Block 17

Permit #96-115

Bay of Islands,

Newfoundland

GEOLOGICAL FIELD OBSERVATIONS

By

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Executive Summary

The surface geology of block 17, western Newfoundland comprises Cambro Ordovician rocks which belong to either thrusted slices or an in-situ sequence. These are both found folded and faulted and large scale, 10 km by 1.5 km, anticlinal structures are present at surface.

Numerous small scale structural features are present e.g. stylolites, boudin, slatey cleavage, pressure solution cleavage and micro-folding all of which indicate a low grade metamorphism of the rocks.

Limestones and sandstones (quartzites) are well cemented and tight, showing no sign of visible porosity.

The low level of metamorphism and the lack of porosity are consistent with estimates that these rocks have been buried to depths well in excess of 4 km. Erosion of the missing section probably started in the Devonian.

The black shales seen in the area have the appearance of once-good oil-prone source rocks, that are now post-mature. Burial history modeling indicates that oil maturity was reached during Silurian sedimentation and thrusting. Gas generation followed rapidly during the late Silurian. Subsequent burial over extended periods of time will have exposed any trapped hydrocarbon to temperatures capable of destroying any oil and gas by thermal cracking.

Thus the surface geology indicates that:

1) potential hydrocarbon source rocks are over-mature,

2) potential reservoirs are well cemented and tight.

Introduction

Drs C. Cornford and R. Standley visited west Newfoundland on behalf of INTERNATIONAL FRONTIER RESOURCES LTD to study the surface geology in and around the permit area and pertinent regional localities in order to determine the potential of the permit area to have generated and trapped hydrocarbons.

Seven days were spent in the field from 11th to 17th September 1997.

Photographs (Plates 1-14) are included with this report and illustrate the nature of the outcropping geology, the severe structuring affecting the rocks and the low levels of metamorphism. The location of each photograph is shown on the structure map (Figure a-1). A Cross section, Figure a-2, depicts the general geological form of the permit area and its relation to the adjacent terrain.

Regional Structural Form

The surface area exposes three major tectonic units separated from one another by major slide/thrust planes. The table below summarizes the lithologies and Formations present within each of these thrust slices.

Slice	Lithology	Formation	Age
[3] *ophiolite*		North Arm Massif	Cambrian- Ordovician
			melange
[2] *Mug Pond*	arkosic ssts	Blow Me Down Fm.	Hadrynian/Lwr Cambrian
			melange
[1] *Governors Pond*	shales, limestones	McKenzies Fm.	Mid Cambrian-Lwr Ordovician
	shales, quartzites	Barters Fm.	Lwr -Mid Cambrian
	quartzites, red-green shales	Mitchells Fm.	Hadrynian/Lwr Cambrian
	Melange, shales =sedimentary blocks		Middle Ordovician
[0] *autochton (cover)*	green shales-siltst., lmst breccia	Goose Tickle Fm.	Middle Ordovician
	massive limestone Ordovician dolostone and shales	St George Group	Mid Cambrian-Mid
	limestones, shales, quartzite	Hawke Bay Fm.	Lwr Cambrian
autochton (basement)	quartzo-feldspathic gneisses	Long Range Complex	Grenvillian basement

(melange consists typically of shales containing large limestone and sandstone blocks)

The permit lies within an area where the thrust slices young and dip to the west in a series of steps brought about by reverse faults / monoclinal - overturned folds which have a NNE-SSW trend. To the north, the strata swings to the WNW and dips steeply to the SSW in another monoclinal structure which brings up the Grenvillian basement of the Gros Morne Highlands (north of the permit).

The outcrop of the slide surfaces appears as a series of stacked synclines plunging to the WNW , which are occupied by the successive slices 1 and 2+3.

The whole area between the Gros Morne Highlands and the Bay of Islands -Old

Man's Pond Outlier forms a large WNW plunging basin/synform (Figure a-1).

The allochthonous (thrust) slices moved from the (south) east during the middle Ordovician as a result of tectonic collision and uplift at the closing stages of the Caledonian orogeny. Furthermore, it is also assumed that the slices were emplaced sequentially, i.e.

1) slice 1 thrust onto the platform autochthon,
2) slice 3 thrust onto 2 outside the area, then
3) slices 2+3 moved together and thrust over slice 1.

It is believed that the slices did not suffer extensive large-scale deformation prior to emplacement, although field observations and outcrop relationships demonstrate that whilst the tops of the individual slices are concordant, they have discordant bases.

Large and Meso Scale Structural Styles

The mappable formations and members form a series of generally asymmetric folds with a NNE strike. Folds often have faulted short, steep, attenuated limbs and shallow dipping long limbs. The faulting is typically steep reverse faults although low angle thrust faults are also recognized. The wave length of these folds is in the order of 1 to 1.5 km, the amplitude is estimated to be in the order of 200 m and, from their topographical associations, they probably are ca 5 to greater than 10 km long. The structural asymmetry is generally to the west, although upright folding and overturning to the east is noted in the eastern part of the permit.

Exposure of the Grenvillian basement – Cambrian basement shows that this structuring is associated with deep seated reverse faults. The variation in trajectory of these deep reverse faults, whether they run parallel to bedding and/or are a result of strain dispersion in zones, accounts for many of the other large scale styles of deformation.

Reverse and thrust faults running parallel to bedding (flats) and ramps are found affecting the massive St. George Group (plates 3 and 8), whereas the lower more inter-bedded strata has been contorted into upright and asymmetric folds (zones of deformation).

The shale dominated McKenzies Fm., Bartes Fm. and even the mixed Mitchells Fm. show intense deformation where the shales have behaved in a very mobile manner forming chevron/kink folds with the competent quartzite/breccia members fracturing in the mobile shales and forming very large boudins (plate 7).

WNW folds, presumed to be of a later date, running parallel to mapped faults, have affected the NNE structures. These later folds are also believed to be related to deep basement faults.

Small scale structures

Structural features visible in outcrop either on or adjacent to the permit area include:

bedding parallel slatey cleavage (commonplace)	
axial planar slatey cleavage (commonplace)	(plate 5)
pencil cleavage	(plate 10)
chevron and kink folds in slates/shales	
boudinage, at all scales	(plate 7)
mullions	(plate 13)
parasitic folds	

pressure solution cleavage	(in siltst., fine sst, and limestones)
platy cleavage	(in limestones)
mineral grain lineation	(in limestones)
micro-stylolites	(in limestones and quartzites)
dolomite vein lattices	(in limestones)
quartz and calcite tension gashes	(plate 12)
(quartz blasto-) mylonites in thrusts	(in limestones)

Taken together these structural features indicate a low level of metamorphism. The growth of new metamorphic minerals was not noted in hand specimen, although the phyllitic appearance of some, generally, greenish slates suggests that the metamorphic grade is approaching or is in greenschist facies.

Development of Porosity & Permeability

Visible porosity was not observed in any of the limestones or arenites. Although limestones show relics of lattice veins, vugs and tension gashes these were invariable filled with secondary minerals, generally carbonated but occasionally silica.

The siliclastic arenites (quartzites, sandstones, breccias and arkoses) are very hard, well cemented and showed no evidence of a preserved porosity. At one location secondary porosity was noted in a road-side cutting where a vertical fault cuts a quartzitic grit-stone. Either side of the fault weathering had produced a porosity through the alteration of the cementing medium. This, however, is likely to be a near-surface weathering phenomena.

The silty mudstones found in shale prone sequences were often hard and indurated with sub-flinty fracture characteristics.

It is concluded that neither at the surface nor in more deeply buried rocks does any significant porosity exist. In rocks with no or very low porosity, permeability can only come from joints and faults. Blocky jointing is often well developed in road-cutting exposures of the massive limestones, but is largely absent from outcrops produced by slow glaciation. Whilst these joints may be present at depth, as they only appear in blasted road cuttings the inference drawn is that the joints are probably the result of rapid release of strain energy during blasting.

Structural Cross Section and Burial Estimates

The cross section (Figure a-2) depicts the gross structure perceived for the permit area. It attempts to show the tectonic pile at the end of the Taconic (Caledonian) orogeny (end Silurian/Devonian) relative to the present day sea level, but it does not attempt to model the ephemeral molasse cover that may have been deposited in hinterland to the mountain belt. The final form and altitude of the area was probably affected by the Acadian (mid-Devonian) and Allegheny (end Carboniferous-early Permian) tectonic pulses, through faulting and uplift.

The section has been based on the published geological maps of the area, field observations, seismic line #1 shot in 1996 on the permit and the deep Lithoprobe seismic lines 1, 2, 3, 11 & 12 which have been shot nearby. It attempts to show at a 1:1 scale the overall form and thicknesses for the area but it has not been "balanced".

Across the permit at least 3 km of Hadrynian and Cambro-Ordovician is shown to have been eroded off the permit area. The presence nearby of the thick Table Mountain-North Arm Massif ophiolites suggests that at least 1km of these ophiolites may well have overlain the Cambro-Ordovician. It is possible, however, that the original aerial extent of the obducted ophiolite masses was not much greater than present. If this is the case, they moved westward across the permit area and came to rest, as shown by Lithoprobe section #1, in the flanking syncline/fore-deep of the mountain belt. The area over which they had traveled, i.e. the permit area, suffering a pronounced iso-static rebound.

It is therefore concluded from the preserved geological record that the permit area suffered burial of at least 4 km during the Taconic orogeny, plus a blanket of molasse of unknown thickness, extent and duration. The Acadian uplift and erosion removed the cover to leave a surface that later received a (semi-) permanent sedimentary platform cover during the Carboniferous of the Deer Lake Basin.

Probably during the Permian and Mesozoic the area was stabilized and peneplained and had a relatively uneventful geological history until the Tertiary or even the Quaternary when intense glacial erosion occurred.

Hydrocarbon Source Rocks

The regional source rock in the south at Port au Port (Locs 13-5 and 13-6) and to the north at Green Point (Loc 14-15) are oil-prone, and in terms of maturity are within the oil window. These conclusions are based on field observations (laminated often waxy mudstones with little induration and no cleavage) and published data (Weaver and Macko, 1987; Fowler, 1995).

Though dark former mudstones are common throughout the stratigraphy of the project area, the stratigraphic equivalents of these black shales in the project area lie within the Goose Tickle Formation. At all locations where the Goose Tickle was met, it is a cleaved mudstone of greenschist facies aspect. These implied elevated levels of maturity are consistent with published conodont colour values in the 4-5 range from Rocky Harbour and East Arm area (Nowlan and Barnes, 1987). At high maturities, one is restricted in the types of analysis that can be undertaken to prove that these rocks had former petroleum potential. Measured total organic carbon (TOC) values need to be corrected to allow for the loss of carbon as oil and gas when rock passed through the hydrocarbon generation/expulsion window. TOC values can be more than halved by greenschist facies levels, with better quality oil-prone kerogens being reduced more than poorer quality gas-prone kerogens.

It is recommended that selected samples are subjected to TOC analysis to establish the levels present in the licence area. If significant values are obtained, further analyses may be warranted.

Source Rock Maturity

The maturity of the project area is in stark contrast to that of the stratigraphic equivalents to the north (Green Point) and to the south (Port au Port). Whilst graptolite reflectance, fluorescence spectra, Rock Eval T-max. and conodont colour analyses confirm the rocks to the north and south to be within the oil window, conodont colour values in the Rocky Harbour and East Arm area to the north of the project area all fall in the low grade metamorphic zone, well beyond the level of survival of, let alone generation of, oil or gas (Nowlan and Barnes, 1987).

A burial history based on the central area of the licence at a time when the obducted ophiolite comprised part of the overburden is reproduced as Figure b-1. The stratigraphy is taken from the reconstructed tectono-stratigraphic cross section. A crude calibration is attempted by adjusting the heat flow to 55mW/m^2 in order to meet an estimated 'vitrinite' reflectance of 4% Ro in the para-autochthonous Lower Cambrian. The heat flow of 55mW/m^2 is an unremarkable value for a passive margin scenario, and is modeled as constant through time.

Formation/Event	Unit Type	Base Age (my)	Top Depth (m)	Thick-ness (m)	Missing Thickness	Lithology
Quaternary	E	5			-1500	
Tertiary	H	65				
Cretaceous	H	145				
Jurassic	H	210				
Permo-Trias	H	290				
Carboniferous	D	360			1000	25sst/75sh
Lost Allochthon	E	400			-1500	
Thrusted ophiolite	D	410			1500	Igneous
Thrusted Hadrinian	F	415	0	1550		Igneous
Thrusted Cambro-Ord	F	420	1550	2250		Igneous
Melange	F	425	3800	200		40sst/30slt/30lst
Goose Tickle	F	465	4000	375		25sst/75sh
Cambro-Ord(TableHead)	F	540	4375	775		40sh/30slt/30lst
Lwr Cambrian	F	570	5150	850		30sst/30sh/20dol/20lst
Hadrinian Allochth	F	590	6000	875		50sst/50sh
Basement	F	600	6875	100		Igneous

The amount of uplift modeled (which does not estimate any ephemeral sediments above the ophiolites) and the heat flow used do not account for the observed levels of metamorphism. If this thermal model together with its parent cross section is correct, then there should be a maturity gradient within the autochthonous and para-autochthonous sequence, with the maturity of the allochthon being established by its pre-thrusting burial to the east.

The general thermal and maturity model could be substantiated and further constrained by maturity measurements on the samples collected during the field work. In particular the establishment of a maturity gradient within the autochthon and para-autochthon forms a key test of the model.

Hydrocarbon Seeps and Shows

Whilst the source rocks to the north and south (see above) are associated with active surface seeps and tested hydrocarbons in the sub-surface, no traces of hydrocarbon or bitumens were seen in the licence area. At the deduced maturity levels, if oil was generated and expelled from the widespread source rock lithologies seen, then subsequent burial and heating of reservoired oil would leave black, shiny, conchoidally fracturing pore fillings of pyro-bitumen within the common interbedded sandstones (now quartzites).

Despite consistent checking, no such pyro-bitumens were seen in the field outcrops, field pyrolysis being employed in cases of doubt. The early occupation of sandstone porosity by oil should inhibit subsequent pore filling and porosity reduction. Once oil occupies porosity it is difficult to remove all traces of carbonaceous matter unless the porosity forms part of a hydrothermal conduit. In this case oxidizing hydrothermal flux can remove oil and residual bitumens as carbon dioxide, leaving no trace of the former in the resulting quartzite.

The other possibility is that gas rather than oil will be the expelled product. In this case no macro-residues would be seen, but fluid inclusions within quartz overgrowths should contain methane as a gaseous phase. Gas may be the major expelled product from an oil prone source rock if very raped burial occasioned by overthrusting of the obducted ophiolite complex led to intra-source rock cracking of oil to gas.

To test these suggestions, further work should be undertaken to investigate the abundance and type of fluid inclusions within the various developments of quartz cements in quartzites closely associated with the carbonaceous shales of the Goose Tickle Formation.

Hydrocarbon Entrapment and Preservation

The interbedding of sands and mudstones (now quartzites and slates) provides good seals for hydrocarbon entrapment. Given the amount to syn- and post-tectonic structuring, a good to excellent seal would be required to ensure entrapment to the present day. Such a seal might be an evaporite such as halite or gypsum. As discussed above, if oil and gas were generated in the licence area, then the indicated subsequent heating would have destroyed both by thermal cracking and by reaction with inorganic phases. The preservation of oil and gas within the metamorphic geology seen in the field must be considered as high risk.