50	0	0	**50**	0	0	**0**	0	5	0	0	**5**	0
32052	1232	Bad Cache Rapids	0	10	0	3	2	**15**	65	0	0	**65**	0	0	**0**	0	20	0	0	**20**	0
32053	1243	Bad Cache Rapids	0	2	0	5	15	**22**	50	3	0	**53**	0	0	**0**	0	25	0	0	**25**	0
32054	1279	Bad Cache Rapids	0	2	0	0	10	**12**	73	0	0	**73**	0	0	**0**	0	15	0	0	**15**	0
32055	1297	Bad Cache Rapids	0	1	0	0	1	**2**	60	0	30	**90**	0	0	**0**	0	8	0	0	**8**	0

Annex 2. Result of the petrographic study of dispersed organic matter in the Netsiq N-01, Beluga O-23, Polar Bear C-11 and Narwhal South N-58 wells. Zoo = undetermined zooclast, chit = chitinozoan, grap = graptolite, hyd = hydroid, scol = scolecodont, Total zoo = total zooclasts, am = amorphinite, proto = protobitumen-bituminite, lip = various liptinite, Total lipt = total liptinite, inert = inertinite, vitr = vitrinite, mig dpt = migrabitumen droplet, iso-mig = isotropic migrabitumen, res-mig = reservoir migrabitumen, aniso-mig = anisotropic migrabitumen, Total mig = total migrabitumen, coke = natural coke.

Well	No INRS	Cd (0 = m, 1 = ft.)	Depth (m) Upper	Lower	Ave. (m)	Formations	Statistics	Reflectance Ch	Gr	Hy	Sc	Lip	Inert	Vitr	Dpt mig	Mig bit	Coke	R_{o-evi}	Pre-metamorphic zones	HC stages
Netsiq N-01	31964	0	450	455	**453**	Williams Island	ave Sx n					0.19 0.02 8	1.13 0.81 17	0.74 0.06 23	2.68 0.71 7	2.48 0.43 7	6.86 1.53 13	**0.74**	**catagenesis**	**oil**
	31968	0	535	540	**538**	Kwataboahegan	ave Sx n					0.11 0.01 4								
	31974	0	860	865	**863**	Red Head Rapids	ave Sx n						1.91 0.50 6							
	31975	0	915	920	**918**	Churchill River	ave Sx n					0.32 0.03 7	1.82 0.17 26	0.45 0.03 39			7.21 0.88 6	**0.45**	**diagenesis**	**immature**
	31976	0	920	925	**923**	Churchill River	ave Sx n					0.22 0.03 25	1.02 0.27 22	0.46 0.04 37	0.38 0.02 4	0.42 0.01 3		**0.46**	**diagenesis**	**immature**
	31977	0	940	945	**943**	Churchill River	ave Sx n						3.98 0.84 7	0.48 0.05 12			9.10 2.62 7	**0.48**	**diagenesis**	**immature**
	31980	0	995	1000	**998**	Bad Cache Rapids	ave Sx n						1.76 0.88 22	0.45 0.04 66		0.43 1		**0.45**	**diagenesis**	**immature**
Beluga O-23	31982	0	580	590	**585**	Williams Island	ave Sx n	0.67 1				0.22 0.05 5	2.05 0.56 42	0.72 0.06 89	0.38 0.03 6	0.38 0.05 15	6.55 0.64 3	**0.52**	**diagenesis**	**immature**
	31984	0	635	640	**638**	Murry Island	ave Sx n	0.89 0.07 8			0.44 0.02 7	0.23 0.06 14		0.58 0.02 5		0.35 0.08 16		**0.51**	**diagenesis**	**immature**
	31985	0	675	680	**678**	Kwataboahegan	ave Sx n					0.19 0.06 61				0.33 0.05 12		**0.45**	**diagenesis**	**immature**
	31986	0	685	690	**688**	Kwataboahegan	ave Sx n					0.13 0.02 27	2.99 1.64 10	0.32 0.01 3	0.35 0.12 9	0.40 0.06 32		**0.55**	**diagenesis**	**immature**

Well	No INRS	Cd (0 = m; 1 = ft.)	Depth (m) Upper	Depth (m) Lower	Depth (m) Ave. (m)	Formations	Statistics	Reflectance Ch	Gr	Hy	Sc	Lip	Inert	Vitr	Dpt mig	Mig bit	Coke	R_{o-evi}	Pre-metamorphic zones	HC stages
Beluga O-23	31987	1	760	765	**763**	Kwataboahegan	ave				0.47	0.23	0.63	0.56	0.92	0.55		**0.67**	**catagenesis**	**oil**
							Sx				0.07	0.02	0.03	0.04	0.21	0.02				
							n				44	14	10	18	9	6				
	31990	0	1070	1075	**1073**	Stooping River	ave									0.39				
							Sx									0.03				
							n									2				
	31991	1	1300	1305	**1303**	Stooping River	ave					0.19				0.41		**0.55**	**catagenesis**	**immature**
							Sx					0.03				0.08				
							n					23				21				
	31993	0	1475	1480	**1478**	Stooping River	ave						5.07							
							Sx						0.69							
							n						5							
	31994	0	1495	1500	**1498**	Stooping River	ave				0.42	0.34	2.14	0.65		0.46	1.36	**0.66**	**catagenesis**	**oil**
							Sx				0.03	0.04	1.00	0.13		0.05	0.04			
							n				16	19	23	15		17	2			
	31995	0	1565	1570	**1568**	Kenogami River	ave					0.26	1.97							
							Sx					0.03	0.08							
							n					4	7							
	31996	1	1610	1615	**1613**	Kenogami River	ave				0.31	0.20				0.33		**0.55**	**catagenesis**	**immature**
							Sx				0.06	0.05				0.01				
							n				29	22				4				
	31997	1	1645	1650	**1648**	Ekwan River	ave	0.76			0.44	0.34				0.50		**0.69**	**catagenesis**	**oil**
							Sx	0.02			0.06	0.10				0.03				
							n	9			26	23				8				
	31999	0	1935	1940	**1938**	Severn River	ave				0.40	0.31				0.42		**0.65**	**catagenesis**	**oil**
							Sx				0.07	0.06				0.07				
							n				36	16				37				

Well	No INRS	Cd 0 = m 1 = ft.	Depth (m) Upper	Lower	Ave. (m)	Formations	Statistics	Reflectance Ch	Gr	Hy	Sc	Lip	Inert	Vitr	Dpt mig	Mig bit	Coke	R_{o-evi}	Pre-metamorphic zones	HC stages
Beluga O-23	32000	0	1980	1985	**1983**	Red Head Rapids	ave Sx n				0.66 0.07 10	0.25 0.03 11				0.54 0.03 4		**0.91**	**catagenesis**	**oil**
	32001	0	1995	2005	**2000**	Red Head Rapids	ave Sx n		0.57 0.07 8		0.45 0.04 17	0.27 0.03 8			0.69 0.08 10	0.43 0.02 12		**0.65**	**catagenesis**	**oil**
	32002	0	2090	2095	**2093**	Churchill River	ave Sx n	0.65 0.03 17	0.60 0.04 11	0.60 0.03 6	0.42 0.02 12	0.39 0.05 15				0.67 0.07 2		**0.61**	**catagenesis**	**oil**
	32003	0	2180	2185	**2183**	Bad Cache Rapids	ave Sx n	0.76 0.02 22			0.39 0.00 3	0.24 0.06 17				0.46 0.04 6		**0.68**	**catagenesis**	**oil**

Well	No INRS	Cd 0 = m 1 = ft.	Depth (ft.) Upper	Lower	Ave. (m)	Formations	Statistics	Reflectance Ch	Gr	Hy	Sc	Lip	Inert	Vitr	Dpt mig	Mig bit	Coke	R_{o-evi}	Pre-metamorphic zones	HC stages
Polar Bear C-11	32013	1	2515	2525	**766**	Kwataboahegan	ave Sx n	0.75 0.04 12				0.20 0.06 2	1.62 0.64 19		0.88 0.06 3	0.86 1.23 10		**0.68**	**catagenesis**	**oil**
	32014	1	2680	2690	**816**	Kwataboahegan	ave Sx n	0.72 0.06 15			0.44 0.03 43	0.14 0.05 7				0.45 0.11 24		**0.68**	**catagenesis**	**oil**
	32016	0	2780	2800	**848**	Kenogami River	ave Sx n	0.80 0.02 20			0.42 0.04 34	0.23 0.09 13	0.70 0.04 3	0.54 0.02 6		0.43 0.09 9		**0.67**	**catagenesis**	**oil**
	32017	1	3085	3095	**939**	Kenogami River	ave Sx n				0.47 0.02 5	0.19 0.02 8	1.35 0.05 3			0.30 0.05 3		**0.72**	**catagenesis**	**oil**
	32019	1	3745	3755	**1139**	Ekwan River	ave Sx n								0.67 0.17 2					

Well	No INRS	Cd 0 = m 1 = ft.	Depth (ft.) Upper	Lower	Ave. (m)	Formations	Statistics	Reflectance Ch	Gr	Hy	Sc	Lip	Inert	Vitr	Dpt mig	Mig bit	Coke	Ro-evi	Pre-metamorphic zones	HC stages
Polar Bear C-11	32021	1	4290	4300	**1305**	Severn River	ave Sx n	0.69 0.04 9			0.38 0.01 5	0.41 7				0.38 0.07 9		**0.62**	**catagenesis**	**oil**
	32022	1	4510	4520	**1372**	Red Head Rapids	ave Sx n		0.57 0.04 12	0.63 0.03 3	0.40 0.05 12	0.40 0.03 24		0.40 0.02 3		 0.09 38		**0.58**	**catagenesis**	**immature**
	32023	1	4600	4610	**1399**	Red Head Rapids	ave Sx n	0.63 0.03 8				0.39 0.05 4						**0.57**	**catagenesis**	**immature**
	32024	1	4770	4780	**1451**	Churchill River	ave Sx n	0.72 0.05 37	0.60 0.06 22	0.68 0.03 24	0.43 0.02 7	0.17 0.06 13				0.43 0.02 5		**0.64**	**catagenesis**	**oil**
	32025	1	4865	4875	**1480**	Churchill River	ave Sx n	0.91 0.12 19			0.44 0.04 12	0.24 0.09 22				0.51 0.10 44		**0.77**	**catagenesis**	**oil**
	32026	1	4935	4945	**1501**	Churchill River	ave Sx n	0.79 0.08 21		0.62 0.05 9	0.46 0.04 26	0.21 0.04 6				0.54 0.09 21		**0.69**	**catagenesis**	**oil**
	32027	1	5025	5035	**1528**	Bad Cache Rapids	ave Sx n	0.76 0.04 53			0.47 0.03 50					0.51 0.15 18		**0.70**	**catagenesis**	**oil**
	32028	1	5100	5110	**1551**	Bad Cache Rapids	ave Sx n	0.73 0.03 24			0.38 0.03 7	0.24 0.09 10				0.51 0.07 30		**0.65**	**catagenesis**	**oil**
	32029	1	5130	5140	**1560**	Bad Cache Rapids	ave Sx n	0.65 0.06 9		0.60 0.10 12	0.41 0.04 19	0.24 0.05 12	0.63 1		0.50 0.06 9	0.48 0.05 10		**0.63**	**catagenesis**	**oil**

Well	No INRS	Cd (0 = m; 1 = ft.)	Depth (ft.) Upper	Depth (ft.) Lower	Ave. (m)	Formations	Statistics	Reflectance Ch	Gr	Hy	Sc	Lip	Inert	Vitr	Dpt mig	Mig bit	Coke	R_{o-evi}	Pre-metamorphic zones	HC stages
Narwhal South N-58	32033	1	1130	1140	**345**	Kenogami River	ave						2.71	0.55				**0.55**	**catagenesis**	**immature**
							Sx						0.92	0.05						
							n						23	50						
	32034	1	1175	1185	**358**	Kenogami River	ave								0.52	0.66		**0.78**	**catagenesis**	**oil**
							Sx								0.02	0.03				
							n								2	8				
	32040	1	2565	2575	**781**	Severn River	ave	0.82				0.24	0.82			0.67		**0.74**	**catagenesis**	**oil**
							Sx	0.04				0.08	0.01			0.06				
							n	46				27	5			6				
	32041	0	2600	2610	**791**	Severn River	ave	0.71	0.77		0.32	0.21				0.35		**0.66**	**catagenesis**	**oil**
							Sx	0.07	0.01		0.00	0.05				0.06				
							n	23	8		2	19				11				
	32042	1	2730	2740	**831**	Severn River	ave					0.30				0.41		**0.56**	**catagenesis**	**immature**
							Sx					0.07				0.05				
							n					21				43				
	32043	0	2845	2855	**866**	Severn River	ave	0.65				0.18				0.41		**0.59**	**catagenesis**	**immature**
							Sx	0.02				0.05				0.03				
							n	2				15				13				
	32044	1	3005	3015	**914**	Severn River	ave	0.70	0.69		0.44	0.15			0.30	0.46		**0.66**	**catagenesis**	**oil**
							Sx	0.02	0.03		0.12	0.06			0.09	0.01				
							n	23	5		22	19			11	3				
	32045	0	3185	3195	**969**	Severn River	ave				0.38	0.28				0.40		**0.62**	**catagenesis**	**oil**
							Sx				0.04	0.08				0.09				
							n				9	60				11				
	32046	1	3270	3280	**995**	Severn River	ave				0.28	0.32			0.40	0.36		**0.51**	**diagenesis**	**immature**
							Sx				0.01	0.07			0.04	0.03				
							n				2	15			9	21				

Well	No INRS	Cd (0 = m, 1 = ft.)	Depth (ft.) Upper	Lower	Ave. (m)	Formations	Statistics	Reflectance Ch	Gr	Hy	Sc	Lip	Inert	Vitr	Dpt mig	Mig bit	Coke	Ro-evi	Pre-metamorphic zones	HC stages
Narwhal South N-58	32049	1	3595	3605	**1094**	Red Head Rapids	ave					0.43								
							Sx					0.05								
							n					2								
	32050	1	3790	3800	**1153**	Churchill River	ave	0.73	0.58	0.63	0.47	0.39		0.62		0.72		**0.66**	**catagenesis**	**oil**
							Sx	0.06	0.01	0.05	0.04			0.05		0.09				
							n	46	2	26	27	1		10		6				
	32051	1	3895	3905	**1185**	Churchill River	ave	0.76		0.69	0.43	0.13				0.45		**0.68**	**catagenesis**	**oil**
							Sx	0.05		0.02	0.04	0.04				0.06				
							n	51		8	27	8				15				
	32052	1	4050	4060	**1232**	Bad Cache Rapids	ave	0.83		0.85	0.52					0.58		**0.76**	**catagenesis**	**oil**
							Sx	0.04		0.04	0.04					0.09				
							n	29		3	20					36				
	32053	1	4085	4095	**1243**	Bad Cache Rapids	ave	0.76			0.49					0.57		**0.74**	**catagenesis**	**oil**
							Sx	0.03			0.04					0.13				
							n	8			58					28				
	32054	1	4205	4215	**1279**	Bad Cache Rapids	ave	0.76			0.45	0.48				0.63		**0.69**	**catagenesis**	**oil**
							Sx	0.02			0.07	0.02				0.10				
							n	23			57	3				45				
	32055	1	4265	4275	**1297**	Bad Cache Rapids	ave	0.74			0.48	0.17				0.50		**0.71**	**catagenesis**	**oil**
							Sx	0.01			0.07	0.07				0.13				
							n	4			10	9				12				

Annex 3. Result of reflectance analysis of dispersed organic matter for the Netsiq N-01, Beluga O-23, Polar Bear C-11 and Narwhal South N-58. Ave = Average, Sx = standard deviation, n = number, Ch = chitinozoan, Gr = graptolite, Hy = hydroid, Sc = scolecodont, Lip = various liptinite, Inert = inertinite, Vitr = vitrinite, Dpt mig = droplet of migrabitumem, Mig bit = undifferentiated migrabitumen, coke = natural coke.

Well	Strat. Unit	Litho.	Depth	No INRS	Ro evi	TOC(%)	PI	GP	Tmax	S1	S2	S3	HI	OI
Beluga O-23	Ekwan R.	Shale-dolo.	1610	31996	**0.55**	0.11	0.33	0.03	371	0.01	0.02	0.01	18	9
			1620			0.40	0.40	0.15	423	0.06	0.09	0.01	22	2
		Lst.-shale	1640	31997	**0.69**	0.09	0.10	0.10	435	0.01	0.09	0.01	99	11
	Red Head Rapids	Limestone	1940	31999	**0.65**	0.08	0.10	0.10	431	0.01	0.09	0.59	112	737
			1950			0.12	0.10	0.29	432	0.03	0.26	0.50	216	416
			1990	32001	**0.65**	0.09	0.38	0.47	425	0.18	0.29	1.98	322	2200
			2000			0.21	0.40	0.98	434	0.39	0.59	1.12	280	533
			2000			0.32	0.69	1.31	428	0.91	0.40	1.97	125	615
			2010			0.12	0.56	0.48	432	0.27	0.21	1.00	174	833
	Churchill R.		2100	32002	**0.61**	0.10	0.37	0.30	435	0.11	0.19	1.49	190	1489
			2170	32003	**0.68**	0.27	0.60	2.40	436	1.45	0.95	1.15	351	425

Well	Strat. Unit	Litho.	Depth	No INRS	Ro evi	TOC(%)	PI	GP	Tmax	S1	S2	S3	HI	OI
Polar Bear C-12	?Kenogami R.	Lst.-shale	2680	32014	**0.68**	0.48	0.06	1.82	427	0.11	1.71	0.32	356	67
			2690			0.36	0.09	1.21	431	0.11	1.10	0.39	306	108
	Severn R.	Lst.-dolo.	4300	32021	**0.62**	0.14	0.07	0.18	436	0.01	0.17	0.19	121	136
	Churchill R.	Limestone, shale	4590	32023	**0.57**	0.17	0.10	0.25	435	0.03	0.22	0.28	129	165
			4610			0.10	0.11	0.19	436	0.02	0.17	0.20	170	200
			4770	32024	**0.64**	0.12	0.13	0.26	438	0.03	0.23	0.29	192	242
			4790			0.32	0.32	1.53	428	0.49	1.04	0.63	325	197
			4870	32025	**0.77**	0.16	0.10	0.29	434	0.03	0.26	0.19	162	119
			4875			0.19	0.08	0.35	434	0.03	0.32	0.28	168	147
			4880			0.18	0.08	0.28	434	0.02	0.26	0.31	144	172
	Bad Cache Rapids		4930	32026	**0.69**	0.15	0.06	0.30	438	0.02	0.28	0.23	187	153
			4940			0.12	0.05	0.34	437	0.02	0.32	0.18	267	150
			4950			0.12	0.05	0.33	439	0.02	0.31	0.17	258	142
			5020	32027	**0.70**	0.14	0.04	0.48	434	0.02	0.46	0.19	329	136
			5030			0.10	0.05	0.31	437	0.01	0.30	0.19	300	190
			5040			0.14	0.04	0.35	436	0.01	0.34	0.17	243	121
			5100	32028	**0.65**	0.12	0.06	0.20	437	0.01	0.19	0.22	158	183
			5110			0.12	0.05	0.16	438	0.01	0.15	0.14	125	117

Well	Strat. Unit	Litho.	Depth	No INRS	Ro evi	TOC(%)	PI	GP	Tmax	S1	S2	S3	HI	OI
Narwhal South O-58	Severn R.	Lst.	2570	32040	**0.74**	0.27	0.04	0.88	432	0.03	0.85	0.45	315	167
		Lst.-shale	2600	32041	**0.66**	0.81	0.03	3.46	424	0.12	3.34	0.68	412	84
			2750	32042	**0.56**	0.19	0.07	0.27	426	0.02	0.25	0.48	132	253
			2760			0.16	0.10	0.13	423	0.01	0.12	0.36	75	225
		Limestone	3010	32044	**0.66**	0.14	0.05	0.34	430	0.02	0.32	0.25	229	179
			3180	32045	**0.62**	0.14	0.06	0.25	430	0.01	0.24	0.26	171	186
			3260	32046	**0.49**	0.09	0.07	0.22	433	0.02	0.20	0.25	222	278
	R,-H.-R.		3290			0.13	0.12	0.07	430	0.01	0.06	0.29	46	223
	Churchill R.	Lst.-shale	3810	32050	**0.66**	0.11	0.07	0.17	433	0.01	0.16	0.32	145	291
			3910	32051	**0.68**	0.19	0.09	0.21	435	0.02	0.19	0.33	100	174
	Bad Cache Rapids	Limestone	4040	32052	**0.76**	0.22	0.03	0.83	432	0.03	0.80	0.28	364	127
			4050			0.24	0.03	0.79	434	0.03	0.76	0.28	317	117

			4060			0.23	0.03	0.72	432	0.02	0.70	0.30	304	130
			4070	32052	**0.76**	0.21	0.04	0.56	431	0.02	0.54	0.27	257	129
Well	**Strat. Unit**	**Litho.**	**Depth**	**No INRS**	**Ro evi**	**TOC(%)**	**PI**	**GP**	**Tmax**	**S1**	**S2**	**S3**	**HI**	**OI**
Narwhal South O-58	Bad Cache Rapids	Limestone	4080	32053	**0.74**	0.20	0.04	0.47	433	0.02	0.45	0.24	225	120
			4090			0.19	0.05	0.41	434	0.02	0.39	0.16	205	84
			4100			0.35	0.67	2.08	431	1.40	0.68	0.31	194	89
			4200	32054	**0.69**	0.17	0.19	0.48	431	0.09	0.39	0.30	229	176
			4210			0.11	0.06	0.22	438	0.01	0.21	0.19	191	173
			4220			0.10	0.06	0.16	436	0.01	0.15	0.16	150	160
		Shale-Sst.	4260	32055	**0.71**	0.14	0.05	0.23	436	0.01	0.22	0.19	157	136
	Basal Sandstone		4280			0.15	0.04	0.30	445	0.01	0.29	0.25	193	167

Annex 4. Correlation between the results of reflectance of dispersed organic matter and Rock Eval data of corresponding intervals (Zhang and Dewing, 2008; Zhang, 2008) for the Beluga O-23, Polar Bear C-11 and Narwhal South N-58 wells. R_{o-evi} = Reflectance of estimated vitrinite, TOC (%) = Total organic carbon in %, PI = Production index, GP = genetic potentiel in mg hydrocarbons/gr of rock (S1 + S2), S1 = surface area of P1 curve (in place hydrocarbons) in mg hydrocarbons/gr of rock, S2 = surface area of P2 curve (pyrolysable hydrocarbons in the kerogen) in mg hydrocarbures/gr of rock, HI = hydrogen index of the kerogen in mg hydrocarbons/gr of TOC, OI = oxygen index of the kérogène in mg of CO2/gr of TOC.