A STUDY OF THE PETROLEUM POTENTIAL AND REGIONAL PETROLEUM PROSPECTIVITY OF THE DEER LAKE GROUP AND HOWLEY FORMATION ON PERMITS 93-103 AND 93-104, DEER LAKE BASIN

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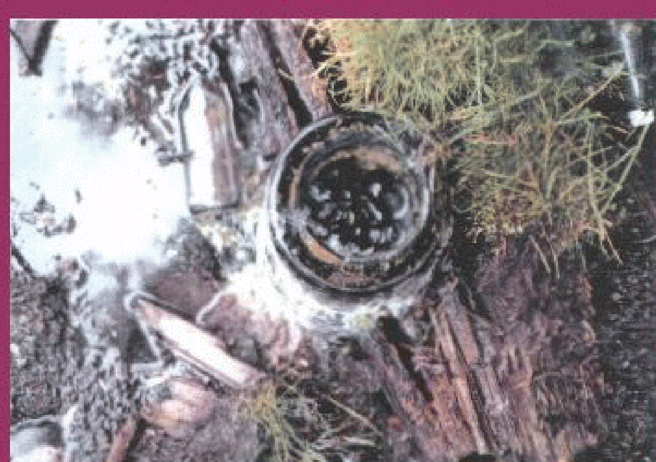
C. Martin, M. O'Brien and J. Tuach at the Mills #1 wellsite, northwestern shore of Deer Lake, early September, 1993



Closeup of intermittent gas bubbles coming from the top of Mills #1 pipe.

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Introduction

This project incorporates a variety of data into a model or series of ideas about how petroleum, particularly oil, might have been generated and preserved in traps beneath Permits 93-103 and 93-104 in the Deer Lake Basin. In an effort bring as much information as possible to bear on the interpretation for the permit lands, the entire body of knowledge presently existing for the Deer Lake Basin as a whole has been used. This includes information from boreholes, geological maps, potential field studies, and geochemical studies from outside the permit lands, as well as basin-scale and regional tectonic models.

The report focuses on three crucial aspects in determining the potential of any basin:

1. **reservoirs**: what are the potential reservoirs and what reservoir characteristics, principally porosity, might be predicted?.

2. **source rocks:** do rich source rocks exist within the basin, or more accurately, did they exist within the

basin at appropriate depths to attain maturity and charge reservoirs during optimum burial conditions?

3. **nape:** were traps available when the bulk of the oil migrated, and have they been preserved throughout the subsequent basin history?

The first two of these were addressed directly by examination of core, petrography, collection of degraded hydrocarbons, and collection of samples of a source rock candidate. The third was addressed by speculative prediction from the somewhat inscrutable surface geology (low relief and heavy vegetation inhibits exposure) and potential field modeling.

Of potential reservoir units, only the North Brook and Howley Formations were studied; the Humber Falls Formation is considered to be too shallow to have preserved significant accumulations of hydrocarbons. The underlying Anguille Group is more highly deformed and much more indurated than Deer Lake Group sediments, and is mostly non-porous.

The main focus of this report is the area of the permit blocks lying to the west and northwest of the Cabot Fault system, which runs northeasterly through the centre of Permit 93-103 and separates the Howley "lateral basin" (of Hyde, 1979) to the east from the Deer Lake "lateral basin" to the west (Figure 3). The main basinal areas, then, occupy all of Permit 93-104 and the northwestern third of Permit 93-103. The easternmost edge of Permit 93-103 just overlaps onto the Howley "lateral basin", and consequently this "lateral basin" is not given detailed treatment in this report, except inasmuch as the D-3 and D-4 wells are involved in the discussion of bitumen, and thus the source potential of the basin.

The map of Hyde (1982) was the main source of information for the base map generated in this report, and were supplemented by maps of Westfield Minerals provided by J. Tuach. Hyde's map should be consulted for detailed information on the geology, shows, topography, access and so on.

In this report and accompanying diagrams the following abbreviations are used:

NB	North Brook Formation
RB	Rocky Brook Formation
HF	Humber Falls Formation
HO	Howley Formation
V	volcanics
z	cumulative thickness
ss	sandstone
cg	conglomerate
ø	porosity
PPN	plane-polarized light
XN	crossed-nicols
ND	no data

Regional Overview

The Deer Lake Basin is situated in western Newfoundland at the northeastern margin of the regional Maritimes Basin (Figure 1), a successor basin which was generated by post-orogenic extensional processes in mid- to late Devonian time, after the main Acadian compressional mountain building episode (Roliff, 1962; Bradley, 1982; McCutcheon and Robinson, 1987) . This basin was enhanced and deformed by strike-slip tectonics intermittently through the Carboniferous period, with the latest deformation probably occurring in the latest Carboniferous or even early Permian (e.g., Belt, 1968a, 1969; Bradley, 1982; Knight, 1983; Langdon and Hall, in prep., 1993). These episodes of strike-slip tectonics were localized along the Cabot Fault system, which is part of a regional strike-slip system trending northeastward through the Maritime Provinces of Canada and into the Caledonides.

The Maritimes Basin is present in all four of the Maritimes Provinces, and in its depocentre under the Gulf of St. Lawrence, is a 9 km thick (Bradley, 1982), virtually continuous succession of molassic sediments, broken only by a short-lived marine incursion in the lower Carboniferous. The present topography of the Maritime Provinces reflects the trends of Carboniferous faults which defined the old basin margins, and which were the loci of compression and deformation.

The Deer Lake Basin is entirely non-marine and was interpreted by Hyde (1979, 1984) and Hyde et al. (1988) to have formed in response to strike-slip movements along the Cabot Fault zone in late Devonian to early Carboniferous times. In the Newfoundland context, the Deer Lake Basin is one of three remnants of the Maritimes Basin located along the Cabot Fault system which display marked similarities to each other in their stratigraphic and structural style. The Bay St. George Subbasin (Knight, 1983) is situated in the southwestern corner of the island of Newfoundland, about 100 km southwestward of the Deer Lake Basin along the Cabot Fault zone. The lesser known St. Anthony Basin (Haworth et al., 1976; Howie and Barss, 1975b) lies mainly offshore east of the Great Northern Peninsula about the same distance to the northeast.

The major stratigraphic divisions of the Maritimes Basin can be correlated onshore western Newfoundland (Figure 2). The Pictou, Cumberland and Canso-Riversdale Groups correspond to the Barachois Group in the Bay St. George and to the Howley Formation in the Deer Lake Basin, the Viséan Windsor Group is represented by the Codroy Group in the Bay St. George Subbasin and by the Deer Lake Group in the Deer Lake Basin, and the late Devonian to Tournaisian Horton Group is represented by the Anguille Group in the Bay St. George Subbasin and by the Anguille Group, Wetstone Point and Wigwam Brook Formations in the Deer Lake Basin (Hyde, 1979).

In the Deer Lake Basin, the Anguille Group is a fining-upward megasequence and represents the initial infill of a late Devonian rift or pull-apart basin (Hyde, 1979; Hyde et al., 1988). Over most of the basin the overlying Deer Lake Group unconformably overlies the Anguille and includes the North Brook, Rocky Brook and Humber Falls Formations (Werner, 1956; Hyde, 1979). These strata form a second fining-upward megasequence, and record the progressive infill of a lacustrine basin formed with the widening and deepening of the original narrow Anguille rift basin (Hyde, 1979). The overlying Humber Falls Formation and overlying Howley Formation define a third fining-upward megasequence, although less clearly defined than the first two. The detailed characteristics of these rocks are listed in Table 1 (pdf - 89kb).

The deformation of these rocks in the Maritimes Disturbance (Poole, 1967; Dewey and Kidd, 1974) is associated with movement along the Cabot Fault zone, and includes the development of en echelon fold axes, recumbent folds, cleavages, steep to inverted bedding, and high angle marginal and in-basin faults. The degree of deformation in both the Bay St. George Subbasin and the Deer Lake Basin is related to stratigraphic level, i.e., the rocks of the late Devonian-Tournaisian Anguille Group are more deformed than those of the Viséan Codroy and Deer Lake Groups. In the Deer Lake Basin area, basement rocks (to the Carboniferous) lie within two tectonostratigraphic zones (Williams et al., 1988): in general rocks of the Humber zone, representing the Lower Paleozoic continental margin of Laurentia, lie to the west of the Cabot Fault, while rocks east of the fault belong to the Dunnage zone, which represents vestiges of oceanic rocks formed at the eastern margin of the Lower Paleozoic Iapetus Ocean (Williams et al., 1988).

Regional Petroleum Potential Of The Maritimes Basin

Hydrocarbons have been recorded in diverse areas and stratigraphic settings in the Maritimes Basin. Offshore in the Gulf of St. Lawrence, gas has been encountered in non-commercial quantities in several wells, and most of these prospects have been drilled on the flanks of salt structures. The majority of the wells in the eastern Gulf of St. Lawrence have evaluated the petroleum potential of younger Carboniferous strata (Canso-Riversdale and younger), with the exception of the St. Paul P-91 well in the Cabot Strait, where structurally-thinned Horton, Windsor and Canso rocks were drilled close to the Cabot Fault zone (MacGregor GeoScience Ltd., 1987).

Several wells on Prince Edward Island have penetrated into the Windsor and Horton Groups, and the

Bradelle well in the northwestern Gulf of St. Lawrence reached the Horton Group. Significant shows in the Gulf have occurred within the Pictou Group in the Naufrage No. 1 well (P.E.I.), and in the Brion No. 1 well north of the Magdalen Islands. The North Sydney I-05 well east of Cape Breton Island also encountered gas shows in the Pictouan sequence.

Onshore in New Brunswick the Stony Creek oil and gas field near Moncton, which produced oil from 1909 to 1990, has been the only commercial oil field discovered in Maritimes Basin strata to date. This petroleum was sourced and reservoired in lacustrine and lacustrine margin facies of the Horton Group. Oil shales, also associated with a lacustrine paleo-environment, are found in northern mainland Nova Scotia, on Cape Breton Island and in the Deer Lake Basin (Howie, 1966).

With the exception of the Viséan marine incursion, and several rapid but short-lived transgressions in the Westphalian (Gibling, 1993), rocks of the Maritimes Basin have been deposited in non-marine paleo-environments. Traditionally, marine rocks have been considered to be the primary source rocks for oil, and terrigenous rocks have been relegated to the role of source rocks for gas. In the last ten years or so, however, this situation has been redressed, with the level of activity in lacustrine basins in Angola, Brazil, Australia, and China in particular, where most of the country's oil is sourced from rocks deposited in non-marine, mainly lacustrine, situations (Huang et at., 1988; Hu et al., 1988).

The Maritimes Basin, then, likely contains large undiscovered accumulations of petroleum in both its liquid and gaseous forms (e,.g., Williams, 1974). Based on volumes of sediment alone, most of this can be expected to be found offshore, but small remnant onshore basins, analogous to the Moncton Basin in their position along the regional strike-slip fault system, will probably be the sites of future petroleum discoveries.

History Of Investigation Of The Deer Lake Basin

The petroleum potential of the Deer Lake Basin has been known since, in the last century, pitch or bitumen outcropping near Deer Lake was used by the local people. Hatch (1919) prepared a report for the Reid Newfoundland Company and compared the geology of the basin to that of the Bay St George Carboniferous. The first major exploration effort was carried out by the British geologist Landell-Mills in 1917-19. As a result of his work three wells were drilled in the area to obtain core in the Carboniferous. The first of these wells, in Nicholsville at the north end of Deer Lake, encountered an overpressured gas zone in the Rocky Brook Formation where: "the eruptions of gas were sufficient to lift the tools, and brine and mud would be blown out of the well with great violence". The well was abandoned at 231 m but was still producing gas 12 months later. This well is still bubbling gas out the top of the surface pipe (Above Image).

The Mills #2 and #3 wells were located just south of the town of Reidville and drilled to 24m and 97m respectively, but encountered no shows. This petroleum drilling was accompanied in 1919 by Hatch's mapping and sampling of the oil shales for the Reid Newfoundland Company.

The next major period of activity began in 1950 when Baird carried out mapping for the Geological Survey of Newfoundland (Baird, 1953, 1955). Claybar Uranium and Oil Ltd. began a petroleum exploration program in 1954, which involved a geological examination of the area by Werner (1955) and culminated in the drilling, in 1955 and 1956, of four wells. Gas was encountered in wells #1 and #3, which were situated on an anticlinal trend in the Big Falls area (Figure 3; Hyde, 1982).

Fleming (1970) reviewed the geology and exploration history of the Deer Lake area, and in the late 1970's geologists of the Newfoundland Department of Mines and Energy began a program to map and evaluate the mineral and coal potential of the Bay St. George Subbasin (Knight, 1983) and the Deer Lake Basin (Hyde, 1979; Hyde and Ware, 1980). At about the same time, Northgate Exploration and Westfield Minerals began a drilling program in the Deer Lake Basin to evaluate the uranium potential of the area. This work was complemented by 2D modeling of potential field data (Miller and Wright, 1984). Gall (1984) studied the petrography and diagenesis of the Deer Lake Group, and Hyde et al. (1988) incorporated petrologic, field, seismic and potential field data into an integrated interpretation of the basin history. To date, the only seismic data acquired in the basin are a 1.5 km (6-fold) line reported in Hyde et al. (1988), and a recent profile of the LITHOPROBE program which traverses the southern half of the basin, but which has been processed only for deep crustal objectives.

Method Of The Current Investigation

Core Examination and Sampling

Core examination and sampling were carried out with two objectives in mind: (1) to allow determinations of porosity within the potential reservoir units of the North Brook and Howley Formations from all available core by both macroscopic and petrographic examination, and (2) to collect representative samples from the Rocky Brook Formation that can be used in further source rock studies if desired.

The following cores, arranged roughly in order from basin margin to basin centre (Figure 3), were examined for porosity and sampled: B-3 (North Brook Formation), A-7 (North Brook Formation), A-4 (North Brook Formation), 80-78 (Wigwam Brook or North Brook Formation), A-6 (Rocky Brook/North Brook Formations), A-3 (Rocky Brook/North Brook Formations), A-5 (Rocky Brook Formation), 79-67 (Humber Falls Formation), D-1 (North Brook Formation?), D-2 (Howley Formation), D-3 (Howley Formation), and D-4 (Howley Formation). Lithologic/radiometric logs from the original drilling of the boreholes by Westfield and Northgate were used as a guide to the stratigraphy, and samples were located on these logs. Sample locations are plotted on the stratigraphic correlation section (Figure 4).

Petrography and Point-Counting

The rock samples collected from the core were studied by thin-sectioning and examination under a petrographic microscope. General lithologies and their relationship to porosity were noted, but the main purpose of this exercise was to determine the amount of visual pore space in the rock by point counting. Between 200 and 300 counts were made on each thin section, depending on its size and condition. Estimates of the modal composition of the rocks in terms of their major constituents - quartz, feldspar, lithic fragments and mica, cements (calcite and hematite), clay minerals, and porosity - were made. The thesis of Quentin Gall (1984) was used as a reference, as Gall supplemented petrographic work with scanning electron microscope examinations and X-ray diffractometry on clay minerals, and pycnometer measurements for effective porosity.

The North Brook Formation is the main reservoir unit of interest over the permit area and was the main focus of the petrography: of the 23 samples studied, 16 were from the North Brook Formation, 4 were from the Howlev Formation, and 1 each were from the Rocky Brook and Humber Falls Formations. The North Brook samples were taken from the A-7, A-4, A-6 and A-3 boreholes on the northwestern side of the basin, while the Howley samples came from the D-3 and D-4 boreholes at the eastern edge of the lease lands. The Rocky Brook and Humber Falls samples came from the A-4 and 79-67 boreholes, respectively.

Stratigraphic Correlation Section

This section utilizes shallow borehole lithologic and radiometric logs from the 1979 drilling program of Westfield Minerals/Northgate Exploration, which are set up at true elevations. On the original logs, the Rocky Brook Formation is subdivided from bottom to top into the "red silts", "mottled beds", "lower grey beds", "brown beds" and "upper grey beds" by company geologists. The most organic rich black shales come from the lower part of the "upper grey beds".

A number of interpretations can be drawn from the stratigraphic correlation section (Figure 4). It is assumed that structural dips measured at the surface represent the attitudes of stratal surfaces and thus time lines. If lithological boundaries cut across these time lines, then facies transitions along the paleo-depositional surface must be present. By projecting the dips between the boreholes the amount of diachroneity of the North Brook/Rocky Brook contact can be estimated. This situation is particularly evident between Boreholes A-3 and A-6. Projection of surface dips between these two boreholes would project the top of the North Brook at ~60 m in the A-6 well, yet the top picked from lithology in the core comes in at + 160 m, a difference of some 100 m. This is an important consideration because it suggests that the North Brook and Rocky Brook are in part coeval, which has implications for source rock-reservoir geometry. A situation where petroleum could migrate updip along stratal surfaces from source rock to reservoir rock is a favorable one. Furthermore, discontinous deposits of sandstone associated with the distal edges of the North Brook alluvial fan-braidplain complexes could be encased in organic rich Rocky Brook shales laid down in a lacustrine environment, setting up the possibility for stratigraphic trap development in close proximity to source rocks.

Bitumen Occurrences

First of all it should be noted that the term "bitumen" has experienced a somewhat loose usage, so it is useful to briefly define it and to compare it to kerogen, another term that varies in its definition and usage. According to Tissot and Welte (1978) kerogen is the insoluble organic constituent of sedimentary rocks, while petroleum geologists generally take it to mean the total organic content of sedimentary rocks. Bitumen (according to the above authors) represents the soluble (in organic solvents) fraction of kerogen and contains a purely hydrocarbon component, comprising both saturated and aromatic hydrocarbons, and a non-hydrocarbon component that includes heavy molecules of the elements C, H, 0, S and N. The hydrocarbon bitumens usually have molecular weights <600, while the non-hydrocarbons have molecular weights generally >500. In general terms this means that bitumen is the component of the organic matter of source rocks that is able to be mobilized and thus transformed, by the maturation and migration process, into liquid hydrocarbons.

The term "bitumen", like the term "oil shale", has suffered from imprecise usage in the literature of the Deer Lake Basin as well. For example, numerous shows of "bitumen" are noted, where in reality, these solid hydrocarbons are residues of liquid hydrocarbons (oil!) that have been degraded by water washing at depth and oxidation as the material was brought closer to the surface by erosion. A more appropriate term for these occurrences would be dead seeps or dead oil seeps. However, for convenience, we will continue to use the term here as it has been used.

There are numerous bitumen occurrences in and around the margins of the Deer Lake Basin. The best known of these occur along the southwestern margin of the basin between Goose Arm road and the Viking Trail (Northern Peninsula Highway). Other important shows occur in the Little Pond Brook Formation (equivalent to Humber Falls Formation) along the southeastern margin of Grand Lake, along the Humber River below Sir Richard Squires Park, and on Taylor's Brook near the northernmost contact of the North Brook Formation with the basement. In core, abundant bitumen is present in the D-2 and D-3 boreholes (Plates 13, 14, 31, 32 and 33) in the Howley Formation, within a kilometre of the Hampden Fault. These occurrences have been catalogued in the Department of Mines and Energy Mineral Inventory Project, and their identification system is used here.

Several further investigations into bitumen occurrence were carried out in this report. 12H/4 Btm 001 (Nicholsville) was visited by J. Tuach and the author, and is the most significant bitumen locality in the Deer Lake Basin (Plate 1 (pdf - 87kb)). Two other occurrences of bitumen were found in the immediate area and sampled. One is noted on Hyde's map and is situated about a couple of hundred metres south of 12H/4 Btm001, on the opposite (south) side of the Goose Arm road, near an old east-west trending trench probably dug by Westgate in the late 1970's. Abundant bitumen was found in fractures in east- facing outcrops of marble along the side of a small hill, mapped as a small isolated outcrop of Map Unit 4a (undivided carbonate rocks) by Hyde (1982). Here the present erosional surface lies approximately along the Carboniferous/pre-Carboniferous unconformity, so that bitumen is preserved in fractured marbles within a metre or two of the unconformity, and takes the form of narrow "veins" or seams up to a centimetre in width. A third occurrence of bitumen was located in the middle of the Goose Arm road between the above two locations. To the author's knowledge, this occurrence was not previously known. The surface of the road here has worn down to where it approximates the unconformity surface, again exposing bitumen in narrow fractures (Plate 2 (pdf - 75kb)).

The Taylor's Brook and Humber River occurrences were visited during the 18th and 19th of September 1993 by J. Tuach, assisted by E. Reid of Reidville. Water levels were high and outcrop in the bed of the brook could not be examined. Two samples were collected from the north and south banks where up to 20 m of thin organic layers occurring as pore filling in sandstone were noted, but these appear to be organic products of surficial weathering (humates), as humate staining is common on bedrock surfaces in the area. Possible coal occurrences were noted at one locality, but no bitumen was observed in outcrop.

Bitumen in Thin Section

In several thin sections black, pore-inhabiting material was noted, and although in some cases it is difficult to distinguish from detrital opaque minerals such as magnetite, its generally amorphous habit and possibly even coalescence into round globules within the pore space suggest that some of this material is in fact dead oil. Occurrences of this material were noted in thin sections NB-2, NB-3, NB-8, NB-11, NB-14, D2-2, D3-3 and D3-4, and are discussed in the captions to the photographic plates.

Evidence for Undegraded Hydrocarbons

Several indications of liquid and gaseous hydrocarbons have been noted from the Deer lake Basin. The Mills #1 well had a gas blowout and a fire, flowed gas for well over a year after it was abandoned, and continues to bubble gas today. The Claybar #1 well also had to be shut down for three days after encountering a gas zone, and the Claybar #3 well also encountered small amounts of gas. Evidence for liquid hydrocarbons is a little more equivocal. During the drilling of the Winkie #37 borehole (Figure 3) the driller noted a difficult drilling interval, and on pulling the drillstring, it was found that the rods were coated with tar. This occurred at a depth of 40-50 ft.

In early September, 1993, Ms. Jean Burton, the proprietor of the Rocky Brook Cabins at Cormack, told the story of her artesian well to the author and Messrs. C. Martin and M. O' Brien of Vinland Petroleum: the well, because of the high salinity of the water, was abandoned to flow on the ground for a year or more. Apparently after a time the ground over which the water was running became covered with a viscous black substance, which seems to have been hydrocarbons coming out of solution in the water.

These accounts from the shallow subsurface provide tantalizing clues to the presence of preserved liquid hydrocarbons in reservoirs at depth.

The occurrence of the bitumen at several different stratigraphic levels and structural situations suggests that migration paths are complex. For example, the shows on the western side of the basin along the contact with the basement just north of Deer Lake point to a migration of petroleum updip essentially along bedding planes from deeper in the basin. The association of fracturing with the unconformity, may reflect a competency contrast between rocks above and below the unconformity, and bitumen within these fractures suggest that the major deformation in this area pre-dated the migration of at least a significant portion of the hydrocarbons.

The voluminous amount of bitumen present in the Howley Formation in the D-2 and D-3 wells, as well as the shows on Grand Lake a few kilometres to the south (see Hyde's 1982 map), suggests that there has been production and migration of liquid hydrocarbons to the east of the Cabot Fault system. This is a significant point, because this portion of the basin (Howley "lateral basin" of Hyde et al., 1988) has been considered by previous workers to be relatively shallow, with Howley Formation unconformably overlying Dunnage Zone (Fleur-de-Lys Supergroup) basement. Consideration of the bitumen shows, however, raises the possibility that Rocky Brook source rocks are present underneath the Howley in this area, because no other potential source rock is known locally east of the Cabot Fault system. An alternative explanation for the bitumen in these two wells is that it was sourced from deeply buried Rocky Brook shales or lower Paleozoic rocks to the west of the Cabot Fault system before it experienced most of its translational motion, presumably in the late Carboniferous. However, this extent of migration to the eastern edge of the Howley "lateral basin" from the other side of the major fault system seems unlikely.

Whatever the exact process or sequence of events leading to petroleum emplacement, the overall broad area encompassed by the shows indicate that there has been a significant and widespread episode of maturation of source rocks and generation of liquid petroleum in or beneath the Deer fake Basin. If a lower Paleozoic source rock is involved, than the fault systems likely provided the conduits for migration. If the Rocky Brook Formation is indeed the source for this oil, then larger volumes of Rocky Brook oil shale than previously suspected must have been buried into the oil window. This further implies that either estimates of the depth of the centre of the basin have been too low, or that the geothermal gradients were higher than expected, that is, that some other heat source such as volcanism may have contributed to the maturation of source rocks.

The Case For A Deeper Basin: Interpretation Of Potential Field Data

The sediments of the Deer Lake Group in the Deer Lake "lateral basin" were interpreted by Miller and Wright (1984) and Hyde et al. (1988), based on 2D modeling of the gravity and magnetics data, to be no thicker than 1.2 - 1.5 km. As part of the current project, R. Wiseman used an improved data set and incorporating simultaneous gravity and magnetic 2½-D modeling (Appendix I). Wiseman's five models running across the strike of the basin (Figures 3 -7 of Appendix I) show that a basin depocentre could exist underneath the lease lands to the west of the fault system: such a basin may be asymmetric, with its deepest part west of centre (Figure 10). The models furthermore present the possibility that the total basin depth may reach 4 km at its deepest point, with the basin floor shallowing gradually away from the axis or depocentre. This represents a significant deepening from the previous estimates for the maximum depth of the basin noted above.

Three additional models were run to assess the maximum possible depth of the denser Rocky Brook shales (relative to North Brook sandstones and conglomerates), by increasing the proportion of the shales. For the given gravity signatures, increasing proportions of Rocky Brook are compensated for in the models by slight increases in the amounts of less dense North Brook rocks; this has the effect of slightly deepening the basin floor in the models. This latter situation is realistic geologically, as Rocky Brook shales and siltstones can be expected to thicken at the expense of North Brook sandstones due to a facies change from the margin to the centre of the basin, as is established in the correlation cross section (Figure 4). The model results indicate that regardless of which of the above alternatives is used, interpretations of Rocky Brook shales down to a present depth of 1.5 - 2.0 km are consistent with the measured gravity field. The important result of this is not so much that the base of the Rocky Brook could presently be at a depth of 1.5 - 2.0 km, but that a significant volume of the formation would have been depressed into the oil window during maximum burial (see following section).

It should be stressed that the new potential field results present an optimum case; both the original interpretation of a shallow basin of Miller and Wright (1984) and Hyde et al. (1988), and the present interpretation of a 4 km deep basin (Wiseman, Appendix I), are admissible models, and represent the "endpoints" of a set of admissible models of the potential field data.

INTERPRETATION AND DISCUSSION

Maturation of Rocky Brook Formation Source Rocks

Detailed studies of the Rocky Brook Formation have been carried out to evaluate the oil shale potential of these rocks (e.g., Macauley, 1981; 1987; Macauley et al., 1985; Kalkreuth and Macauley, 1989; Hyde, 1984; Fowler, studies in progress). To date, geochemical studies have been restricted to samples from the surface and shallow drillcore. The following is a summary of the salient points of the conclusions drawn by Kalkreuth and Macauley (1989):

- total organic content in the Rocky Brook shales ranges from 1.86 to 15.43%, representing a broad range of oil shale quality.

- oil shales of the Rocky Brook Formation are Type 1 lamosites, deposited in a continental lacustrine environment, and the main constituent maceral is lamalginite.

- vitrinite and fluorescence reflectances of the lamalginite indicate a low to moderate level of thermal maturity, resembling the level of maturity of the Albert Formation oil shales in New Brunswick. However, Rock-Eval data indicate that these beds are thermally immature, in contrast to the moderately mature results for the New Brunswick beds.

- geochemical results indicate that the oil shales exposed along the surface in general have not yet yielded hydrocarbons, but "optical properties indicate that these kerogens are on the verge of hydrocarbon generation" and "only minor additional depth of burial (thermal stress) would be necessary to mature these beds to the point of significant petroleum generation" (p. 41).

These results are not particularly encouraging with respect to the prospect of mining oil shales from the surface, but curiously, in the Deer Lake Basin literature, the connection between the oil shales at the surface and the potential for the generation of liquid hydrocarbons at depth within the basin has been somewhat underplayed. The presence of marginally mature oil shales at the surface may be a blessing in disguise: if additional amounts of burial of Rocky Brook can be supported by other lines of investigation, then these oil shales could have yielded liquid hydrocarbons. Indeed, if oil shales presently exposed at the surface were more mature, then any additional burial would have pushed these rocks towards a state of overmaturation, and the situation would be less favorable.

It remains, then, to assess the possibility that significant volumes of Rocky Brook source rock resided in the oil window during the time of peak petroleum generation, which most likely occurred in the Permian. Maximum burial of the regional late Paleozoic basins occurred in the early Permian (ca. 270 Ma), as these basins began to be uplifted and eroded and to supply clastics to the incipient North Atlantic rift basins by Triassic time. Between 1 and 3 km of additional sediment are thought to have overlain much of the Maritimes Basin (Grist et. al., 1992; Ryan and Zentilli, 1993), which accounts for the maturation levels currently observed at the surface, although locally these thicknesses may have been less. The central issue is the additional thickness, and thus additional burial depth, that can be assigned to the present day outcrop of the Rocky Brook Formation.

In most schemes of hydrocarbon generation as a function of burial of the source rock (Figure 5), the principal zone of oil and wet gas formation (catagenesis) lies between about 1.5 km and 3.5 km with the oil zone above 3 km, depending specifically on the type of kerogen, burial history and geothermal gradient. If this model is taken as a general guideline, the Rocky Brook shales exposed at the surface today would have been buried to a maximum depth of about 1.5 km. The present revised estimates of the maximum depth of the Rocky Brook increase the probability that a reasonable volume of the kerogenous shales could have reached an additional depth of at least another kilometre, which would have placed them squarely in the oil window.

Significance of Bitumen Shows
As noted above, the shows of bitumen are oil seeps that have been altered by prolonged separation from the reservoir. Alteration of oil once it leaves the reservoir occurs in both the subsurface and at the surface. The alteration of oil seeps occurs by a combination of several factors (Kinghorn, 1983):

- evaporation of hydrocarbons up to the mid-C20's (most of the lighter hydrocarbons will have been removed after a few months of exposure)

- water washing, which will remove the water soluble compounds

- biological processes such as microbial degradation which will readily remove many components

- certain chemical processes related to the presence of sunlight and atmospheric oxygen.

However, the major significance of the bitumen shows is that their presence at various widely-separated locations around the basin suggests that liquid petroleum has been produced in substantial quantities. The occurrence of this dead oil at the surface, combined with a general knowledge of basin formation and deformation, indicates that either:

(1) Oil generation postdates major trap formation: the latest tectonic event occurred in the late Carboniferous to early Permian, oil generation peaked in the early Permian and oil migrated both into nearby deep reservoirs and to shallow reservoirs or to the paleo- land surface. Traps were both structural and stratigraphic, related to the latest strike-slip episode. The occurrence of bitumen in fractures at the unconformity suggests that at least some migration coincided with or post-dated the last major tectonic event.

(2) Oil generation predates major trap formation: oil was originally generated and trapped in minor (?) stratigraphic traps in the Carboniferous, perhaps associated with local rapid burial in the late Carboniferous, and these traps were subsequently disrupted by tectonism associated with strike-slip movements along the Cabot Fault system in the latest Carboniferous to early Permian. The traps in this case would be mainly stratigraphic in nature. What we are seeing in this case is the product of a secondary migration, either to shallower reservoirs or to the paleo- land surface. The degradation of the oil would have occurred immediately after this migration if no shallower reservoirs were involved, or later (Triassic?) during erosion and breaching of a shallower reservoir.

(3) Early Permian migration of lower Paleozoic oil: oil has migrated into the basin from underlying lower Paleozoic rocks, particularly in the Deer Lake "lateral basin". The presence of marbles in outcrop at the western edge of the basin suggest that lower Paleozoic carbonates were here highly deformed in the Acadian deformation. Furthermore, according to Wiseman's potential field modeling (Appendix I), "it is unlikely that any significant amount of carbonates exist beneath the North Brook and Rocky Brook sediments within the Deer Lake Basin". The possibility does exist, however, that some locally undeformed carbonates, or organic-rich shales, could be the source rock for the bitumen.

In either of the above cases, some traps were likely breached and eroded in Triassic times, and the absence of live oil shows at the present indicates that the main migration event was completed by the Triassic. In scenario 1 above in particular, the potential for the preservation of traps seems high, as no major tectonic activity has affected these lands since the early Permian. Many deep stratigraphic traps formed in scenario 2 above would also have a high potential for preservation.

Discussion of Maps

Sandstone Richness Map (normalized net sandstone): Figure 6 "Sandstone richness" was calculated by dividing the total cumulative thickness of sandstone and dividing it by the penetrated thickness of the North Brook or Howley Formation to obtain a sandstone percentage for individual wells. The richness or percentage approach, rather than using total net sand or net porous sand, was necessary because in almost all cases the reservoir formation was not fully penetrated and the gross sand interval not known.

For the North Brook Formation this map clearly shows higher percentages of sandstone (>50%) along the western margin of the Deer Lake "lateral basin" which decrease systematically eastward toward the paleo-basin centre (10%). The exception is the borehole 38 along the Wigman Fault, which shows a value of 57%. It should be noted that the sandstones in this hole may belong to the Wigwam Brook Formation, which is slightly older than the North Brook.

Data from the Howley "lateral basin" are tightly grouped along the Hampden Fault and cannot be used to predict trends toward the east. The values are moderately high, however, ranging from 32 to 48%.Porosity Richness and Porous Rock Richness Map (normalized ø-h and net porous ss+cg): Figures 7 and 8

The "porosity-richness" and "porous rock-richness" contours were generated in a similar fashion, by dividing ø-h (porosity * thickness) by cumulative thickness of sandstone + conglomerate, and by dividing net porous sandstone + conglomerate by cumulative thickness of sandstone + conglomerate, respectively. Ø-h values were calculated by combining point- counting porosity estimates with visual estimates from core of the thickness of porous zones.

Although only a few data points were involved in this calculation, the contouring suggests that "porosity richness" in the North Brook increases from about 10*10-3 at the north western margin to >60*10-3 in the centre of Permit 93-104. On the other hand, the "porous rock richness" contours decrease from borehole A-7 at the northern edge of Permit 93-104 toward the centre of the permit, a seemingly contradictory trend. Although too much should not be inferred form this small number of data points, the general indication is that smaller overall amounts of porosity are concentrated in a large number of porous zones near the basin margin, and conversely, that greater amounts of porosity are concentrated in fewer porous zones in the deeper, more distal part of the basin.

Significance of the Porosity Studies

Although the small number of data points precludes detailed predictions about porosity development, some general conclusions can be drawn. The maps demonstrate that fair to good porosity is present in both the North Brook and Howley Formations. The values obtained for porosity in this study are in close agreement with those of Gall (1984) who combined point-counted total porosities with effective porosities obtained from pycnometer measurements.

It is useful here to briefly summarize Gall's work, as it concentrates on the stratigraphy and petrography of the drill hole cores. Although Gall's work does not provide a treatment of the petroleum potential, it contains much useful data, particularly on the matter of diagenetic control of porosity.

The three coarse clastic formations of the Deer Lake Group (North Brook, Humber Falls and Howley Formations) are all similar to each other in terms of their composition. They comprise three textural groups:

(1) interlayered, polymictic, pebble conglomerates

(2) immature to submature sandstones

(3) minor siltstones, mudstones and claystones

In terms of textural evolution the North Brook to Howley Formations exhibit an overall fining-upward trend. The sandstones of the North Brook and Howley Formations contain clasts of quartz, feldspars, lithic fragments, muscovite, biotite, chlorite and accessories. On tertiary plots of quartz, feldspar and lithic fragments, the rocks of the Howley Formation plot near the feldspar apex, while the North Brook and Humber Falls clastics show proportionately more quartz with variable amounts (up to 50%) of lithic fragments. Diagenetic minerals occurring as both matrix and cement include calcite, hematite, dolomite, quartz overgrowths, and a variable suite of clays, including kaolinite, illite, chlorite, montmorillonite, and minor amounts of others. Clay minerals play an important role in the diagenetic history of the sandstones and conglomerates (Gall, 1984).

A paragenetic sequence in a sedimentary rock is the apparent sequence of diagenetic events which contributed to the preservation of that rock in its present form. Gall worked out two paragenetic sequences for the strata of the Deer Lake Group, a "sandstone" sequence, pertaining to the diagenetic history of the North Brook, Humber Falls and Howley Formations, and a "shale" sequence, pertaining to that of the Rocky Brook Formation. Here we are concerned with development of porosity in the coarse clastics, but both sequences are illustrated in Figure 9.

An early and a late stage of secondary porosity development is recognized in the North Brook, Humber Falls and Howley Formations. The early stage involves silicate grain, especially plagioclase and microcline, dissolution. The late stage resulted mainly in the precipitation of hematite cement. Gall states that "perhaps successive stages of cementation occluded the early pore space in the sandstones, and the present effective porosity is equal to the amount of late pervasive dissolution which followed" (p. 147).

During the early stage of secondary porosity development, porosity was produced by the dissolution of detrital feldspar grains, feldspathic rock fragments and quartz grains. The early porosity development is

further indicated by the development of authigenic clay minerals and carbonate cement within intergranular and intragranular pore space formed as a result of the dissolution (Gall, p. 185).
An episode of pervasive secondary porosity development was the last diagenetic change to take place in the sandstones, and can be distinguished from the early phase by the fact that it affected all the detrital framework grains and diagenetic mineral phases, including the hematite cement (Gall, p. 189). The two events common between the two paragenetic sequences are:

(1) carbonate cementation stage of the sandstones and the blocky calcite stage of the shales

(2) late stage pervasive secondary porosity of sandstones and late stage secondary, intercrystalline vuggy and open microfracture porosity of shales.

It is evident that there is a strong facies control on the diagenetic history of these rocks, and this is not surprising since the "shale" paragenetic sequence evolved under alkaline conditions in a lacustrine environment, and shows a more complex chemical history than the mainly subaerially-deposited sandstones. In general, though, the "sandstone" paragenetic sequence points to changes from oxygenated, acidic conditions early on (evidenced by kaolinite and quartz overgrowths formed by leaching of feldspars) to a later shift in the geochemical environment to alkaline conditions, evidenced by the formation of blocky calcite crystals below the water table. At the same time, the precipitation of pyrite and uraninite witnesses the continued local persistence of anoxic and acidic conditions.

The above discussion has referred to a relative sequence of events only. An idea of the absolute time involved in the diagenesis comes from the paleomagnetic study of Irving and Strong (1984) which utilized some of the same drill cores as Gall's paragenetic sequence work. Based on the paleomagnetic work, the redbeds of the Deer Lake Group have a Kiaman (latest Carboniferous to early Permian) overprint, which would be related to the episode of hematite cementation. This indicates (according to Gall) that it must have taken 40 - 80 m.y. (after deposition) for the "sandstone" sequence to reach the stage of hematite cementation. This cementation event, then, would have occurred sometime in the latest Carboniferous to early Permian (Gall, 1984).

Although Hyde et al. (1988) assign most of the major strike-slip movement along the Cabot Fault in this area to the lower Carboniferous, the work of the present author in the Cabot Strait-Bay St. George areas (Langdon and Hall, in prep.) suggests that an important basin-deforming strike-slip episode occurred along the Cabot Fault system in the mid- and late Carboniferous to early Permian. This episode in particular would coincide with the hematization as constrained by the paleomagnetic data. In this scenario, late stage secondary porosity would have post-dated or partially coincided with these events. This is also consistent with the interpretation above that oil migrated into fractures at the margins of the basin after a late faulting episode.

Sequence of Events Leading to Petroleum Accumulation

The following general sequence of events is suggested for the accumulation of petroleum on the permit lands:

1. deposition of reservoir and source beds in Visean time in a tectonically active, fluvial to lacustrine basin. Formation of stratigraphic traps associated with depositional geometries.

2. initial shallow burial, diagenesis and lithification (including early secondary porosity development) in middle to late Carboniferous times.

3. late Carboniferous movement on the Cabot Fault system, late stages of diagenesis including hematization, development of fractures at the basal unconformity and of en echelon anticlines and other structures associated with transpression; formation of structural traps.

4. burial into the oil window; main generation of oil from Rocky Brook shales, peaking with maximum burial in the early Permian (Ryan and Zentilli, 1993).

5. migration of oil into basal unconformity-related fractures (Goose Arm road bitumen), and into reservoirs in both the Howley and Deer Lake "lateral basins" (Figure 10).

6. Possible mid-late Permian strike-slip fault movement and breaching of some traps, but formation of other "hybrid" traps. Uplift and erosion, resulting in exposure of shallow reservoirs by late Permian time.

Structural Cross Sections and Potential Trapping Scenarios (Figure 10)

Three unexaggerated cross sections were constructed to illustrate interpretations of the current position of potential reservoirs and source rocks and potential trapping configurations on the permit lands. Information from the Claybar #1, #2 and #3 wells, and several boreholes involved in this study have been projected into these sections, and illustrates the maximum depths penetrated by the drill bit in this basin. The sections are based on a series of structural cross sections by J. Tuach, and include information from the 1:50000 map of Westfield Minerals/Northgate Exploration (provided by Tuach) and the 1:100,000 map of Hyde (1982). The difference with earlier cross sections is that the present author has been able to take advantage of the potential field re-interpretations of Wiseman (this study) to constrain the maximum thickness of the basin. It must be stressed that the cross sections are speculative and present an optimistic or upside case for the sourcing and trapping of oil in the basin. If the basin is shallower than the maximum or lies between the shallow and deep limits, then a somewhat reduced potential exists for the sourcing and trapping scenarios discussed below.

If the maximum basin thickness case is accepted here for the purpose of discussion, interpretations of thicker Carboniferous overall, and of the Rocky Brook Formation in particular, can be made. The partial coevality of the North Brook and Rocky Brook Formations can be rendered to show a thick depocentre of Rocky Brook kerogenous shales occupying the centre of the basin under the permit lands. This is a realistic geologic situation: even in earlier North Brook times it is likely that lacustrine conditions already existed at least locally in the deeper centre of the basin itself. The deepening and spreading ("transgression") of this lake into a full-blown Rocky Brook situation probably occurred gradually as the basin developed, and coarse grained, alluvial fan facies North Brook rocks likely at all stages had some distal lacustrine equivalents.

Three types of trapping scenarios can be imagined. Firstly, a purely structural trapping situation is responsible for the accumulation of small amounts of shallow gas in the two Claybar wells. This is a small anticlinal trend, and was interpreted by Hyde (1979) as an en echelon structure associated with strike-slip fault along the Cabot Fault system. Judging from the surface geology, however, these small anticlines appear to be mainly restricted to the Big Falls area at the northeastern corner of Permit 93-103.

Secondly, purely stratigraphic traps may be present. This seems a particularly viable scenario, given the geometries depicted on sections B-B' and C-C' (Figure 10) for the transition from North Brook to Rocky Brook facies. In sedimentological terms, these small isolated pods would be abandoned deltaic and fluvial channels, which would have been eventually encased in shale as the Rocky Brook gradually overstepped the fluvial systems. Bars at the distributary mouths and offshore would also have become isolated and encased in shale. Sandstone bodies in these positions could be expected to be more texturally mature than those closer to the basin margin (that is, most of the sandstones presently visible in core or in outcrop). With this picture in mind, then, the Rocky Brook Formation would provide both source and seal to North Brook reservoirs.

The disadvantage of prospecting for such targets is that they are often very difficult to see seismically, due to the low impedance contrast between shales and porous sandstones. Normally, these reservoirs can only be identified by careful seismic facies studies, involving a grid of high quality data, or, more fortuitously, where gas in the reservoirs shows up as a "bright spot" or "DHI" (direct hydrocarbon indicator).

A third trapping scenario represents a hybrid between the first two. Sandstone bodies may be sealed laterally by faults, which either controlled the original deposition of the sandstone, or which cut the sandstone body after its deposition. The former case may apply to the wedging or "buttressing" of North Brook clastics against fault blocks at depth along the northwestern margin of the basin, a case which is indirectly supported by the presence of a high basement block, and thinned North Brook Formation, in A-6 (Figure 4). The latter case may exist at the "Humber River Fault" (Figures 3, 6, 7 and 10; informally named here) which parallels the Cabot Fault but which is discontinuous both north and south along its trend. North Brook sandstones may have been cut and sealed by late movement along this fault.

Although cross-sections have not been generated for the Howley Formation, the revised basin profiles of Wiseman (this study) indicate that the "Howley lateral basin" may reach a maximum depth of around 4 km at its easternmost margin, and 1.5 to 2 km in the western and central parts. Like the "Deer Lake lateral basin" discussed above, any Rocky Brook source rocks beneath the Howley Formation would have likely been buried to the oil window, a case that is supported by the presence of bitumen shows in the D-2 and D-3 wells.

Risks Associated with Prospecting for Petroleum on the Permit Lands

The above discussion has presented a somewhat idealized picture of the spatial and temporal mechanisms by which petroleum could be generated and accumulated in rocks over part of the Deer Lake Basin. As in any exploration effort, it is useful to identify the risks that would be involved in prospecting for such petroleum.

Based on the results of the core examination, there appears to be a strong possibility of reservoir development on the permit lands. Some risk is involved in making the connection between porosity present today at shallow levels, which almost certainly has experienced some enhancement due to dissolution of cements by meteoric waters, and that present at depth within the basin. This risk is probably offset somewhat by the possibility that deep porosity may have actually been preserved by early migration of hydrocarbons into reservoir units, a situation well known in the oil industry. The message here is: if hydrocarbons have been generated in significant quantities, it is likely that reservoir units were available to store them, given the richness of sands and conglomerates in the intervals examined (Figures 4 and 6).

A second element of risk is that of correlating bitumen and dead oil shows with liquid hydrocarbons, particularly with enough hydrocarbons to charge reservoirs. An offshoot of this question is: do the shows represent oil generated in situ in the Deer Lake Basin, i.e., is it Carboniferous oil? These questions may be able to be addressed to some degree by oil-source correlation studies.

A third element of risk is associated with the interpretation of a maximum basin depth at 4 km. In probabilistic terms, the most likely situation is one where the basin depth is somewhere between 1.5 and 4 km.

Undoubtedly, the major element of risk associated with prospecting on the western permit block (#93-104) and the northwestern half of Permit 93-103 has to do with the lack of structural culminations at the surface which can projected to depth as trapping geometries. Such a culmination has been tested at Claybar #1 and #3, although arguably Claybar #3 stopped short of fully evaluating all potential reservoirs. Similar structures may be present over the depocentre of the basin (in the centre of Permit 93-104) but may be obscured by vegetation, and it is worth remembering that structures with considerable vertical closure at depth may only be faintly expressed at the surface, due to differential compaction. Potential field data (Appendix I) suggest some structural differentiation and compositional variability in rocks forming the substrate to the basin, and these may have been the loci of formation of structures - at depth within the basin - during late Carboniferous transpression.

The eastern permit block (#93-103) straddles the Cabot Fault system, and this increases the level of risk as regards not only the formation but also the preservation of traps. If the regional strike-slip movement continued into the Permian, than a strong possibility exists that reservoirs on structural blocks located within the strands of the fault system would have been affected by the faulting. It should also be noted that the fault system through here is interpreted by Hyde et al. (1988) as a flower structure, a situation where upward-splaying faults exhume deeply buried rocks, often superposing them on or juxtaposing them against, younger rocks at shallow levels. Such movement would be expected to have a negative impact on reservoired hydrocarbons.

Summary And Conclusions

1. Core examination and petrography demonstrate that the North Brook and Howley Formations of the Deer Lake Basin have fair to good porosity in sandstones and conglomerates. This is in agreement with the thesis work of Gall (1984) who recognized good effective porosities, and linked the presence of porosity at the present day to a late-stage, pervasive dissolution event in the basin. These studies make a case for good reservoir development in the basin.

2. Three independent lines of investigation, taken together, support the idea that oil was generated, migrated and reservoired within the Deer Lake "lateral basin" (Hyde, 1979): (i) type I kerogenous shales presently exposed at the surface are good potential source rocks for oil, (ii) bitumen shows suggest that oil was generated and underwent migration, and (iii) new potential field studies incorporating an improved data set, and utilizing simultaneous gravity and magnetic 2½-D modeling, enable estimates of the present maximum depth of the basin to be increased from 1.5 km to 4 km, and that of the Rocky Brook shales to reach 2 km. The revised maximum paleo-depth of the Rocky Brook shales increases the probability that these rocks were buried into the paleo- oil window.

The circumstantial nature of this evidence makes it crucial that more direct correlations between the degraded oil and the source rock should be attempted (see "Recommendations for Future Work").

3. The possibility exists, however, that original estimates of the Deer Lake "lateral basin" depth of 1.2 - 1.5 km are correct, in which case the potential for both source rock thickness and maturation and for the trapping of hydrocarbons would be limited. If 1.5 and 4 km are considered "endpoint" cases, the actual basin depth may lie somewhere between these two values.

4. Structural cross-sections across the Deer Lake "lateral basin" illustrate that structural, stratigraphic and combined structural-stratigraphic traps may be present. The present state of knowledge of the surface geology does not permit any detailed interpolation of structures to depth in the centre of the basin.

5. A large area of Permit #93-103 straddles the Cabot Fault zone, and is at high risk as regards the preservation of hydrocarbons. The eastern edge of the Permit overlies the western edge of the Howley "lateral basin", which may have a potential similar to that of the Deer Lake "lateral basin".

Recommendations For Future Work

1. The equivocal nature of the interpretations of basin depth make it imperative that oil - source rock correlation be attempted, in order to test the correlation between bitumens (representing degraded oil) and the Rocky Brook shales (representing the source rock). The main question mark in this respect is whether or not the degraded bitumen can be typed and correlated, since it is very old and has no doubt been exposed to biodegradation and oxidation for a long time. I have been in touch with Dr. T. Abrajano of this department, who advises that isotopes will be least affected by the degradation, and proposes a pilot project, using approximately 5 samples (e.g., 3 from Goose Arm road bitumen, and 2 from Rocky Brook shale), to determine if the isotopic signatures of the bitumen are still intact, and if they can be correlated with the Rocky Brook. If this approach is successful, the study can be expanded to include a more comprehensive sampling of bitumens and source rock across the basin.

The results of the geochemical correlation should provide further input into a decision on whether or not a seismic profile should be acquired: if a Carboniferous, in situ oil source rock can be established, the potential for the basin is considerably higher than if the oil has migrated from older source rocks, which are not evident in the vicinity of the Deer Lake Basin.

2. Seismic data: if the petroleum potential of the Deer Lake "lateral basin" is to be completely assessed, a seismic profile should be run across the depocentre (Permit #93-104) to determine its deep structure. This profile would help address the following questions: (1) what is the nature of the basal unconformity in the depocentre, and what possible trapping geometries might be associated with it, and (2) what structural overprinting has affected the deeper basin sediments, and can any purely structural traps be identified? Ideally, more than one profile would be necessary to fully ascertain the dimensions of such traps. The possibility also exists that "direct hydrocarbon indicators" would be seen, particularly in the case of gas or associated gas.

Good seismic data have been acquired from a similar structural position along strike in the onshore part of the Bay St. George Subbasin (Hall et al., 1992), and suggest that possible trapping configurations such as are here depicted for the Deer Lake Basin may be able to be identified by seismic profiling.

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