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ORGANIC GEOCHEMISTRY OF SOME CAMBRIAN-PROTEROZOIC SEDIMENTS COLVILLE HILLS, NORTHWEST TERRITORIES

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ABSTRACT

Ninety samples from cores of Cambro-Proterozoic sediments at eight locations were analyzed by Rock-Eval pyrolysis to determine both kerogen type and thermal maturation levels as a means of assessing source beds and petroleum potential relative to known gas accumulations in the Old Fort Island sandstones in the Colville Hills.

Organic-rich partings in dolostones within the Mount Cap - Old Fort Island section contain Type II kerogen which has been thermally matured high into, and possibly in part beyond, the oil generation window in the Colville area. Dark grey shales of the Mount Cap Formation are also potential source beds. Those shales exhibiting a greenish cast contain too little organic carbon to have source potential. Total organic carbon in Proterozoic beds is low and their source potential is questionable.

To the west in the Ontaratue area, Cambro-Proterozoic strata are all low in organic carbon and are interpreted to be thermally overmature. Greenish Mount Cap beds in the Mackenzie Depocentre are too low in kerogen to be source beds or to define a level of thermal maturity.

INTRODUCTION

The Mackenzie Corridor is significant as a pipeline route from the Mackenzie Delta, the Beaufort Sea and the Arctic for hydrocarbon distribution to the consuming areas of southern Canada and the United States. Oil has been produced from the Devonian Kee Scarp reef at Norman Wells for many years. An evaluation of exploration potential for further Kee Scarp reef accumulations as well as for other potential reservoir intervals has naturally followed, as additional reserves within this corridor would greatly enhance the potential for pipeline development.

As part of a full geological review of the stratigraphic section within this area, Williams (1987) noted the occurrence of gas at three locations in the Cambrian Old Fort Island Formation in the Coleville Hills area (Fig. 1). Knowledge of both the source for this gas and the thermal maturation level of the source beds is essential to any assessment of the economic potential of the Old Fort Island and other possible reservoir intervals. This report presents the geochemical analyses (Rock-Eval pyrolysis) of possible source beds from both the Cambrian Mount Cap and Proterozoic strata respectively overlying and underlying the Old Fort Island sandstones.

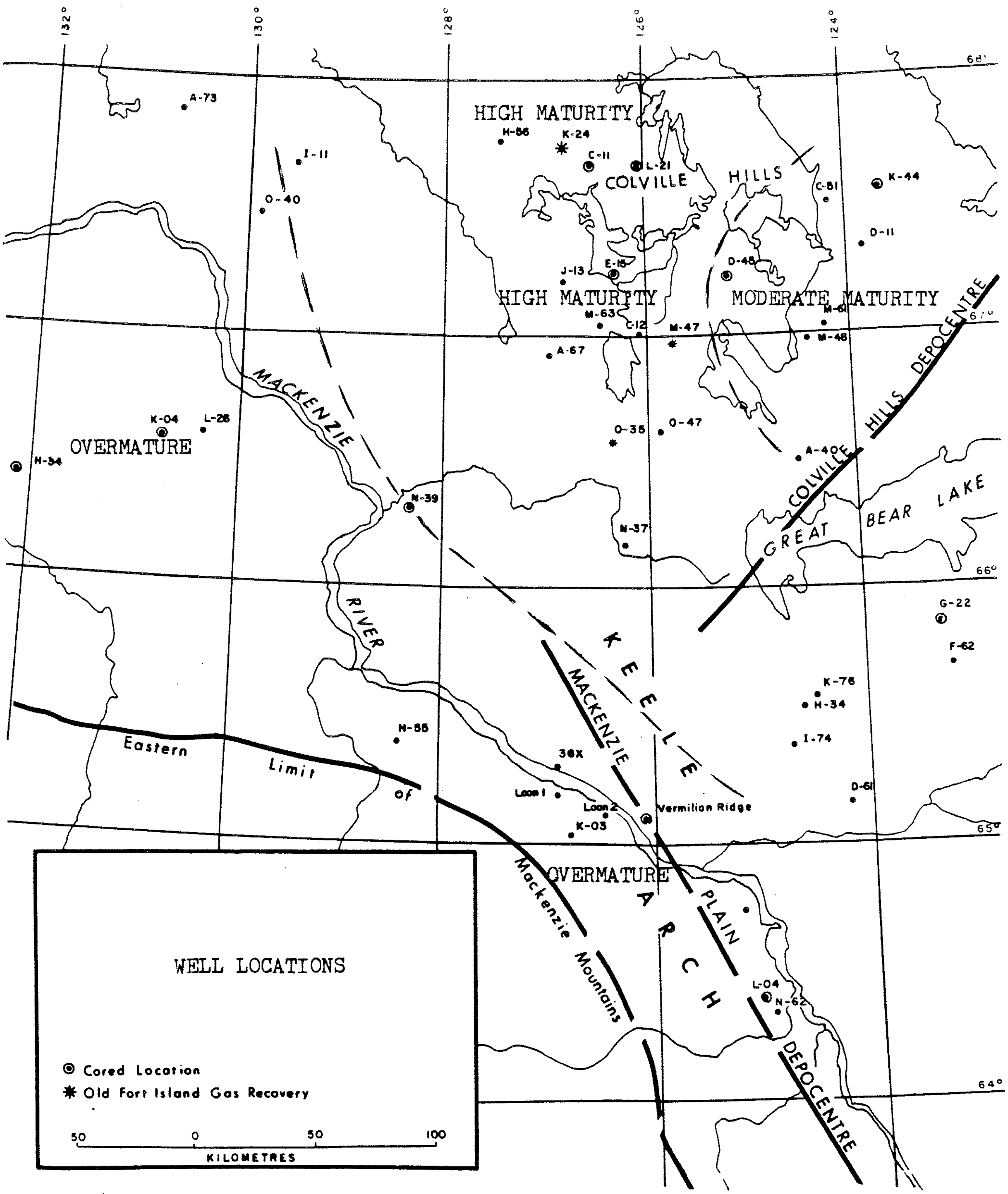


Figure 1: Location map, with boundaries of thermal maturity levels.

Several key stratigraphic publications were reviewed for this study, including Aitken et al. (1973), Cecile (1982), Meijer-Drees (1975, 1986) and Tassonyi (1969); however, by far the most reliance was placed on Williams (1987) wherein all of the regional geology is summarized, a large reference body has been utilized and subsurface well samples and geophysical logs have been incorporated into his final analysis. Williams' report provides all the background detail required for the broad utilization of the geochemical data contained herein.

Although the recognition of Cambrian-Proterozoic source rocks and their maturation levels, as obtained by the analysis of core samples, was the prime objective of this study, the cores were described in sufficient detail (Appendix A) that some observations are also made on regional stratigraphy, depositional environments and reservoir characteristics.

Over 2000' of core were examined for sampling, of which the major part (1500'+) covered the Cambrian section below the Saline River salt downward through Proterozoic beds at Mobil Colville E-15 (Fig. 1). All wells have been drilled and logged under the footage system of measurement, except for Ewakka C-11, a recent metric hole. To prevent error in transferrence to the metric system, and to ensure greater ease in relating the samples to the core, especially for any further sampling, all depths are recorded in the original drilling units.

Other geochemical and related data (TOC distribution, elemental analysis, carbon isotope analysis, saturate hydrocarbon analysis, vitrinite reflectance and visual kerogen type interpretation) are presented in "Lower Mackenzie Energy Corridor Study" (AGAT, 1977), an industry report available for examination at the Calgary office of the Canadian Oil and Gas Lands Administration (COGLA), Government of Canada. That report, prepared jointly be AGAT Consultants Ltd. and Geochem Laboratories (Canada) Ltd., encompasses the entire stratigraphic section. Not all their investigative processes could be applied to the Mount Cap - Proterozoic interval. The Rock-Eval Pyrolyzer had not then been developed as an analytical process.

Sampling Technique

Low maturity organic-rich beds, even those containing relatively low total organic carbon content (TOC), will generally exhibit some degree of brownish color tint, at least in the streak if not readily apparent in the rock itself. The color will also be toward the dark side. Primary sampling targets were thus the darker grey to brownish-grey shale beds, especially those exhibiting a brown streak. To ensure a proper assessment of the organic content, lighter colored grey beds were also sampled, although less frequently, as were occasional greenish-grey shales.

Numerous dark brownish-grey to almost black solution laminae and partings to thin beds often occur within both dolostone and sandstone intervals. These apparently organic beds were selectively sampled, and will not be representative of significant thicknesses of source material but can provide excellent kerogen type and maturation data. Potential hydrocarbon volumes cannot be calculated from these particular samples.

Dark grey to black shales, without brownish tinge and with grey streaks, were also sampled to detect possible zones of thermally overmature kerogen. High to overmaturity can be suspected from the presence of gas at the three hydrocarbon shows in the area.

A few dolostone zones appear organic, especially those with a resinous lustre: several were sampled as were some earthy dolostones and dolostone muds.

STRATIGRAPHY

Although most of the Cambro-Proterozoic section encountered in the Mackenzie Corridor is reportedly marine (Williams, 1987), fossils are scarce with only limited trilobite remains providing scattered Middle Cambrian age determinations within the Mount Cap section. The Middle and late Lower Cambrian burrowing form *Scolithus* is common in the Old Fort Island sandstone interval but is probably more significant as a facies than as a time indicator. Regional distribution of the various lithologies and facies variations, in conjunction with unit relationships established from adjacent surface areas, must therefore be used to define the sequences encountered in the subsurface. Williams (ibid) has made an excellent such interpretation, especially relative to suggested unconformable relationships. Some further comments on depositional continuity and facies relationships are presented herein.

The Cambrian-Proterozoic section, significant to the source potential of the Colville Hills, can be summarized as follows:

Franklin Mountain Formation: a widespread sequence of grey dolostones, sparsely fossiliferous, representing uninterrupted deposition from Upper Cambrian through Lower Ordovician.

Saline River Formation: a series of upper variegated (green, red) shales underlain by a salt member containing anhydrite and gypsiferous shale, sometimes represented only by the dominant red beds with salt casts and gypsum to indicate the highly saline environment.

Mount Cap Formation: dominated by green to greenish-grey shale, lesser siltstones, some sandstones and interbedded carbonates, but also containing red bed intervals.

Old Fort Island Formation: white to grey and some red sandstones with uppermost beds of light brown dolostone and many interbeds of green and greenish-grey shales, glauconitic sandstone beds are common at the top of the unit, mostly carbonate cement.

Proterozoic: dominated in the cores examined by grey shales which often have good brown streaks, commonly much darker color than those of the overlying Cambrian, and with distinctly different green hues, occasional red intervals, with zones of orthoquartzites, sandstone injection dikes common at sandstone-shale contacts, generally does not appear to be more indurated than the Cambrian. Significant differences may occur on a regional basis.

Discussion

At Mobil Colville E-15, the base of the main Saline River salt is at 4463', and the base of the lowest salt bed is at 4506', here selected as the Saline River - Mount Cap contact. Greenish-grey shales typical of the Mount Cap occur in the intervening 43'; however, anhydrite, typical of the Saline River, is encountered as low as 4565', some 59' below the selected contact. Occasional red shale is also present in this interval. From this core, and a brief comparison of this borehole to others in the immediate area, the Saline River - Mount Cap contact is a transitional facies contact. Neither the base of the last salt penetrated nor the base of the lowest massive salt body will represent a stratigraphic datum.

Dolostones, most of which appear to be initial mud deposits, are common within the Mount Cap section even though green tinted shales are the distinguishing lithology of this formation. Sandstones are present but are less prevalent than the dolostones. Dolostones containing fossiliferous debris occupy an interval at the base of the Mount Cap beds and these react identically to the sandstones of the underlying Old Fort Island sandstones on geophysical well logs. The sandstones and dolostones are also interbedded. The Mount Cap - Old Fort Island contact has been variably selected by different sources from as high as 4906' to 4954' at Colville E-15 (4954' in the core descriptions herein). Williams (1987, Section L-1) indicates a facies relationship for this boundary, a conclusion supported from this core study. Whether to select the boundary at the top of the dolostone or on the dominance of sandstone is arbitrary: perhaps utilization of downhole well logs will be the most satisfactory system for the subsurface.

Glauconite is often considered to be a distinctive mineral of Cambrian strata and glauconite zones do occur in the Old Fort Island sandstones. Rather than being widespread, glauconite appears to be limited in the area of the Colville cores to thin (<5')sandstone beds at the top of, or above, the main sandstone depositional sequence.

Differentiation of the Mount Cap and Proterozoic shales is generally not difficult because of the much darker color and deeper green cast prevalent in the older beds, although Mount Cap type shales can occur within the Proterozoic. Sandstones of the Old Fort Island Formation are much burrowed and generally thicker than those of the Proterozoic. Sandstone injection dikes are distinctive of the older interval. Glauconitic zones are present but not common in the Proterozoic. Micaceous shales are more common in the Proterozoic than in the Cambrian but certainly do not dominate in the section.

The Old Fort Island - Proterozoic contact is cored at Mobil Colville E-15 where sandstone rests with apparent conformity on light colored shale beds. There is no indication of erosion or of any angular discordance. Over an interval of 135', the shales lose the light greenish and some red character and darken to the dominant grey of the Proterozoic with indications of organic content by a brown streak. The olive-green color in the interval 5035-5105 is unique to, but is uncommon within, the Proterozoic shales. As seen in the E-15 core, the Cambrian-Proterozoic boundary is a transitional feature with deposition continuous across that time boundary. The dating of the Proterozoic must be made only on the comparison to similar lithologies in surface areas where an erosional break separates the units (Aitken et al., 1973). Williams (1987) considers that the Colville High overlies a possible depocentre, in which case deposition may have been continuous in the centre, but not on adjacent highs. Although one can speculate that the cored contact is not truly indicative of the unit relationships, or that an erosional break was not recognized in the core, or that the actual contact had been removed from the core itself, these speculations were so uppermost in the mind of the examiner that none could be readily accepted to explain the lack of any apparent unconformable break at the Cambro-Proterozoic boundary. Rather than continuous deposition from Proterozoic through Cambrian, the beds normally assigned in this area to the Proterozoic may indeed be Cambrian with the unconformity not penetrated. Williams (pers. comm.) commented that the Proterozoic as here described was not completely comparable to surface Proterozoic beds.

ENVIRONMENTS

According to Williams (1987), the Cambro-Proterozoic section is reported in literature to be predominantly marine sedimentation. From examination of Old Fort Island beds at 7 locations, the sandstones of that unit are concluded to be continental fluvial deposits based on individual bed thicknesses (too thick to be transgressive beaches), the presence of basal coarser grains fining upward, some high angle cross-bedding, and rip-up shale clasts (clay galls) of apparent underlying and laterally equivalent clay deposits.

The dolostone beds overlying and lateral to the sandstones are composed of much organic detritus and may represent the shoreface or lagoonal equivalents of the sandstones. Extreme burrowing of the greenish colored shales can be as typical of lagoonal sedimentation as of open marine: indeed, a lagoonal origin is here preferred. The thin glauconitic sandstones at the top of the sequence and within the Mount Cap section are considered to be characteristic of transgressive beach deposits.

Shales of the Proterozoic appear to be open marine deposits although the presence of red beds, both as shale and as sandstone, indicate possible intermittent tidal flat conditions. Water depth was possibly quite shallow throughout. The color change of the shales below the influx of the the fluvial sandstones is characteristic of the variations anticipated in the change from marine to continental sedimentation. A review of the borehole logs indicates that the base of the sandstone is as much a facies boundary as is the top. This is seen in the core at Mobil Colville E-15 (Fig. 1, Appendix A), and is evident on the log of PEX-Fina N. Colville L-21 where there is obvious interbedding with shales (this well is illustrated by Williams, 1987; Section L-1).

Old Fort Island sandstones represent the optimum condition for the incursion of continental sediments into the area, with the return to marine conditions represented by the thin uppermost glauconitic sandstones and the fossiliferous dolostones, both of which are interpreted to be shore-face deposits. Many of the extremely burrowed green sandstone-shale sequences within the uppermost Old Fort Island are probably flood plain sediments, but the greyer burrowed intervals higher in the Mount Cap Formation may be shallow marine in origin.

Greenish coloration is much less distinct in the Mount Cap shales above the major burrowed shales and thus appears to represent shallow marine conditions, possibly also defined by the dolostone mud beds. Marine conditions prevail upwards through the Saline River Formation where salt may represent a deeper water restricted environment although the interbedding of red shales can be considered as tidal flat deposition near the edge of the salt basin. At Imperial Vermilion Ridge #1 (Fig. 1, Appendix A) and Atlantic Ontaratue K-04 (Fig. 1, Appendix A), shale beds encountered within cored salt intervals are distinctly light grey, probably representative of the deeper part of the salt basin.

Although not provable from the present limited data, the continued deposition of a thick sequence of Proterozoic and Cambrian strata in the area of the present-day Keele Arch and Colville Hills (the early Mackenzie Plain and Colville Hills depocentres of Williams, 1987), is one possibility from interpretation of the core data. Williams deleted one unconformity, at the base of the Saline River Formation, in his interpretation. A second generally accepted unconformity, at the base of the Old Fort Island Formation, is not necessarily a reality in the Colville Hills area as a greater thickness of Cambrian strata may be present than has previously been considered.

In his review of the Mackenzie Corridor Proterozoic, Williams (1985) stated, "Criteria for differentiating Paleozoic from Proterozoic strata are not yet satisfactory, especially in the subsurface." One cannot but agree with this conclusion.

RESERVOIRS

On the basis of the cores studied herein, combined with some review of publications and stratigraphic well logs in the area, a lack of significant reservoir beds is the greatest deterrent to exploration for Cambro-Proterozoic hydrocarbon accumulations in the Mackenzie Corridor. Only scattered, poor, thin porosity zones are encountered in any of the Mount Cap dolostones, such as a few discontinuous vugs in the interval 4906-4933 at Mobil Colville E-15 and in the interval 3705-3710 at PEX-Fina N. Colville L-21. At both locations the porosity occurs in the detrital type dolostones associated with the Old Fort Island sandstones and possibly should be included in the lower unit. None of the dolostone porous zones straddle more than a few inches and are thus of no exploratory interest from present data.

Exploratory potential is therefore limited to the Old Fort Island sandstones, where gas has been recovered at 3 locations (Fig. 1). The environment of deposition here becomes a most significant factor. If these sediments are marine, the potential for thick continuous reservoirs, especially if regressive beaches can be defined, would be good. If they are continental fluvial, as here concluded, the potential for continuous thick porosity development is considered to be much more limited in view of the indicated facies relationship to the above mentioned dolostones and to the shales of the Mount Cap Formation. Within such sequences, the continuity of fluvial channels, especially where numerous clay-rich strata are also interspersed, can be limited and areally large reservoirs may not be present. The poor, discontinuous nature of the sandstone porosity evidenced in these cores is certainly discouraging to the anticipation of economic reservoir conditions.

GEOCHEMISTRY

All samples were processed at the Institute of Sedimentary and Petroleum Geology, Calgary on a Rock-Eval analyzer. Using a standard program, the S1 peak was obtained at 300°C, and the S2 was measured during heating at 25°C/min. and collected to a temperature of 600°C. The S3 peak was collected to a temperature of 390°C. TOC content was determined by burning all the carbon in a separate oxidation oven built into the analyzer and operated at 600°C in air. In order to ensure uniform results and that all the organic carbon was burned, all samples were ground to a particle size of approximately 150 micrometres. A double run was standard for each sample. Samples were run against a calibration standard with nominal values of S1=0.04, S2=0.87, S3=0.63, Tmax=437°C and TOC=1.65%. Appendix B contains the results of the Rock-Eval analyses.

Interpretation

By far the greater number of samples contain considerably less than 1% total organic carbon (TOC) and have commensurately very low S2 hydrocarbon yields (Appendix B), less than 1.0 milligrams/gram (mg/g = kilograms/tonne, kg/t). Where the S2 peak is of such limited magnitude, Tmax value is unreliable because the computer is unable to define accurately the top of the S2 peak position. The Hydrogen and Oxygen indices, and the Yield Ratio (kg/t/%TOC), are widely variable as only small errors in the TOC measurement will create large ranges for these parameters.

An initial visual comparison of the geochemical data to the described cores indicated a degree of correlation between geography and geology. The southernmost locations, Keele L-04, Vermilion Ridge and Losh Lake G-22 (Fig. 1), have common characteristics; the Ontaratue K-04 and H-34 sections are similar; and the results in the Colville High area indicate compatibility.

Southern Area

TOC content from core samples at the three southern locations, Keele L-04 and Vermilion Ridge within the present structural Keele Arch (Williams, 1987), and Losh Lake G-22 in the Plains-type area to the east, is maximum at 0.11% and averages close to 0.06%. There is essentially no S1 light hydrocarbon recovery and S2 heavier hydrocarbon recovery does not exceed 0.53 mg/g. Tmax values are widespread, from a low of 370°C to a high of 575°C. The majority of Tmax values are above the oil generation window. Because of the low organic carbon content and minimal S2 recoveries, the Hydrogen and Oxygen indices are not thought to be useful.

Samples from all three locations are described as light to medium grey shale, generally with a slight greenish tinge, somewhat laminated, with trilobite debris. Cores of the westerly two wells are from within thick sections of such shale, whereas that at Losh Lake G-22 is contained within a ten foot interval immediately above the Old Fort Island sandstone. The lighter grey color and the greenish cast are confirmed as characteristic of minimal kerogen content. Both lithologically and geochemically, the shale at Keele L-04 is characteristic of Mount Cap section.

Because of the problems inherent in the Rock-Eval analysis of low organic carbon samples, no maturation level can be confidently interpreted for this area from the three cores sampled. Overmaturity can be suspected but certainly not confirmed. This type of Mount Cap shale is also an unlikely source bed.

AGAT (1977) projected overmaturity for the Mount Cap Formation on the basis of overmature to high maturity levels in younger beds as no Cambrian samples were studied for this area.

Ontaratue Area

One sample of a light grey shale from within the Saline River salt section at Ontaratue K-04 yielded only traces of light petroleum product and no S2 peak from 0.16% maximum TOC content. This organic -poor lithology, without source potential, was also noted in core of the salt section at Imperial Vermilion Ridge.

At Ontaratue H-34, a grey dolostone and a grey shale of the Mount Cap Formation? (possibly Saline River or lower Franklin Mountain) contained a maximum 0.24% TOC and yielded only hydrocarbon traces. Tmax values were generally above the oil window range and yield ratios negligible. Although the greenish cast of the more southern area was not so evident, a slight increase of TOC can here be related to the greyer color of the sediments.

At the two Ontaratue locations, seven samples of medium to dark grey shale contained up to 0.67% organic carbon, produced virtually no light petroleum and traces only of S2 hydrocarbons, and had Tmax values, where measureable over both sample runs, well above the oil generation level. Although greater TOC content would provide more confidence for interpretation of the thermal maturation, overmaturity is strongly suspected. The lack of S1 component may indicate a level of dry gas generation or gas destruction. AGAT (1977) mapped the Mount Caps beds of this area as overmature.

The presence of TOC in the range 0.50 to 0.67% in apparently overmature beds can indicate depositional TOC in excess of 2 to 3%, in which case these Proterozoic beds may have generated significant quantities of oil. If these beds can be found in less thermally mature areas, or if generated hydrocarbons may have migrated to a less mature reservoir, the potential for petroleum exploration must not be discounted entirely.

Williams (ISPG) provided an analysis of black parting material from a Proterozoic dolostone at Ontadek N-39, east of the Ontaratue wells. Although TOC is high (5.97%), all parameters (HI = 57, PI = .33, yield ratio = 0.86), except Tmax (435°C), are indicative of the extremely low yield and seem to indicate a high maturation level near the top of, or just through, the oil generation window. This material is suspected to be bitumen, in which case a Rock-Eval response is difficult to predict and the actual response difficult to interpret. The TOC content of the parting may also be considerably higher, the results having been here reduced by inclusion of country rock in the analyzed sample. AGAT (1977) interpreted these beds to be at a mature level, bordering on overmaturity, but with oil potential remaining because of a minor solvent extractable fraction.

Colville Area

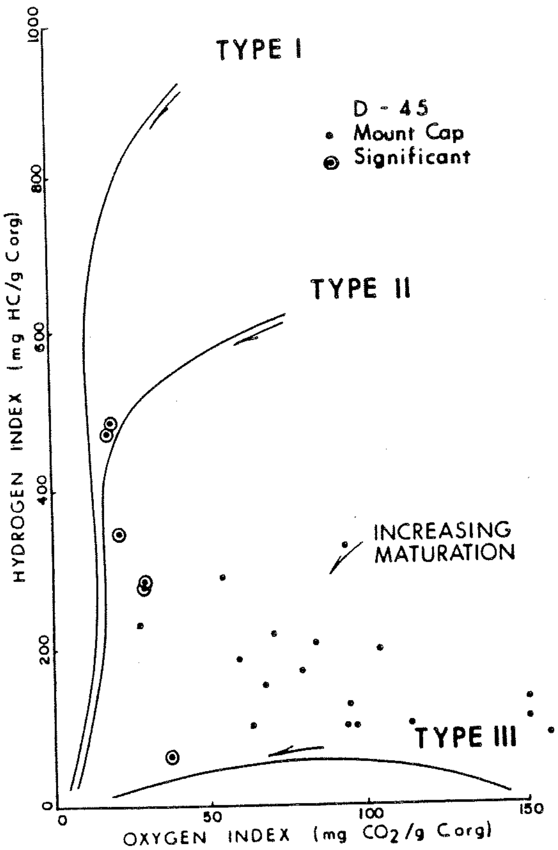
More analyses are available in the Colville area because of the continuously cored Colville E-15 location. Cores are described from Ewakka C-11 and Stopover K-44, forming background for the environmental and reservoir comments, but for which there are no geochemical analyses as the section cored comprised only coarse clastic sediments.

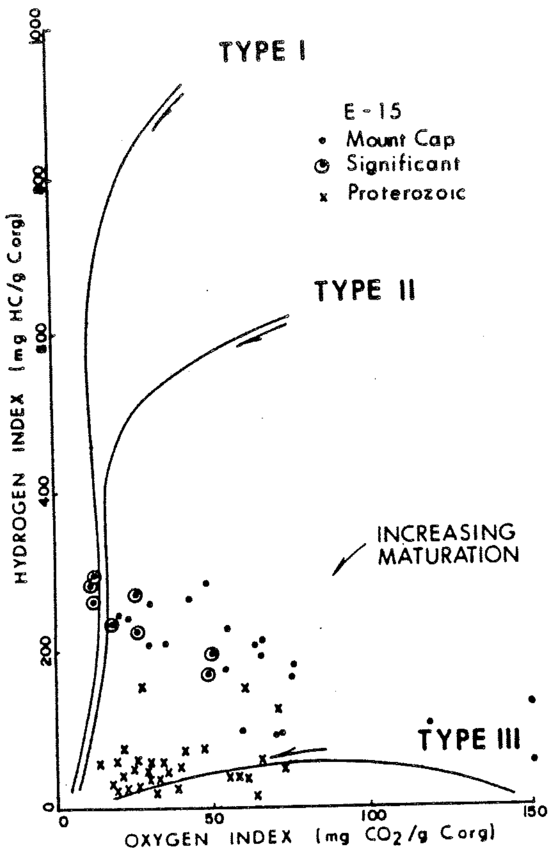
Two samples of Saline River beds, one each at E-15 and L-21, contain minimal TOC. No source potential is recognized.

Shales of the Mount Cap Formation in the Colville area are a purer grey, with less noticeable green cast, than to the south and west; however, the greenish colors by which the unit is partly defined are present in the section (Appendix A). A wider range of organic carbon is present, mostly 0.1 to 0.9%, but with several samples in the 1 to 2% range within the grey shale lithology. AGAT (1977) also encountered higher organic carbon content in the darker and greyer shales. Those samples with greater than 1% TOC usually show dark organic laminations and/or slickensides. Hydrogen Indices range from negligible to almost 500 (Fig. 2), but are commonly in the 200-300 range. Type III kerogen is not anticipated in Cambrian strata; therefore, the OI values are for the most part meaningless. Elemental analyses by AGAT (ibid.) also indicate high oxygen content. Production Indices are also variable (.10 to .50). Yield ratios are higher than in the Keele and Ontaratue areas, but, in the general range of 1 to 4 kg/t/%TOC, they are considerably less than for immature Type II or Type I kerogens (Macauley et al., 1986). The highest yield ratios generally correspond to the highest PI values. Tmax values at D-45 are possibly near an average 445°C. Rock-Eval data, especially the Hydrogen Indices, although by no means definitive, can be interpreted at the D-45 (Fig. 2a) and E-15 (Fig. 2b) locations to indicate moderate thermal maturation of Type II kerogen within the oil window. At Colville L-21, somewhat higher Tmax values (456-475°C) and lower yield ratios may indicate thermal maturation into the range of gas, beyond the oil generation window. The higher HI values at L-21 (Fig. 2c) may relate to difficulty in measuring accurately low TOC content. HI values for the more trusted significant analyses are lower than for the E-15 and D-45 locations. Considering that some of the original carbon may have been lost through petroleum generation, some of the darker shales are here border-line to probable source beds. As in other areas, the greenish beds contain little organic carbon.

AGAT (1977) considered Mount Cap beds at Colville D-45 to be thermally immature, and those at E-15 mature, a somewhat lower range than interpreted herein (Fig. 1). AGAT (ibid.) interpreted that the gas occurrence at Tedji K-24 resulted from migration of the gas phase from Mount Cap beds of greater maturity located in a trough to the south, whereas oil shows were generated in situ. The maturation level at Colville L-21 may well be sufficient to be within the source area for the K-24 gas accumulation.

At Colville E-15, a vitrinite reflectance measurement (Ro%) of 0.75 (AGAT, 1977) indicates moderate thermal maturity, slightly lower than projected from the Rock-Eval data. True vitrinite is not anticipated in sediments of Cambrian age; consequently, the exact nature of the reflecting material must be in doubt. Reflectance values are lowered where live hydrocarbons have impregnated the reflecting substance (Hutton and Cook, 1980; Kalkreuth and Macauley, 1984). If the reflectance is from





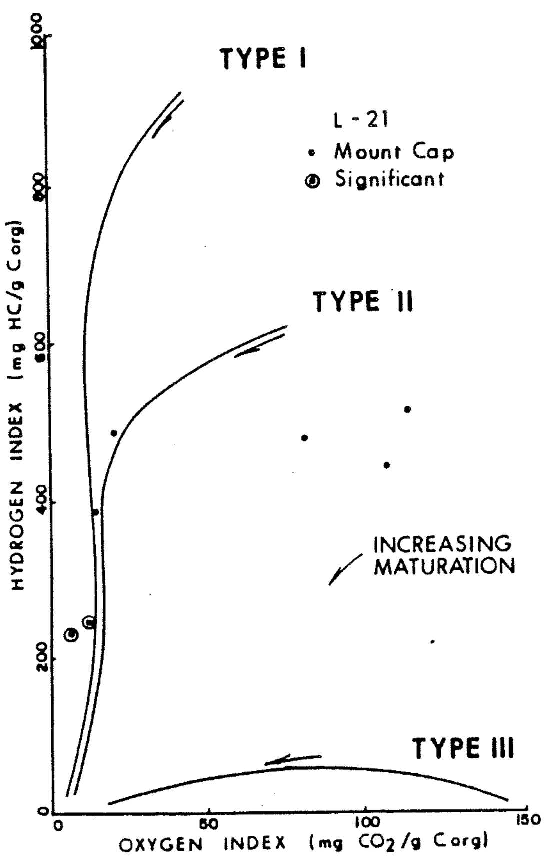


Figure 2: Hydrogen Index versus Oxygen Index, indicating the most reliable (significant) analyses from the highest TOC samples.

maturing sapropelic residue, reflectance will be lowered until overmaturity is reachd and all petroleum product destroyed, at which point the reflectance values are no longer adversely affected (Macauley, et al., 1986). AGAT (ibid.) has visually assessed the kerogen as dominantly amorphous sapropel with both herbaceous (cuticle) and coaly secondary kerogen components. The recognition of these latter kerogens must be in doubt for Cambrian age strata such as the Mount Cap Formation.

TOC in the range 1-6% is encountered within organic partings in dolostone sections, similar to that at Ontadek N-39. Kerogen type and maturation level in these partings in the Colville area confirm those indicated by the shale samples. Some variation is recognized within the double run of each sample: this can be attributed to the laminated nature of the partings and consequent difficulty in the uniform selection of small amounts of material from the crushed sample. These comprise most of the significant (most reliable) analyses (Fig. 2).

Several origins may be attributed to the partings. They may be bitumen injected into fractures and/or along bedding planes, they may have been concentrated ahead of a dolomitization and/or mineralization front, or they may have resulted from concentration through pressure solution of enclosing carbonate during the lithification process. From examination of the cores, the latter explanation is preferred, in which case the kerogen of the partings presents a true thermal history of the enclosing rock. The dolostones appear to have replaced initial lime mud sediments. Whether or not significant kerogen is present throughout the large area of dolostones is not determinable from present data, but these appear to be the most probable Mount Cap source beds.

Proterozoic shales at Colville E-15 contain organic carbon in the range 0.10 - 0.70%, certainly not prime source bed potential. Tmax values cover a wide range, but are commonly above the oil generation values. Extremely low yields and yield ratios, coupled with widely diverging PI values, indicate probable high to overmaturity for these strata, which is confirmed by the plot of the HI values (Fig. 2b).

Brownish colored streaks are common in Proterozoic beds, but do not appear to correlate to higher organic content. Zones of reddish color were noted and some reddish-grey intervals exhibit distinct reddish streak, possibly indicating iron content. The recorded brownish tinges and streaks could well be reddish rather than brown, but not sufficiently deep to mask the grey, and thus a net brownish cast has resulted. This tint may be more indicative of iron than of kerogen.

Although depositional discontinuity between the Cambrian and Proteozoic sections cannot be confirmed lithologically, there is a distinct break in the geochemical parameters across this boundary (Fig. 2b).

SUMMARY

In the Colville Hills area, Type II kerogen has been moderately to highly matured, certainly within the upper range of the oil generation window, and possibly into the gas generation phase. Dolostones within the Mount Cap Formation, and in part laterally equivalent to the Old Fort Island sandstones, are the most probable source beds although the greyer colored Mount Cap shales may also have had source potential. Greenish colored and tinted shales contain insufficient organic carbon to be petroleum sources.

Although only gas has been reported to date from tests in the Colville Hills area, oil staining is present in cores and oil potential is present on the basis of this geochemical evaluation. Thermal maturation is sufficient that wet gas may have been generated in situ.

TOC content in Proterozoic strata is generally too low to be be of major source interest in the Colville Hills area. Thermal maturation in these beds is considered to be beyond the oil generation window and is distinctly greater than that of the overlying Cambrian Mount Cap Formation.

Although the interpretation of Rock-Eval analyses is hindered because of low TOC content and a consequent wide range for the measured parameters in the Ontaratue area, thermal maturation is here considered to be beyond the oil generation window, although initial kerogen may have been sufficient that both Mount Cap and Proterozoic shales have been petroleum source beds.

To the south, especially in the Mackenzie Depocentre, Mount Cap shales are greener than to the north, containing proportionately less organic carbon. Thermal maturation levels cannot be confidently defined, but TOC content is generally too low for these to be considered as hydrocarbon source beds.

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APPENDIX A

CORE DESCRIPTIONS

CAMBRO-PROTEROZOIC STRATA

COLVILLE HILLS AND ADJACENT AREAS

Northwest Territories

Southern Area

IMPERIAL VERMILION RIDGE #1

Saline River
4450 - 4470 Salt, white, with rubble of light grey finely laminated, flat lying, fissile shale, only a small total core recovery, appears structurally undisturbed

5255 - 5275 Salt, clear to grey, some light grey shale rubble

Mount Cap
5788 - 5806 Shale, light to medium grey, slight green tinge, poorly laminated, sub-fissile, uniform throughout, identical to shale at Keele L-04; samples at 5788.5, 5804.0

5952 - 5972 Shale, medium grey, in part with slight green tinge, reddish-grey (maroon) zone 5757-5762, sub-laminated, sub-fissile, flat-lying, rare trilobite fragments; samples at 5952.5, 5960.5 and 5970.0

* Core stored in wooden boxes

SHELL KEELE L-04

Undefined (Mount Cap ?)
3233 - 3255 Shale, light/medium grey, slight green tinge, uniform section, sub-laminated and poorly fissile, flat-lying, scattered trilobite fragments; samples at 3235.0, 3241.0, 3247.0 and 3254.0

* Core stored in wooden boxes

BP et al LOSH LAKE G-22

Mount Cap
3718 - 3721 Siltstone, to very fine grained sandstone, some with green tinge, reddish at base, tight, very fine poorly continuous pale green to pale red (at base) argillaceous laminae, flat lying
3721 - 3722 Shale-Sandstone, green to some red in sandstone, extremely bioturbated to massive with continuous burrows filled by clean sandstone, all original bedding essentially destroyed
3722 - 3732 Shale, medium grey with distinct green tinge, laminated, fissile, flat lying, interbeds and laminae light grey to green-grey sandstone, shale zones with abundant trilobite debris on bedding planes; samples at 3723.5, 3726.2 and 3731.7
Old Fort Island
3732 - 3740 Sandstone, white with pale green zones at top and reddish zones at center and base of interval, very fine grained, hard, tight, zone red argillaceous siltstone 3735.6 - 3736.1, some green shale laminae near top, generally flat

BP et al Losh Lake G-22 (continued)

lying where shale beds present, some high angle dips and cross-beds in the massive sand sections, 1/4 inch pebbles of overlying shale type in top inch of sandstone, shale - sandstone contact sharp at wavy 10 degree angle, fluvial section

Ontaratue Area

ATLANTIC et al ONTARATUE K-04

Saline River

7966 - 7968 Anhydrite, rusty-brown, micro to fine crystalline, hard, laminated and wavily interbedded with 20% rust-red shale, some shallow water slump texture, 15 degree dip, shale content increases down to

7966 - 7985 Shale, rusty-red with zones of green-grey, massive to poorly laminated, with thin beds anhydrite as above, several beds of orange anhydrite show expansion into the shale, 20% anhydrite beds, 15 degree dip

7985 - 7994 Anhydrite, light grey, argillaceous, abundant laminae and beds medium green-grey shale, 15 degree dip, wavy irregular bedding, some vertical fractures filled by orange anhydrite

7994 - 8005 Shale, mostly rust-red with minor green-grey zones, massive but 15 degree dip shown by numerous interbeds (20%) rust-brown finely crystalline anhydrite in red shale zones and green-grey anhydrite in green-grey shale zones, wavy irregular bedding grading to smooth laminated anhydrite-shale contacts, only minor anhydrite in basal 4' which is almost entirely red shale

8005 - 8026 Dolostone, light/medium grey-brown to brown-grey, microcrystalline to aphanitic, abundant laminae and thin beds medium green-grey shale with wavy irregular distribution, dessication cracks, slump zones, scattered injection beds of, and fractures filled by, orange anhydrite, 20 degree dips, an initial mud

8090 - 8126 (recovered 6' core from total interval) Salt, white, most of recovered interval is light/medium grey shale, possible slight brown tinge, laminated, fissile, 10 degree dip; sample at 8093.0 (depth estimated, but possibly inexact because of poor recovery)

Proterozoic

8761 - 8784 Siltstone-Shale, interbedded medium/dark grey shale and light/medium grey to green-grey siltstone, siltstone is quartzose, hard, argillaceous, possible both silica and dolomite cements, interbedded in zones from laminated to 6" beds for both lithologies, approximate 60-40 siltstone-shale, 10 degree dip, wavy smooth bedding contacts between lithologies, some intra-formational rip-up clasts of siltstone in the shale, some discontinuity of laminae and lenses, shale has grey streak, some structurally disturbed zones near base show minor thrust-fold structures, otherwise not deformed any more than above cored beds, some

ATLANTIC et al K-04 (continued)

slickensides which increase downward commensurate with increasing deformation which occurs dominantly on bedding planes, scattered fine vertical fractures filled by orange dolomite; samples at 8761.5, 8772.0 and 8782.0

ATLANTIC et al ONTARATUE H-34

Mount Cap (Saline River?, or basal Franklin Mountain?)

9480 - 9481 Shale, light grey-green, some red bands, 4" band light green argillaceous dolostone, 1" sandstone stringer with shale rip-up clasts at top, laminated to wavy bedded, thin red shale bands are fissile, 5 degree dip

9481 - 9482 Sandstone, red to white and some pale green tinted, abundant laminae and lenses red shale, wavy irregular discontinuous bedding at 5 degree dip, fine grained quartzose, siliceous cement, tight

9482 - 9484 Shale-Sandstone, interbedded green and red shale and red sandstone, laminated to 1/2" beds at thickest, wavy to very irregular discontinuous bedding, 5 degree dip

9484 - 9497 Dolostone-Shale, interbeds from laminae to 1/2" in general of light/medium green-grey aphanitic to micro-crystalline dolostone and light/medium green-grey dolomitic shale, even to slightly wavy sharp bedding contacts, rhythmic deposition, occasional bands to 1/2" and irregular patches light grey fine to medium crystalline anhydrite, 1" light grey fine grained quartzose siliceous sandstone near base, 10 degree dip, color darkens to medium grey in lower 5' of interval, bands medium grey-brown micro-crystalline argillaceous dolostone toward base; samples of dolostone at 9495.9 and of grey shale at 9496.9 from above and below sandstone lens

9497 - 9499 not recovered

Old Fort Island (?)

10004 - 10023 Siltstone, light grey, quartzose. siliceous, in part grading to fine grained sandstone, hard, tight, numerous laminae and interbeds to 1/4" dark brown-grey shale with distinct brown to reddish-brown streak, shale beds are in part finely laminated fissile and may be shiny but not slickensided on bedding planes, dip variable 5 - 10 degrees, shale occurs as regular to wavy beds to discontinuous beds and laminae, could be fluvial flood plain deposit, slight reddish zones and with red on fractures near 10007 and 10011; samples taken selectively of the shale laminae and are not averages for the zone; samples at 10007.0 and 10016.0

Proterozoic

10602 - 10632 Shale, medium grey, slight green tinge, with very fine grained hard indurated argillaceous siltstone laminae, almost totally shale in top 10'and 90-10 shale-siltstone below, 5 to 10 degree dip, bedding regular laminated to some wavy in top half of interval and varve-like in lower half, shale very hard indurated, no fissility even though well laminated, grey streak; samples at 10605.0, 10617.0 and 10630.0

11348 - 11352 Shale-Siltstone, medium grey to green-grey siltstone interbedded with dark grey shale, sharp wavy to even bedding contacts, some discontinuous shale and siltstone lensing, soft sediment downward injection of sandstone-siltstone into shale zones, some wavy irregular

mottled zones ressemble re-working, shale almost looks graphitic; sample at 11352.0

Colville Hills Area

MOBIL COLVILLE E-15

Saline River

- 4463 Base main Salt interval

4463 - 4467 Shale, red, some light green, anhydrite blebs and laminae

4467 - 4469 Shale, medium green-grey to grey-green, laminated, minor thin anhydrite laminae

4469 - 4471 Dolostone, laminite, light brown with very thin dark brown organic laminae, micro to very finely crystalline; sample at 4470.0

4471 - 4472 Shale, medium grey to green-grey

4472 - 4478 Salt

4478 - 4500 Shale, medium green-grey to grey-green, some darker grey slickensided, with anhydrite lenses to 2" thick, occasional thin lenses light brown dolomite mud

4500 - 4505 Salt

4505 - 4506 Salt, with red shale and thin carbonate laminae, some very fine vuggy porosity along dolomite laminations

Mount Cap

4506 - 4507 Dolostone, light brown mud, interbedded grey-green shale, minor anhydrite

4507 - 4513 Shale, light grey-green grading downward to medium to dark brownish-grey to brown at base, green laminae in basal 6", occasional sandstone lense; samples dark brown-grey shale at 4510.5 and 4512.0, samples separated by zone containing green beds

4513 - 4518 Dolostone, sub-laminated mud, with lenses and laminae green shale, no apparent organic intervals

4518 - 4522 Shale, pale greenish-grey, with laminae of dolomite mudstone at the top and grading down to more massive green to dark green-grey shale, 2" anhydrite band at base

4522 - 4525 Shale, pale green laminated with laminae pale brown dolomite mudstone

4525 - 4540 Core missing

4540 - 4544 Shale, medium grey-green, bands lighter colored silty

4544 - 4547 Shale, red, with green laminae

4547 - 4554 Shale, dark grey, variably slight brown and green tinges, mostly laminated with approximate 10 degree dip; sample at 4752.5

4544 - 4555 Dolostone, light brown mud, dips to 30 degrees, scattered organic laminae

4555 - 4558 Shale, medium green to brown-grey, poorly laminated, minor anhydrite bands

MOBIL COLVILLE E-15 (continued)

4558 - 4565 Anhydrite and Dolostone, irregularly laminated, with shale laminae and partings

4565 - 4567 Shale, dark brown-grey with some green-grey laminae and lenses; sub-laminated brown-grey; sample at 4566.0

4567 - 4570 Shale, medium to light grey-green, occasional dark intervals

4570 - 4576 Shale, medium grey, with interbeds anhydrite and dolostone

4576 - 4577 Shale, medium green

4577 - 4583 Sandstone, light grey to white, with interbedded grey-green shale

4583 - 4588 Shale, medium to dark grey, very slight brown tinge; sample at 4587.5

4588 - 4595 Dolostone, light brown mudstone, shale interbeds and laminae

4595 - 4608 Shale, medium to dark green-grey, laminated, dip < 5 degrees

4608 - 4609 Shale, Dolostone, interbedded, medium grey shale

4609 - 4611 Shale, medium to dark green-grey, grading down to

4611 - 4644 Shale, medium to dark grey with occasional brown tinge, some very slight green in upper beds only, becoming dark below 4633, 6" light brown dolomite mud at 4648, a few thin sandstone beds in basal three feet; samples at 4630.0 medium grey with 10 degree dip; at 4643.0 dark grey; 4649.0 medium grey

4644 - 4666 Sandstone, light grey, quartzose, hard, irregular bedding, dark grey to brown grey shale laminae, possibly some light brown dolostone zones, burrowed, shale beds in part appear to be concentrated organic partings; sample at 4660.5

4666 - 4677 Shale, medium grey, laminated, sub-fissile; samples at 4672.0 and 4675.0

4677 - 4678 Sandstone, light grey, with lesser shale as above

4678 - 4680 Not cored

4680 - 4704 Shale, pale green to light grey, some mottled bioturbated, grey zones with slight green tinge, 10 degree dip

4704 - 4712 Shale, grey and green, variably mottled and banded, more grey than above and no pale green, some darker and possibly organic where finely banded-laminated; sample 4704.5 medium to dark grey with organic (?) laminae

4712 - 4714 Shale, pale green mottled bioturbated

4714 - 4723 Shale, medium grey, no apparent green tinge; sample 4722.0 sub-laminated

4723 - 4738 Shale, grey-green to light grey-green at base, some laminated color mottling

4738 - 4739 Shale, grey, in part with very slight green tinge; sample at 4739.0

4739 - 4740 Shale, very pale green-grey, massive

4740 - 4741 Dolostone, medium brown, aphanitic, boudinage structure, silty, argillaceous

4741 - 4748 Shale, medium grey, sub-laminated; sample at 4746.0

4748 - 4755 Dolostone, medium browm, boudinage, argillaceous inter-boudinage matrix with grey streak only

4755 - 4762 Shale, medium green-grey, laminated, essentially flat lying, becoming greyer and darker in basal foot

MOBIL COLVILLE E-15 (continued)

4762 - 4763 Dolostone, medium brown, appears to be organic, some dark brown laminae, argillaceous zones and thin interbeds; sample at 4762.5

4763 - 4765 Dolostone, medium brown aphanitic, possibly organic, with bands dark brown-grey organic shale (brown streak)

4765 - 4770 Shale, dark brown-grey, laminated, brown streak, with numerous laminae to thin inter-beds light grey hard fine grained sandstone; sample at 4767.0 of dark brown-grey hard shale with brown streak and occasional slickensides

4770 - 4771 Dolostone, light brown laminated mud

4771 - 4773 Dolostone, dark brown microcrystalline, massive to some laminated, hard

4773 - 4780 Core missing

4780 - 4788 Dolostone, light brown to light grey, mostly aphanitic mud, in part with irregular mottling

4788 - 4793 Dolostone, light brown, aphanitic mud, abundant wavy irregular solution partings, interbedded with and grading down to shale, basal part with light grey silty partings

4793 - 4796 Shale, light grey to green-grey, abundant silt partings, some dolostone partings, partings disappear downward as zone grades to

4796 - 4850 Shale, light green-grey, scattered zones with maroon tint, sub-laminated to poor horizontal breakage, zones with small orbiculoid brachiopods, possible trilobite debris; samples at 4819.0 and 4849.0, organic content not anticipated

4850 - 4870 Sandstone, light grey, very fine grained, argillaceous, light green-grey shale partings, bioturbated with irregular mottle of the shale partings, tight

4875 - 4882 Shale, light green-grey, with abundant light grey sandstone laminae and lenses, flat to minor dip, bioturbated but bedding still distinct

4882 - 4906 Shale, green-grey, slight green tinge, sub-laminated to fissile

4906 - 4933 Dolostone, dark brown to grey, fine to microcrystalline, hard, massive, in part possible fossil detritus, in part silty and argillaceous, a few organic solution partings, zone in part appears rubblized, a few scattered small discontinuous vugs, otherwise tight, some wavy irregular hozontal brown laminae from solution or burrowing; sample at 4910.0 of organic parting in the dolostone; becoming light brown in basal 8 feet and grades down to

4933 - 4945 Shale, medium grey, in part with faint green tinge, poorly laminated to sub-fissile

4945 - 4954 Dolostone, light brown to medium grey, massive fossiliferous debris, scattered organic solution partings with brown streak, microcrystalline, irregular siltstone interbeds in basal 2 feet and mostly siltstone in basal 6"

Old Fort Island

4954 - 4960 Sandstone, light to pale brown, very fine grained, tight, occasional irregular horizontal organic laminae

4960 - 4962 Dolostone, medium grey, fine to microcrystalline, indeterminate fossiliferous debris in mud matrix

MOBIL COLVILLE E-15 (continued)

4962 - 4975 Sandstone, pale brown to grey, very fine grained to silty, massive, with very fine irregular organic laminae, mottled, burrowed, basal 3 feet with irregular shale partings with continuity almost destroyed by the burrowing and grading down to

4975 - 4978 Shale, medium grey, very slight green tinge, sub-laminated to massive

4978 - 4986 Sandstone, grey, extremely bioturbated, tight

4986 - 5009 Sandstone, pale brown, almost white, fine to medium grained, tight, poorly laminated seen by very fine irregular wavy color laminae although no distinct clay or organic material, flat at top to 10 degree dip at base

Proterozoic (?)

5009 - 5035 Shale, pale to dark grey and light green, some red, 10 degree dip

5035 - 5105 Shale, red, green light colors to pale, some olive-green, grey-green, sandy zones near top, approximate 10 degree dip

5105 - 5144 Shale, mostly light grey but with zones green to green-grey, no red, color becoming greyer and darker downward, medium grey at base, one inch light grey very fine grained sandstone at 5133, poorly laminated to massive, the greyer beds have a few slickensides; sample 5138.0

5144 - 5183 Shale, medium to dark grey, massive to poorly bedded but some breakage on 10 degree dip, a few very thin (1 to 2 inch) green and reddish zones, some slickensides in darkest intervals, scattered thin beds (1 inch maximum) and numerous laminae light hard fine grained sandstone with possible burrows and definite injection structures at base of sandstones; samples of darker grey at 5145.0, 5155.0, 5174.0 and 5179.0; depths of latter two may be erroneous because of confusion in box numbering

5183 - 5195 Orthoquartzite, red hard, in part grading to red shale

5195 - 5380 Shale, dark grey, some faint brown tinge, some slickensides with brown streak, numerous thin beds and laminae light grey fine grained hard sandstone, horizontal to 10 degree dips, thin zone hard red quartzite and red shale 5219-5221; samples from darkest beds, especially with slickensides, at 5197.0, 5211.5, 5224.0, 5236.5, 5255.0, 5269.0, 5278.5, 5304.0, 5317.0 and 5341.5

5380 - 5392 Sandstone, white to light grey and some with light reddish tint, very fine grained, hard, massive, tight

5392 - 5401 Sandstone, (85%) with grey shale interbeds (15%)

5401 - 5501 Sandstone-Shale, 60%-40%, medium grey at top darkening downward to base, abundant sandstone injection into shale at base of sandstone beds, slickensides common on shale beds and partings, brown streak common, especially on thinnest shale partings; samples at 5402.5, 5435.0, 5462.5, 5489.0 and 5495.0

5501 - 5510 Shale, olive-green, sandstone interbeds

5510 - 5566 Sandstone. light grey, very fine grained, hard, interbedded medium to dark grey shale, variably 60-100% sandstone, 40-0% shale, shale increases downward

5566 - 5641 Sandstone-shale, 85-15 ratio decreasing to 75-25 below 5597, sandstone beds up to 1/4 inch thick separated by shale laminae to very thin beds, shale often slickensided and with brown-grey streak; samples of shale laminae at 5599.0, 5604.5 and 5615.0

5641 - 5897 Sandstone, medium grey to green-grey, grading down to lighter colored, very fine laminae and beds of light green shale, some white patches and bands from possible irregular cementation, very hard, the green is much brighter and has in part a bluish tint in contrast to greens encountered above, becomes darker again below 5435, generally flat to low angle bedding, no structural deformation, some vertical fractures to 1.5" filled by white dolomite, sandstone often with abundant glauconite; sample of blue-green clay at 5407 for XRD; grades down to

5897 - 5922 Siltstone-Sandstone-Shale, grey, hard, grey shale laminae with grey streak, 10 to 15 degree dip

5922 - 5956 Sandstone-Siltstone-Shale, grey, abundant dark grey shale laminae, brown streak, often slickensided, streak becomes greyer and slickensides decrease to base of interval; sample at 5924.0

5956 - 5985 Sandstone, medium to dark grey, to conglomerate and very course breccia, some dark grey shale interbeds and grey slickensided laminae with brown streak

5985 - 5997 (TD) Sandstone, light to dark grey depending on argillaceous and/or organic content, hard, massive, 20 degree dip by color variations, abundant white crystalline dolomite filling vertical fractures, scattered pebble zones;sample at 5994.0

PEX-FINA N. COLVILLE L-21

Mount Cap

3685 - 3693 Shale, medium grey at top of interval, slight green tinge, becoming greener to base, laminated, fissile, grey streak, flat lying, scattered orbiculoid brachiopods, a few trilobite fragments, sandstone laminae and thin interbeds in basal foot; samples at 3685.5 and 3691.0

3693 - 3695 Shale, light green, siltstone zones most evident in zones of mottled bioturbated, flat lying, poorly laminated, sub-fissile

3695 - 3705 Shale, medium grey-green to green-grey, flat-lying, fissile; samples at 3698.5 and 3703.5 rests with irregular surface on

3705 -3710 Dolostone, medium grey-brown, finely crystalline clear dolomite with dark brown (organic?) flecks to give medium color, abundant bioturbation, extremely hard, indeterminate fossil debris, trace small discontinuous vugs, numerous solution partings and concentrated medium to dark grey bands of possible organic material with brown streak; sample of dark brownish-black concentrate band at 3706.0, and of dark brown finely crystalline resinous dolostone at 3708.5

3710 - 3712 Dolostone, light brown, abundant irregular mottled light grey-green argillaceous solution partings and laminae, bioturbated

PEX-FINA N. COLVILLE L-21 (continued)

3712 - 3716 Dolostone, as in 3705-10, bioturbated with scattered small discontinuous vugs, shaly zone 3714-15 fairly laminated flat-lying, dolostone has some indeterminate fossil debris but is entirely mud toward base of interval; sample of resinous brown dolostone at 3714.5

Old Fort Island

3716 - 3731 Sandstone, light grey to light brown, some green tinge, quartz, glauconite, abundant laminae light green shale, strongly bioturbated, hard, very fine to fine grained, tight

3731 - 3733 Sandstone, medium grey, grey shale partings, hard, fine grained, tight, flat-lying

3733 - 3749 Sandstone, light grey to green-grey and grey-green, quartz, very glauconitic, thin interbeds and partings grey-green shale, irregular wavy bioturbated flat bedding, a few distinct green sandstone zones, grey color increases downward

3749 - 3752 Sandstone, medium grey, organic (?) shale partings, fine pebble beds, 10 degree cross-bedding at base and slightly coarser to medium grained sandstone, appears to be fluvial sedimentation from bedding, color and grain size distribution

3752 - 3755 Sandstone, white to pale green, fine grained with scattered pebbles, abundant light green shale partings and thin laminae to beds, essentially flat-lying, one foot rubble breccia at base

3755 - 3760 Sandstone, light grey-brown in top 1.5' grading down to rusty-red, fine grained, siliceous, hard, tight, grey-green clay laminae at top and rusty-red laminae in basal section, irregular discontinuous bedding and inter-lamination, dips to maximum 15 degrees but mostly flat, probably fluvial

UNION MOBIL COLVILLE D-45

Mount Cap

3018 - 3027 Shale, medium grey, in part with slight green tinge, grading to medium grey siltstone, and with discontinuous light grey to white sandstone lenses, laminated, 5 degree dip, minor bioturbation; samples at 3020.0, 3022.5

3027 - 3028 Sandstone, dark greenish-grey, glauconitic, massive

3028 - 3032 core not recovered

3032 - 3054 Sandstone, light grey, greenish tinge from abundant light green argillaceous partings and laminae, very fine grained, quartzose, hard, tight, extreme bioturbation, zone light purple-red 3034.0 - 3035.5 with red shale partings, general 5 degree dip, grades down, as shale content increases, to

3054 - 3058 Sandstone-Shale, much as above with increasing shale downward to

3058 - 3081 Shale, medium grey, very faint green tinge, laminated, fissile, maximum 5 degree dip or less, scattered orbiculoid brachiopods, traces trilobite debris; samples at 3065.0 and 3074.0

UNION MOBIL COLVILLE D-45 (continued)

3081 - 3088 Sandstone, light green to green-grey, very fine grained, quartzose, hard, with abundant (up to 40%) light grey-green shale partings and laminae, wavy mottled bedding, much burrowing, scattered glauconite and almost solid glauconite in basal 3"

3088 - 3093 Dolostone, light to medium grey, abundant dark brown-grey organic (?) solution partings and laminae, finely crystalline, tight, partings irregular and wavy, in part appears burrowed, probably an initial mud deposit; sample including organic lamination at 3090.0

3093 - 3096 Dolostone, light brown to some grey, micro to some very finely crystalline, tight, initially a mud, scattered green to grey solution laminae and partings, essentially flat lying

3096 - 3102 Sandstone, pale brown, fine grained, dolomitic, massive, scattered horizontal argillaceous partings, interbeds to 2" of medium grey silty shale in basal 2', grades down to

3102 - 3107 Shale, medium grey, laminated, fissile, 5 degree dip, numerous silt and sandstone laminae; sample at 3105.3

3107 - 3111 Sandstone, light grey, with interbedded shale as above, irregularly stratified, burrowed, grades down by increasing shale content to

3111 - 3116 Shale, medium grey, very faint green tinge, light grey streak; sample at 3113.0

3116 - 3120 Sandstone, dark grey-green, quartz with up to 60% glauconite, fine grained, massive, tight

3120 - 3128 Sandstone, light brown, very fine grained, quartz, dolomitic, massive, occasional remnants light grey argillaceous partings, burrowed

3128 - 3136 Shale, medium grey, laminated, fissile, 5 degree dip, occasional light grey sandstone laminae; sample at 3133.0

3136 - 3139 Shale-Sandstone, 60-40, light grey shale, white sandstone, interbedded to inter laminated, flat lying, burrowed

3139 - 3141 Shale, medium grey, laminated, fissile, < 5 degree dip

3141 - 3144 Shale-Sandstone, beds 6" to 12" alternating shale-sandstone as above

3144 - 3153 Shale, medium green-grey, with numerous sandstone beds and laminae, bioturbated, irregular wavy flat bedding to possible 5 degree dip

3153 - 3154 Shale, medium grey, green tinge, laminated but poorly fissile, scattered burrows filled with light grey sandstone; sample at 3153.9

3154 - 3156 Sandstone, medium grey, fine grained dolomitic, possible very slight poor porosity, wavy irregular bedding, some very fine bitumen (?) debris and as grain coatings

3156 - 3158 Shale, medium grey, sub-laminated, sub-fissile, with irregular patches and burrows filled by grey sandstone

3158 - 3174 Dolostone, medium brown to brown-grey, micro to fine crystalline, resinous, very fine organic deposits between crystals, laminae and bands of concentrated organic (?) solution partings throughout, shale zone at 4160-4160.5, dolostone probably initial mud, scattered small white fossil (?) detritus although these could be burrows, scattered sand and silt content, 6" medium grey sandstone bed at 3174, 4" dolostone laminite bed with 10 degree dip at base of interval; samples - resinous dolostone, with black parting, at 3163.5, concentrated organic band (brown-black with brown streak) at 3167.5, medium to fine grained dolostone at 3169.5, organic parting at 3171.0, and laminite at 3173.9

Old Fort Island

3174 - 3183 Sandstone, light to medium grey, quartz, fine grained at top grading down to some coarse grained intervals and pebble zone at base, laminae and interbeds light grey shale, 5 degree dip, some concentrated organic (?) bands

3183 - 3185 Siltstone, light grey, massive but with flecks and discontinuous laminae bright light green shale

3185 - 3187 Shale, light green, light grey sandstone laminae, 5 to 10 degree dip, burrowed zones along sandstone interbeds where shale grades to grey

3187 - 3188 Siltstone, light grey to pale brown, abundant bright green discontinuous laminae to flecks

3188 - 3189 Shale, light to medium green, some discontinuous irregular sandstone laminae and interbeds

3189 - 3193 Siltstone, pale brown with some faint green patches, in part burrowed, in part with discontinuous laminae to thin lenses light green shale

3193 - 3203 Sandstone, green-grey mottled, one zone one foot of reddish mottle, irregular patches light to medium green shale inclusions, patchier color zones probably bioturbated, becoming pink-grey in basal three feet, 8" interbeds of medium grey-green laminated fissile shale at 3199 and 3201

3203 - 3230 Sandstone, medium brown oil stained, medium to some coarse grained, some darker grey zones where black bitumen coats the grains, thick 6" encrusted zone 3119.5 - 3120.0, flat lying to cross-bedded with 15 degree dips, good intergranular porosity, 4" pale grey rip-up shale inclusion at 3208.5, fluvial sediments

3230 - 3232 Shale, medium grey, laminated, fissile, 5 degree dip, discontinuous wavy sandstone laminae and lenses, no bioturbation, fluvial (?)

UNION-IMPERIAL STOPOVER K-44

Old Fort Island

2750 - 2840 Dominantly Sandstone, lesser shale, rust-red, minor green intervals, 2' white sandstone at top and patches throughout of white which have been leached of color by interstitial water movement, variably fine to coarse grained but no pebble beds, smaller intervals becoming finer from coarse grained at base upward to red shale, burrowing in interbedded thin sandstone-shale intervals, dessication cracks in shales, load cast deformation at sandstone-shale contacts, some rip-up clasts, one small shale (3/4") detrital clast, fair porosity in coarser sandstones, some irregular wavy bedding, generally flat-lying, no cross-beds, thickest sandstones are massive, fluvial, no apparent source beds

FOREWARD et al EWAKKA C-11

Mount Cap

1279 - 1279.5m Shale, medium grey, slight green tinge, sub-laminated to sub-fissile, very slightly silty with scattered quartz, flat lying, transitional contact over 1/2" down to

Old Fort Island

1279.5 - 1282m Sandstone, light to medium grey, in part argillaceous and with scattered discontinuous irregular dark grey shale partings, laminae and irregular patches, fine to coarse grained, massive to poor irregular wavy flat bedding where shale laminae present, one pebble zone fines rapidly upward and rests sharply on underlying sandstone, major vertical fracture filled by coarse crystalline clear to white dolomite

APPENDIX B

ANALYTICAL DATA

ROCK-EVAL PYROLYSES

COLVILLE HILLS AND ADJACENT AREAS

Northwest Territories

Depth ft.	TOC Wt%	Tmax °C	S1 mg/g	S2 mg/g	S3 mg/g	HI	OI	S1+S2 kg/t	PI	Ratio kg/t /%TOC
SHELL KEELE L-04										
Mount Cap ?										
3235.0	0.05	560	0.00	0.24	0.12	480	240	0.24	.00	4.80
	0.04	508	0.00	0.35	0.33	875	825	0.35	.00	8.75
3241.0	0.06	526	0.00	0.40	0.11	666	183	0.40	.00	6.66
	0.06	492	0.00	0.53	0.35	883	583	0.53	.00	8.83
3247.0	0.07	517	0.00	0.40	0.10	571	142	0.40	.00	5.71
	0.05	485	0.00	0.40	0.32	800	640	0.40	.00	8.00
3254.0	0.03	549	0.00	0.05	0.14	166	466	0.05	.00	1.67
	0.02	572	0.00	0.18	0.35	900	1750	0.18	.00	9.00
IMPERIAL VERMILION RIDGE No. 1										
Mount Cap ?										
5788.5	0.08	469	0.01	0.06	1.61	75	2012	0.07	.17	0.88
	0.10	370	0.00	0.01	0.36	10	260	0.01	.00	0.10
5804.0	0.07	476	0.02	0.27	0.65	385	928	0.29	.07	4.14
	0.08	547	0.00	0.13	0.32	162	275	0.13	.00	1.63
5952.5	0.07	380	0.02	0.05	1.03	71	1471	0.07	.33	1.00
	0.09	-	0.00	0.00	0.25	0	277	0.00	--	0.00
5960.5	0.07	-	0.05	0.00	0.80	0	1142	0.05	1.00	0.71
	0.11	490	0.03	0.01	0.22	9	290	0.09	.75	0.36
5970.0	0.07	-	0.03	0.00	1.29	0	1842	0.03	1.00	0.73
	0.09	-	0.00	0.00	0.26	0	400	0.00	--	0.00
BP et al LOSH LAKE G-22										
Mount Cap										
3723.5	0.06	-	0.00	0.00	0.12	0	200	0.00	--	0.00
	0.05	575	0.00	0.09	0.39	180	780	0.09	.00	0.00
3726.2	0.04	387	0.00	0.02	0.15	50	375	0.02	.00	0.50
	0.08	456	0.00	0.11	0.36	137	450	0.11	.00	1.37
3731.7	-	-	0.00	0.00	0.02	-	-	0.00	--	--
	0.07	525	0.00	0.13	0.36	185	514	0.13	.00	1.86
ATLANTIC et al ONTARATUE K-04										
Saline River										
8093.0	0.13	-	0.07	0.00	0.45	0	346	0.07	1.00	0.54
	0.16	-	0.06	0.00	0.11	0	62	0.06	1.00	0.38
Proterozoic										
8761.5	0.13	566	0.06	0.39	1.53	300	1176	0.45	.14	3.46
	0.14	576	0.00	0.34	0.06	242	42	0.34	.00	2.43
8772.0	0.15	565	0.00	0.10	0.32	66	263	0.10	.00	0.67
	0.16	583	0.00	0.03	0.09	18	56	0.03	.00	0.19
8782.0	0.20	508	0.05	0.27	0.14	135	70	0.32	.16	0.80
	0.21	-	0.00	0.00	0.07	0	33	0.00	--	0.00
ATLANTIC et al ONTARATUE H-34										
Mount Cap										
9495.9	0.13	-	0.00	0.00	0.33	0	253	0.00	--	0.00
	0.16	424	0.00	0.03	0.19	18	118	0.03	.00	0.18
9496.9	0.21	559	0.15	0.11	0.09	52	42	0.26	.58	1.24
	0.22	581	0.17	0.05	0.08	22	36	0.22	.77	1.00

Depth ft.	TOC Wt%	Tmax °C	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	HI	OI	S1+S2 kg/t	PI	Ratio kg/t /%TOC
ATLANTIC et al ONTARATUE H-34 (continued)										
Old Fort Island										
10007.0	0.24	577	0.03	0.24	0.09	100	37	0.27	.12	1.12
	0.22	587	0.02	0.02	0.12	9	54	0.04	.50	0.18
10016.0	0.22	-	0.00	0.00	0.13	0	59	0.00	--	0.00
	0.22	-	0.00	0.00	0.13	0	59	0.00	--	0.00
Proterozoic										
10605.0	0.00	-	0.00	0.00	0.51	-	-	0.00	--	--
	0.39	333	0.01	0.01	0.23	2	58	0.02	.50	0.05
10617.0	0.31	416	0.00	0.20	0.62	64	200	0.20	.00	0.64
	0.53	-	0.00	0.00	0.07	0	13	0.00	--	0.00
10630.0	0.58	495	0.00	0.04	0.36	6	62	0.04	.00	0.07
	0.50	-	0.00	0.00	0.06	0	12	0.00	--	0.00
11352.0	0.67	-	0.00	0.00	0.36	0	53	0.00	--	0.00
	0.67	-	0.00	0.00	0.04	0	5	0.00	--	0.00
ONTADEK N-39										
Proterozoic ?										
5880.	5.97	435	1.71	3.41	0.43	57	7	5.12	.33	0.86
UNION MOBIL COLVILLE D-45										
Mount Cap										
3020.0	0.16	461	0.06	0.57	0.14	356	87	0.63	.10	3.64
	0.24	504	0.06	0.46	0.24	200	104	0.52	.12	2.26
3022.5	0.33	442	0.08	0.78	0.09	236	27	0.86	.09	2.61
	0.33	445	0.06	0.88	0.18	266	54	0.94	.06	2.85
3065.0	0.13	432	0.09	0.14	0.12	107	92	0.23	.41	1.77
	0.12	574	0.07	0.13	0.18	108	150	0.20	.35	1.67
3074.0	0.07	360	0.07	0.06	0.11	85	157	0.13	.58	1.86
	0.07	569	0.06	0.17	0.12	242	171	0.23	.27	3.29
3090.0	0.58	443	0.54	1.28	0.40	220	68	1.82	.30	3.14
	0.63	443	0.53	0.95	0.42	150	66	1.48	.36	2.35
3105.3	0.08	435	0.05	0.08	0.09	100	112	0.13	.42	1.63
	0.07	557	0.04	0.13	0.14	185	200	0.17	.25	2.43
3113.0	0.08	445	0.06	0.11	0.12	137	150	0.17	.37	2.12
	0.08	557	0.04	0.23	0.14	287	175	0.27	.15	3.37
3133.0	0.16	428	0.12	0.14	0.10	87	62	0.26	.46	1.62
	0.19	533	0.09	0.33	0.15	173	78	0.42	.21	2.22
3153.9	0.06	447	0.05	0.09	0.13	150	283	0.14	.36	6.00
	0.07	566	0.03	0.19	0.27	271	385	0.22	.14	3.14
3163.5	1.62	436	0.04	0.80	0.63	49	38	0.84	.05	0.52
	0.43	443	0.21	0.88	0.36	204	83	1.09	.36	2.54
	0.45	468	0.16	0.45	0.43	100	95	0.61	.27	1.36
3167.5	0.23	443	0.15	0.28	0.45	121	195	0.43	.19	1.84
	1.57	445	0.69	5.51	0.34	350	21	6.20	.11	3.94
	1.58	446	0.70	4.65	0.39	294	24	5.35	.13	3.38
3169.5	0.72	444	0.60	1.34	0.43	186	59	1.94	.31	2.70
	0.27	447	0.13	0.16	0.56	59	207	0.29	.46	1.07
3171.0	2.93	446	1.36	14.53	0.56	495	19	15.89	.09	5.46
	0.84	443	0.63	1.10	0.79	130	94	1.73	.37	2.06
3173.9	0.07	505	0.00	0.02	0.13	28	185	0.02	.00	0.29
	3.11	446	1.43	15.18	0.61	488	19	16.63	.19	5.35

Depth ft.	TOC Wt%	Tmax °C	S1 mg/g	S2 mg/g	S3 mg/g	HI	OI	S1+S2 kg/t	PI	Ratio kg/t /%TOC
MOBIL COLVILLE E-15										
Saline River										
4470.0	-	427	0.09	0.17	0.44	-	-	0.26	.35	-
	0.20	-	0.07	0.00	0.33	0	165	0.07	1.00	0.35
Mount Cap										
4510.5	-	479	0.11	0.12	0.16	-	-	0.23	.50	-
	0.27	580	0.09	0.25	0.20	92	74	0.34	.26	1.25
4512.0	-	397	0.06	0.15	0.09	-	-	0.21	.30	-
	0.19	570	0.06	0.18	0.15	94	78	0.24	.25	1.26
4552.5	0.06	458	0.01	0.06	0.41	100	683	0.07	.17	1.16
	0.09	418	0.01	0.12	0.40	133	444	0.13	.08	1.44
4566.0	-	423	0.17	0.31	0.09	-	-	0.48	.35	-
	0.34	428	0.16	0.70	0.10	205	29	0.86	.19	2.53
4587.5	0.48	439	0.50	0.92	0.31	191	64	1.42	.35	2.98
	0.40	442	0.38	0.70	0.30	175	75	1.08	.35	2.70
4630.0	0.45	414	0.52	1.03	0.22	288	48	1.55	.34	3.43
	0.49	412	0.46	1.13	0.27	230	55	1.59	.29	3.25
4643.0	0.73	420	0.76	1.76	0.14	241	19	2.52	.30	3.45
	0.88	428	0.79	2.20	0.15	250	17	2.99	.27	3.40
4649.0	0.44	428	0.50	1.23	0.12	279	27	1.73	.29	3.93
	0.51	432	0.50	1.41	0.22	276	43	1.91	.26	3.74
4660.5	1.33	429	1.41	3.78	0.16	284	12	5.19	.27	3.90
	1.47	431	1.38	3.92	0.22	266	14	5.30	.26	3.61
4672.0	0.88	430	1.19	2.04	0.33	231	37	3.23	.30	3.67
	0.89	432	1.16	1.61	0.67	180	75	2.87	.42	3.23
4675.0	1.16	434	1.47	3.04	0.38	262	32	4.51	.33	3.80
	1.25	438	1.46	2.58	0.80	206	64	4.04	.31	3.23
4704.5	1.30	447	3.15	2.81	0.47	216	36	5.96	.53	4.58
	1.46	447	3.22	2.58	0.79	176	54	5.80	.56	3.97
4722.0	0.29	439	0.15	0.34	0.36	117	124	0.49	.31	1.69
	0.30	447	0.09	0.09	0.59	30	196	0.18	.50	0.60
4739.0	0.14	424	0.07	0.10	0.30	71	214	0.17	.44	1.22
	0.15	-	0.05	0.00	0.33	0	220	0.05	1.00	0.33
4746.0	0.31	445	0.11	0.43	0.47	138	151	0.54	.20	1.74
	0.36	448	0.08	0.20	0.55	55	152	0.28	.29	0.77
4762.5	0.60	425	0.48	1.26	0.39	210	65	1.74	.28	2.90
	0.73	423	0.40	0.73	0.44	100	60	1.13	.36	1.55
4767.0	1.89	433	2.21	5.22	0.28	276	14	7.43	.30	3.93
	2.07	435	2.17	4.94	0.41	238	19	7.11	.31	3.44
4819.0	0.05	380	0.04	0.10	0.20	200	400	0.14	.29	2.80
	0.06	469	0.01	0.32	0.27	533	450	0.33	.03	5.50
4849.0	0.04	466	0.05	0.12	0.19	300	475	0.17	.31	4.25
	0.04	528	0.06	0.31	0.45	516	750	0.37	.17	9.25
4910.0	1.16	440	0.41	2.28	0.60	196	51	2.69	.15	2.32
	1.14	444	0.40	1.86	0.56	163	49	2.26	.18	1.98
Old Fort Island										
Proterozoic										
5138.0	0.38	459	0.08	0.17	0.22	44	57	0.25	.33	0.66
	0.37	-	0.08	0.00	0.24	0	64	0.08	1.00	0.22
5145.0	0.27	419	0.10	0.11	0.16	40	59	0.21	.50	0.77
	0.27	578	0.10	0.18	0.18	66	66	0.28	.36	1.04

Depth ft.	TOC Wt%	Tmax °C	S1 mg/g	S2 mg/g	S3 mg/g	HI	OI	S1+S2 kg/t	PI	Ratio kg/t /%TOC
MOBIL COLVILLE E-15 (continued)										
5155.0	0.56	419	0.14	0.15	0.14	26	25	0.29	.50	0.52
	0.55	569	0.14	0.24	0.14	43	25	0.38	.37	0.65
5174.0	0.45	343	0.08	0.11	0.13	24	28	0.19	.44	0.42
	0.46	576	0.09	0.17	0.12	36	26	0.26	.35	0.56
5179.0	0.27	469	0.09	0.17	0.11	62	40	0.26	.35	0.96
	0.23	576	0.07	0.13	0.07	56	30	0.20	.35	0.88
5197.0	0.19	471	0.06	0.13	0.09	68	47	0.19	.33	1.00
	0.17	581	0.05	0.03	0.11	17	64	0.08	.62	0.47
5211.5	0.41	431	0.19	0.17	0.13	41	31	0.36	.53	0.88
	0.37	566	0.14	0.19	0.26	51	70	0.33	.44	0.89
5224.0	0.47	400	0.13	0.16	0.14	34	29	0.29	.46	0.62
	0.45	577	0.08	0.10	0.15	22	32	0.18	.44	0.89
5236.5	0.26	536	0.10	0.16	0.10	57	35	0.26	.38	1.00
	0.30	577	0.08	0.47	0.08	156	26	0.55	.15	1.80
5255.0	0.40	458	0.12	0.14	0.12	35	30	0.26	.46	0.65
	0.38	574	0.11	0.18	0.15	47	39	0.29	.39	0.76
5269.0	0.72	400	0.13	0.22	0.12	30	16	0.35	.30	0.48
	0.70	568	0.13	0.26	0.13	37	18	0.39	.34	0.56
5278.5	0.54	403	0.15	0.34	0.10	62	18	0.49	.31	0.91
	0.49	573	0.12	0.29	0.07	59	14	0.41	.30	0.84
5304.0	0.11	459	0.11	0.14	0.08	127	72	0.25	.46	2.27
	0.10	576	0.10	0.15	0.06	150	60	0.25	.42	2.50
5317.0	0.62	420	0.09	0.15	0.11	24	17	0.24	.37	0.39
	0.60	546	0.08	0.35	0.15	58	25	0.43	.19	0.71
5341.5	0.48	479	0.06	0.16	0.10	33	20	0.22	.27	0.46
	0.45	566	0.06	0.15	0.28	33	62	0.21	.30	0.47
5402.5	0.03	431	0.00	0.06	0.07	200	233	0.06	.00	2.00
	0.03	436	0.01	0.02	0.10	65	333	0.03	.50	1.00
5435.0	0.59	443	0.15	0.20	0.14	33	23	0.35	.44	0.58
	0.61	552	0.13	0.43	0.14	70	22	0.56	.23	0.92
5462.5	0.33	416	0.03	0.10	0.07	30	21	0.13	.25	0.39
	0.32	561	0.02	0.12	0.09	37	28	0.14	.14	0.44
5489.0	0.43	484	0.03	0.10	0.09	23	20	0.13	.25	0.30
	0.46	567	0.02	0.10	0.18	21	39	0.12	.17	0.35
5495.0	0.37	368	0.13	0.14	0.09	37	24	0.27	.50	0.73
	0.38	539	0.11	0.12	0.05	31	13	0.23	.50	0.60
5599.0	0.46	464	0.03	0.16	0.09	34	19	0.19	.17	0.38
	0.44	545	0.04	0.15	0.28	34	63	0.19	.22	0.43
5604.5	0.80	387	0.26	0.18	0.09	22	11	0.44	.59	0.55
	0.73	-	0.21	0.00	0.15	0	20	0.21	1.00	0.28
5615.0	0.76	445	0.07	0.11	0.09	14	11	0.18	.39	0.25
	0.68	565	0.07	0.10	0.14	14	20	0.17	.44	0.25
5924.0	0.21	374	0.00	0.02	0.10	9	47	0.02	.00	0.09
	0.20	-	0.00	0.00	0.13	0	65	0.00	--	0.00
5994.0	0.27	385	0.04	0.05	0.10	18	37	0.09	.50	0.33
	0.34	539	0.05	0.37	0.10	108	29	0.42	.12	1.24

Depth ft.	TOC Wt%	Tmax °C	S1 mg/g	S2 mg/g	S3 mg/g	HI	OI	S1+S2 kg/t	PI	Ratio kg/t /%TOC
FINA PEX N. COLVILLE L-21										
Saline River										
2860.	0.38	376	0.09	0.14	0.5	37	145	0.23	.36	0.60
Mount Cap										
3685.5	0.26	434	0.22	1.20	0.21	461	80	1.42	.15	5.46
	0.28	468	0.03	1.06	0.05	378	17	1.09	.03	3.82
3691.0	0.15	500	0.13	0.76	0.49	506	326	0.89	.15	5.93
	0.19	495	0.01	0.91	0.04	478	21	0.92	.01	4.84
3698.5	0.05	496	0.00	0.39	0.32	780	640	0.39	.00	7.80
	0.09	540	0.00	0.47	0.10	522	111	0.47	.00	5.22
3703.5	0.09	505	0.01	0.24	0.35	266	388	0.25	.04	2.78
	0.15	481	0.00	0.65	0.16	433	106	0.65	.00	4.33
3706.0	5.06	456	0.45	13.04	0.67	257	13	13.49	.25	2.67
	6.05	475	5.40	15.84	0.47	234	6	21.24	.25	3.14
3708.5	0.18	416	0.04	0.10	0.75	55	416	0.14	.29	0.77
	0.24	472	0.05	0.06	0.41	25	170	0.11	.50	0.45