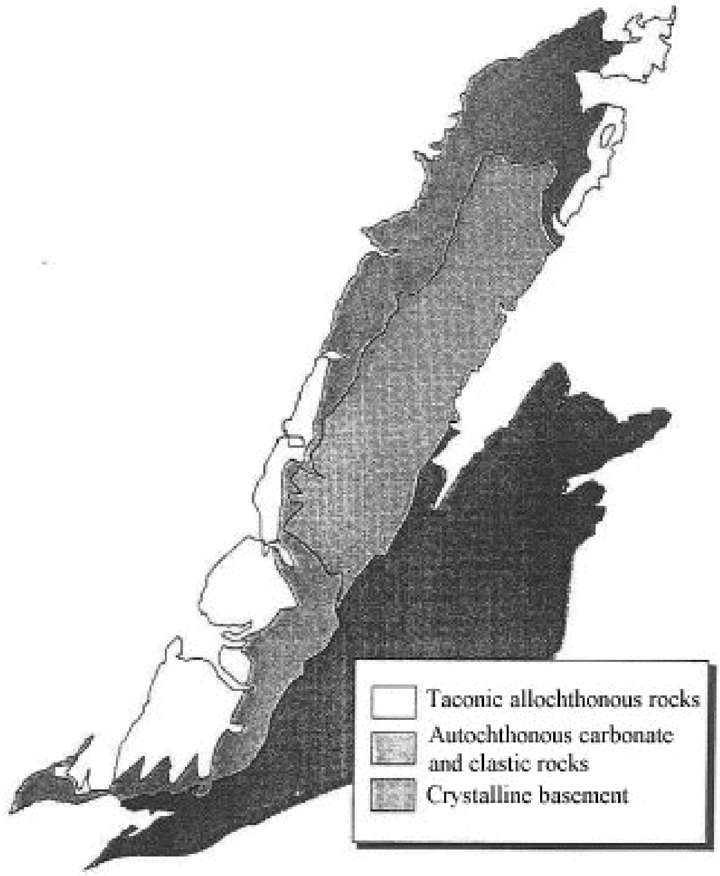
Thermal Maturity Of Potential Paleozoic Source Rocks In Western Newfoundland



A Report to Mobil Canada
by

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Plates

mature and
metamorphosed rocks.

Plate 5 (pdf - 313kb): Figure 1. Typical leiofusid acritarch from immature and marginally mature rocks. Fossil is pale yellow in (a) transmitted light and bright yellow in (b) fluorescence. Figure 2. Very large sphaeromorph acritarch from immature and marginally mature rocks. Fossil is pale yellow in (a) transmitted light and bright yellow in (b) fluorescence.

Plate 6 (pdf - 593kb): Figure 1. Gently dipping pebble and cobble conglomerate with thin sandstone and siltstone interbeds.
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Plate 7 (pdf - 207kb): Early Devonian spore assemblage from Red Island.
Figure 1. Retusotriletes sp. Figure 2. Anapiculatisporites sp. Figure 3. Emphanisporites sp.

Summary

The early Cambrian Labrador Group sediments of the Bradore, Forteau and Hawkes Bay formations are generally composed of coarse siliciclastics and subordinate carbonates deposited under well oxygenated conditions, although a few finer grained, darker lithologies occur locally. Deformed black shales from the Forteau Formation near Gros Morne Mountain are thermally overmature with a very low organic content (0.01-0.05% TOC). Samples from the Hawkes Bay and Forteau formations collected from roadcuts along Highway 430 between Wiltondale and Rocky Harbour are generally devoid of organic material, but rare particulate matter confirms that the rocks in this area are overmature. The March Point Formation of the Port au Port Group contains appreciable amounts of particulate organic matter, with TAI and fluorescence data indicating thermal maturities within the oil window; it might form potential Type I or Type II source rock should sufficient organic material be present. Unlike most other potential units, they stratigraphically underlie possible reservoir rocks in the St. George Group.

The presence of several graptolitic horizons within the Laignet Point member of the Catoche Formation in the Port au Choix area indicates low oxygen conditions during deposition of this unit; TAI's of 2.95 and R. of 1.11% suggests that the strata lie just below the oil window in the transition to overmature and metamorphosed rock. An equivalent interval does not appear to have been recorded from the Port au Port area, although a 50 m petroliferous dolostone interval is present.

The level of organic material increases upwards through the Table Head Group, with dark grey to black, graptolitic shales making up much of the Table Cove Formation on both the Northern Peninsula and Port au Port Peninsula. Average TOC's of 0.82% have been recorded for the Table Cove Formation, which is marginally mature in much of the latter area. The transition into the overlying Black Cove Formation represents a continued increase in proportion of black shale with TOC's up to 1.25%. The Black Cove Formation varies from marginally mature to mature passing from west to east across the Port au Port Peninsula and adjacent areas, and along with the laterally equivalent Cape Cormorant Formation, which contains similar black shales as a major component, is here considered to have the best potential as a source rock in the Port au Port area. In the Daniel's Harbour- Port au Choix region, TAI'S, graptolite reflectances and CAI's suggest that the units are here are overmature and metamorphosed.

The late Middle Ordovician Winterhouse Formation of the western Port au Port Peninsula, composed of medium to fine-grained siliciclastics, contains some darker, apparently organic-rich intervals. A TAI of 1.02, however, suggests probably immature organics.

On the Port au Port Peninsula, low R_o and TAI values suggest that sediment burial depths for the late Ordovician to Carboniferous strata were probably never much more than 1 km and that only a relatively thin structural allochthon slice was ever present. Higher thermal maturity values in autochthonous strata east of the Port au Port Peninsula and on the Northern Peninsula were probably due to structural control,

and indicate the subsequent emplacement of overlying allochthonous thrust sheets.
Samples from the Cow Head Group of the Northern Peninsula typically have abundant and fluorescing bitumen. Dispersed "fluffy" organic matter also fluoresces brightly in yellow and blue; the relatively high palynomorph diversity and abundance, TAI values of 1.25-2.29 and fluorescence colours of blue and bright yellow suggest transition to mature source rocks. With burial these are likely to be excellent candidates for productive Type I or Type II source rocks; previous studies have pointed to the Green Point Formation of the Cow Head Group as the likely source of oil recovered from Parsons Pond and St. Pauls Inlet.

Oil production can occur at much lower temperatures in older rocks than in more recent units. It is known that strata 100 million years old may be thermally mature at temperatures of 3O°C or less, but little work has been carried out to compare oil producing rocks of Lower Paleozoic age. Evidence from the Cow Head Group suggests that Cambro- Ordovician organic rich sediments with TAI's as low as 1.25 and Graptolite Reflectance R_o's of 0.53-0.57% are thermally mature and at levels of optimum oil production, despite having been subjected to paleotemperatures of less than 3O°C.

The Geological Evolution and Stratigraphy of Western Newfoundland

The island of Newfoundland may be divided into four major tectonostratigraphic zones, each of which was moulded by distinct evolutionary processes prior to the end of the Ordovician Period (Williams, 1979; Williams et al., 1988). These zones are, from east to west, the Avalon, Gander, Dunnage and Humber zones; the rocks of western Newfoundland, including those of the Northern Peninsula and the Port au Port Peninsula, belong to the Humber Zone (Fig. 1).

Following its initial opening in late Precambrian and early Cambrian times, the Iapetus Ocean divided the Humber Zone from those areas now comprising central and eastern Newfoundland until its subsequent closure during late Ordovician and early Silurian times. Most of the sediments in western Newfoundland which were deposited during this interval were thus associated with the eastern margin of the ancient North American continent of Laurentia, and can be readily correlated with other parts of the Appalachian region in eastern Canada and the U.S.A.

The geology of western Newfoundland may be grouped into seven discrete packages, each of which were formed under different conditions and have distinct tectonic histories (James et al., 1988, 1989; Knight and Cawood, 1991).

1. Precambrian basement rocks
The earliest rocks in western Newfoundland are the Precambrian gneisses, schists and granites which make up the core of the Great Northern Peninsula; these were formed during the Grenvillian at about 1250-1000 Ma (Owen and Erdmer, 1986). Following their original formation, the rocks underwent high grade regional metamorphism and were subsequently intruded by a series of mafic dykes at about 600 Ma (Stukas and Reynolds, 1974; Williams et al., 1985) during early stages of rifting related to the opening of Iapetus.

2. Precambrian sedimentary and volcanic rocks
The Bateau Formation, comprising terrestrial red conglomerate and sandstone, and the Lighthouse Cove Volcanics, which include subaerial, columnar-jointed lava flows, both rest directly on crystalline basement in places (Fig. 2); elsewhere the Lighthouse Cove Volcanics overlie the Bateau Formation, which had been previously faulted and intruded by dykes. These two units make up the basal divisions of the Labrador Group.

3. Lower Cambrian to Middle Ordovician autochthonous sequence
Cambrian to early Middle Ordovician sediments in western Newfoundland may be divided into autochthonous strata which formed generally within relatively shallow, nearshore settings (Fig. 2), and allochthonous units which were formed under relatively deep, oceanic conditions originally some distance

(probably over 100 km: James and Stevens, 1986) to the east. The Lower Cambrian to early Middle Ordovician autochthonous sediments are divided into the Labrador, Port au Port, St. George, Table Head and Goose Tickle groups.

The earliest Cambrian, predominantly siliciclastic, sediments of the Bradore, Forteau and Hawke Bay formations represent continued deposition of the Labrador Group during the initial rifting and opening of the lapetus Ocean on the southeast margin of Laurentia. The Bradore Formation, which in places lies directly on the crystalline Precambrian, grades upwards from pebbly, subarkosic sandstones into quartz-rich sediments, before giving way to shallow marine, fine-grained siliciclastics and carbonates of the Forteau Formation (Hiscott et al., 1984; Debrenne and James, 1981). The overlying Hawke Bay Formation marks a return to coarser, siliciclastic sedimentation that appears to be related to a regressive sequence with an unconformity or disconformity at its upper boundary (Palmer and James, 1979).

Deposition of the Port au Port and St. George groups marked a radical change from siliciclastic to carbonate-dominated sediments; these formed within shallow shelf settings under low-latitude conditions only a few degrees south of the paleoequator (James et al., 1988). The Port au Port Group was deposited during Middle and Upper Cambrian times; the basal interval of the lowermost March Point Formation contains glauconite and phosphate-rich siliciclastics and detrital carbonates, but the remainder of this unit and the overlying Petit Jardin Formation is dominated by oolites, algal mounds, and bedded limestones, shales and dolostones (Chow, 1986; Chow and James, 1987). Such lithologies continue upwards into the Berry Head Formation, although this generally lacks the shaly component.

The Lower Ordovician St. George Group comprises the Watts Bight, Boat Harbour, Catoche and Aguathuna formations; its stratigraphy was revised by Knight and James (1987). The Watts Bight Formation is characterized by a 70-90 m thick succession of muddy, bioturbated carbonates with thrombolite mounds, deposited mostly in subtidal conditions. Its stratotype is in the northern part of the Northern Peninsula, but the formation is also well developed at Isthmus Bay on the Port au Port Peninsula. Peritidal Uthologies at the top and bottom of the unit reflect episodes of slowed subsidence relative to sea level.

Knight and James (1987) considered the transition into the overlying Boat Harbour Formation to be conformable on both the Northern Peninsula and Port au Port Peninsula. This unit is composed of 120-150 m of interbedded dark grey limestones and dolostones of early Ordovician age. Much of the material was deposited in low-energy, peritidal and shallow subtidal conditions, but with some higher energy, subtidal conditions also present (Pratt and James, 1986). Subaerial karstification occurred late in the formation's history, resulting in stratigraphic dolomitization, silicification, pitted solution surfaces and breccias (Knight and James, 1987).

The Catoche Formation is composed of 160 m of well-bedded, fossiliferous, bioturbated, grey limestone with a mudstone to packstone texture and intercalated lenses or thin beds of rippled bioclastic to intraclastic grainstone. It also contains thrombolite mound horizons, which were scattered across an extensive shelf up to 300 km wide and formed a semicontinuous barrier complex near the shelf margin (Stevens and James, 1976; James et al., 1988). The sediments of the upper part of the Catoche Formation would have been deposited in an open, subtidal setting with sediment reworking by storms (Knight and James, 1987). The original limestones have been variably affected by dolomitization since their original deposition (Haywick and James, 1984); in some instances, only burrows and selected macrofossils have been replaced, while in the most extreme cases coarse, crystalline dolomite has completely destroyed the original sedimentary fabric. Near Daniel's Harbour the coarse white epigenetic dolomites host the extensive zinc mineralization exploited by Newfoundland Zinc Mines until recently (Collins and Smith, 1975; Lane, 1984, 1990).

The uppermost formation of the St. George Group is the Aguathuna Formation, comprising a series of finely crystalline, grey peritidal dolostones and minor interbedded limestones. Although named after Aguathuna Quarry on the Port au Port Peninsula, the stratotype section is at Freshwater Bay, just north of Table Point, where it is 63 m thick (Knight and James, 1987). The base of the formation is apparently conformable at the type section, although it is marked by a pronounced disconformity at one locality on

River of Ponds Lake to the north (Knight and James, 1987). The top of the unit is represented by a major erosional contact at many localities in western Newfoundland, but not at Table Point where the unconformity is hidden within the formation. Here the upper boundary, although distinctive, represents a gradual transition into the overlying dolostone-rich Springs Inlet Member of the Table Point Formation (Ross and James, 1987; Stenzel et al., 1990). Recent work (Knight et al., in press) indicates the presence of a major unconformity 15 m below the top of the Aguathuna Formation at Table Point, which correlates with the erosional contact between the Aguathuna and Table Point formations seen in the northern part of the Northern Peninsula and on the Port au Port Peninsula. This intra-formational unconformity separates a lower member from upper members, the latter marked by similar lithologies but associated with the first appearance of quartz and chert sand, and pebble beds and laminations. It is this upper member that rests unconformably upon the Catoche Formation at the River of Ponds (Knight and Boyce, 1984), indicating substantial erosion locally.

The commonest lithologies of the Aguathuna Formation are massive to laminated microcrystalline dolostone, burrowed dolostone and limestone, stromatolitic boundstone, mud-cracked shale, chert-replaced evaporate and breccia (James et al., 1988). The sediments accumulated in muddy peritidal settings ranging from open but restricted marine to intertidal and high supratidal mud flats. Breccias, shales, quartz-rich sand layers and paleokarst surfaces indicate periods of subaerial exposure, suggesting a significant number of minor breaks in the sequence. Two narrow intervals of dark, dolomitic mudstone near the base of the formation at Table Point yield a monospecific graptolite fauna (Williams et al., 1987). The Aguathuna Formation was deposited during the initial stages of continental margin flexure and synsedimentary uplift which led to topographic irregularities during the final stages of deposition (Lane, 1984; Knight, 1985; Stenzel et al., 1990).

The Table Head Group as redefined by Stenzel et al. (1990) is a 360 m thick, limestone- dominated sequence, comprising the Table Point, Table Cove and Cape Cormorant formations. The lower boundary of the table Head Group is placed at the first limestone bed in the Table Point Formation, which at Table Point conformably overlies dolostones of the Aguathuna Formation. The lower part of the Table Head Group is a succession of peritidal carbonates composed of limestones and some dolostones and is referred to the Springs Inlet Member of the Table Point Formation (Ross and James, 1987). The remainder of the Table Point Formation, which measures a total of 250 m thick at Table Point, consists of subtidally deposited, fossiliferous wackestones, packstones and grainstones similar in lithology to those of the Catoche Formation, with minor small sponge bioherms (Klappa and James, 1980). Much of the nodular and pseudoconglomeratic appearance of the limestones is diagenetic in origin, although several slumped and intraformational conglomerate horizons indicate deposition in an unstable shelf setting. Despite some local variation, the general depositional history records gradual deepening, followed by a shallower marine setting. The overlying Table Cove Formation is a sequence of carbonates deposited on a gently dipping slope. Lithologies range from bioturbated, fossiliferous wackestone and packstone in the basal 20 m through flat bedded, parted limestone, ribbon limestone and black shale in the remaining 70 m;. all are characterized by synsedimentary folding, slumping and brecciation. The increasing proportion of ribbon limestone and black shale in the upper portion indicates deposition in an ever deepening environment.

The Table Head Group was formed during the submergence and breakup of the outer continental margin during Middle Ordovician times. This was related to the first stages of closure of the Iapetus Ocean, when back-arc basins and associated volcanics were overthrust and obducted onto other oceanic sediments, crust and mantle during the Taconic Orogeny. The onset of progressively deeper water conditions is reflected by the change from massive, continuous limestone deposition in the Table Point Formation, through alternating limestones and black shales in the Table Cove Formation, into black shale deposition in the Black Cove Formation of the overlying Goose Tickle Group. Spectacular, thick carbonate breccias and conglomerates of the Cape Cormorant Formation, found only on the Port au Port Peninsula (Figs. 3, 4), are lateral equivalents of the Table Cove and Black Cove formations (Stenzel et al., 1990). They were deposited by massive debris flows along submarine fault scarps which formed during the foundering of the continental margin.

The Goose Tickle Group was erected by Stenzel et al. (1990) for the package of shales, siltstones and sandstones overlying the Table Head Group in western Newfoundland. The Black Cove Formation, which had formerly been included within the Table Head Group (Klappa et al., 1980) was reassigned as the basal formation, and the overlying coarser sandstones redefined as the American Tickle Formation.

The Black Cove Formation is a thin (up to 14 m) black shale, marking the cessation of carbonate deposition and the onset of starved sedimentation in a deep water euxinic setting. It is gradationally overlain by interbedded siltstones, sandstones and shales of the American Tickle Formation, the boundary being placed where greenish-grey, silty shale and green siltstone laminae become noticeable components (Stenzel et al., 1990). The coarser sandstones include brown and green chrome and spinel grains, indicating derivation from an ophiolidc source terrane.

The Goose Tickle Group was formed by sediments derived mainly from the southeast and composed of transported and obducted oceanic materials. This contrasts with all earlier detritus which had been eroded and transported off the Laurentian continent to the northwest. In addition to turbidite sandstones and shales of the American Tickle and Mainland Sandstone formations, a number of lensoid carbonate debris flow breccias and turbidite sands, referred to the Daniel's Harbour Member, represent similar, but more minor, sedimentary deposits to those of the Cape Cormorant Formation. They are generally thin, but are widely developed throughout western Newfoundland outside the Port au Port area (Stenzel et al., 1990).

4. Lower Cambrian to Middle Ordovician allochthonous sequence

The sediments of this sequence are assigned to the Humber Arm Supergroup, made up of the Cow Head and Curling groups. The Cow Head Group forms the structurally lower package and was probably transported a shorter distance following its original formation to the southeast of its present position. Estimates of the transport distances involved vary, but by comparison with the autochthonous sequence and modern day carbonate platforms, must have been over 100 km (James and Stevens, 1986). The Cow Head Group is composed of a series of Middle Cambrian to Lower Ordovician deep-water marine limestones, shales and carbonate conglomerates and megabreccias. They were deposited at the ancient continental edge and continental slope by turbidites and debris flows which transported shallow marine carbonate detritus from its site of formation. Within exposures of the Cow Head Group, a change is seen from upper slope, relatively proximal sediments in the northwest, dominated by megabreccias, conglomerates and limestones, to lower slope, distal settings in the southeast composed largely of red and green shales (Figs. 5, 6). The Curling Group comprises the higher structural package, although evidence from recent studies (e.g. Botsford, 1988) does not indicate a more distal setting, lithologies being somewhat similar to those of the Cow Head Group. During the Taconic Orogeny, the two groups of the Humber Arm Supergroup were thrust over the contemporaneous autochthonous rocks which had formed on the neighbouring carbonate platform.

5. Allochthonous Cambrian-Ordovician ophiolite complexes

The rocks of the Bay of Islands and Little Port complexes within the Bay of Islands represent remnants of oceanic crust and mantle that were obducted over both the autochthonous and allochthonous sediments during the Taconic Orogeny (Cawood, 1991). Recent publications now refer these units to isolated slices of the Dunnage Zone, which is in itself almost entirely allochthonous in nature. The ophiolites include peridotite and other ultramafic intrusive rocks characteristic of the mantle, crustal intrusive bodies, sheeted dykes and pillow lavas of mafic composition, and deep marine cherts and shales.

6. Middle-Upper Ordovician parautochthonous sediments

The parautochthonous Middle-Upper Ordovician Long Point Group is divided into a carbonate-dominated Lourdes Formation, and an upper, siliciclastic-dominated Winterhouse Formation (Bergstrom et al. 1974; Stait, 1988). It has traditionally been interpreted as resting unconformably on both the allochthonous Humber Arm Supergroup and authochthonous Table Head and Goose Tickle groups on the Port au Port Peninsula, suggesting that all major transport within the allochthon had occurred prior to the deposition of the Long Point Group (Rodgers and Neale, 1963; Stevens, 1970). Stockmal and Waldron (1990) have recently, however, suggested that the supposed unconformity is actually a structural contact, shedding doubt on this conclusion.

7. Late Silurian to Carboniferous sediments
Shallow marine carbonates of late Silurian and/or Devonian age are known from two areas in the Humber Zone, on the west side of White Bay and on the western tip of the Port au Port Peninsula (Smyth and Schillereiff, 1982; Riley, 1962; Rodgers, 1965). Those on the western Port au Port Peninsula, which unconformably overly the Long Point Group, are assigned to the Clam Bank Formation (Figs. 3, 4), which also contains interbedded terrestrial and shallow marine red sandstones and conglomerates. The uplift and erosion which occurred prior to its deposition was probably related to the uplift of the Long Range Mountains during the early Acadian Orogeny.

Following this time, Newfoundland was part of a stable landmass on the supercontinent of Pangaea. A widespread network of successor basins enveloped the Appalachian mountains of Newfoundland from the late Devonian through the Carboniferous, including the Deer Lake Basin and Bay St. George Subbasin. Dominantly non-marine, terrestrial sediments filled these basins, including late Carboniferous coal measures. Some basins were deformed by strike-slip movements that occurred along major faults which ran parallel to the trend of present-day mountains (e.g., the Long Range Fault in western Newfoundland). The Bay St. George Subbasin is the northeastern extension of the Maritimes Basin, and contains some 10 km of sediments late Devonian to late Carboniferous in age (Knight, 1983; Knight and Cawood, 1991), the Anguille, Codroy and Barachois groups of Carboniferous age resting unconformably on all earlier rocks. They were deposited mostly in fluvial, lacustrine and deltaic environments, demonstrated by the presence of red and grey sandstones and conglomerates, with thin localized coal beds in the Barachois Group; the Codroy Group also contains evaporates and shallow marine strata including limestones. The red conglomerate and sandstone sequence exposed on Red Island off the southwest coast of the Port au Port Peninsula (Fig. 3) was probably deposited by fluvial processes within a small separate basin or subbasin during the late Devonian or early Carboniferous. The conglomerate, dominated by clasts of silicic volcanic material, is unlike any other lithologies exposed elsewhere in western Newfoundland, and in this report is assigned to an informal "Red Island formation".

Previous Records of Hydrocarbon Occurrences In Western Newfoundland

Oil and gas shows have been encountered in four regions of western Newfoundland, namely Parsons Pond and St. Pauls Inlet on the Northern Peninsula (Fig. 5), the Port au Port region (Fig. 3), the Deer Lake Basin, and the Bay St. George Subbasin. The first two occurrences are associated with rocks of both the Humber Arm Allochthon and the autochthonous Table Head Group (Cote, 1962; Department of Energy, 1989). Wells in the latter two regions encountered significant gas shows within Carboniferous terrestrial deposits, while oil shales also occur in the upper part of the Rocky Brook Formation of the Deer Lake Basin.

1. Parsons Pond and St. Pauls Inlet
From the 1860's to the 1960's, in addition to oil related surface shows, some 27 wells were drilled and 6000 barrels of oils produced in this area (Department of Energy, 1989). All wells were within the allochthonous Cow Head Group (Fig. 6), although surface seeps also suggest some hydrocarbon occurrence within associated autochthonous units. Macauley (1987a), Weaver and Macko (1987) and Weaver (1988) considered the Green Point Formation of the Cow Head Group to have provided a possible source for the organics, Weaver and Macko (1987) suggesting the Broom Point Member of that formation to have been the most likely. Macauley (1987a) recorded two marginally mature samples from the Green Point Formation to have TOC's of 2.76% to 5.06%, and HI's of 486 to 650; other samples from unspecified stratigraphic levels include three with lower TOC's and HI's of 0.09-0.72% and 5-29% respectively, but one, which Sinclair (1990) considered to have originated from the Stearing Island or Factory Cove Member of the Shallow Bay Formation, had TOC's of 1.68-1.79% and HI's of 454-463. Weaver and Macko (1987, table 1) listed TOC's varying from 0.06% to 5.2% from the various members of the Cow Head Group, concluding that the older, Tremadoc samples generally had higher values than younger, Arenig samples. They also found increased organic content when passing from relatively proximal to more distal facies, and recorded a trend in increasing ^{13}C values and bitumen content eastwards towards the Long Range Mountains, considered to be related to structurally deeper burial. Previous records of CAI's in the Cow Head Group (Stouge, 1986; Nowlan and Barnes, 1987a, b) suggest

that these sediments are marginally mature, probably falling within the oil generation window.

Samples from the Broom Point Member at Martin Point, analysed by Sinclair (1990) yielded TOC values of 0.47% and 1.74%, with HI's of 276-370, while a sample from the Martin Point Member at Green Point yielded 3.04% TOC and HI's of 437-454. Fowler (in Sinclair 1990, p. 26) considered that, based on geochemical data, hydrocarbons collected from oil-filled fractures in the Green Point Formation were most likely to have been derived from the Martin Point Member. Other samples analysed by Sinclair (1990) were from the Stearing Island Member of the Shallow Bay Formation of Martin Point and the Cow Head Peninsula, the lateral proximal equivalent of the Broom Point Member of the Green Point Formation. TOC's ranged from 0.94% to 2.08%, with HI's of 231-390. Sinclair (1990) recorded Tmax values for the Cow Head Group samples of 441-448oC, and suggested the presence of mature, marginal Type II or mixed Type II and Type III source rocks.

2. Port au Port

Shoal Point forms the prominent, northward-directed, peninsula on the east side of West Bay, Port au Port Peninsula, while the bitumen seeps south of Point au Mal lies to the southwest corner of Two Guts Pond 10 km northwest of Stephenville (Fig. 3). Surface exposure is poor, but both localities lie within rocks of unknown age belonging to the Humber Arm Allochthon. A total of 9 wells have been drilled on the northwest side of Shoal Point (Cote, 1962; Corkin, 1965; Department of Mines, 1989), one of which (Shoal Point No. 1, drilled for the Golden Eagle Refining Company in 1965) passed through the structural base of the allochthon and penetrated 49 m of autochthonous Table Head Group at about 800 m, encountering a tarry residue in the upper part of the Table Head Group. Limited production from the wells was achieved during the early part of this century.

Sinclair (1990, fig. 14) indicates collection of a sample from Point au Mal, but apparently makes no mention of it in the text or in his rock-evaluation analyses (1990, table 1). Two outcrops of apparently calcareous, silt and sandstone were sampled during the present study; their odour and presence of visible bitumen clearly demonstrate their hydrocarbon content, although it appears that these are reservoir, rather than source rocks.

Until the Humber Arm Allochthon in this region is studied more thoroughly, few critical observations regarding stratigraphic control of these shows may be made, as much of the unit is now known to represent a melange (Williams and Cawood, 1989). Macauley (1987a) recorded one sample (GP-1, which he erroneously considered to be Green Point Formation: Sinclair, 1990) from the Humber Arm Allochthon on the northwest Port au Port Peninsula north of West Bay to have TOC of 7.78-8.37% and HI of 688-753, suggesting a good source rock potential. His other in situ samples from the allochthon had low TOC's of 0.11-0.28 % and HI's of 2- 100.

Crude oil and bitumen staining have also been recorded from the Table Head Group in a number of wells drilled in the autochthon to the southwest of Lourdes (Fig. 3; Appendix 6), while one additional show was recorded in the parautochthonous Long Point Group midway between Lourdes and the most northeasterly point of Long Point (Cotes, 1962; see Fig. 3).

Broadly equivalent shales of the Humber Arm Allochthon in the Bay of Islands region, belonging to the Upper Cambrian and Lower Ordovician Cooks Brook Formation of the Curling Group, have relatively high organic carbon levels (3%) (Botsford, 1986). CAI values of 5 suggest, however, that most of this unit is oven-nature (Stouge, 1986).

3. Deer Lake Basin

The Deer Lake Basin includes 1700 m of predominantly fluvial and lacustrine, Carboniferous sediments (Hyde, 1981). The uppermost unit, the Howley Formation, contains minor coal horizons. A total of 7 wells have been drilled in the basin, three of which encounted appreciable gas shows in the Rocky Brook and underlying North Brook formations of the Deer Lake Group (Department of Energy, 1989). The Rocky Brook Formation contains oil shales, commonly interbedded with other lithologies, in its upper part, with hydrocarbon yields ranging from 55-155 litres/tonne (Hyde, 1984; Macauley, 1987b). Rock evaluation pyrolisis by those authors indicated Type I (oil prone) Kerogen, while Hyde et al. (1988) concluded an average paleotemperature of 1OO°C based on vitrinite reflectance values and clay data. Both these data, and the deeper occurrence of gas shows in the North Brook Formation indicates, therefore, that they are derived from an older source rock which is as yet unknown.

4. Bay St. George Subbasin

The Bay St. George Subbasin contains some 10 km of late Devonian and Carboniferous, mostly non-marine, sediments, divided into the Anguille, Codroy and Barachois groups (Knight, 1983). The Anguille Group is composed of fluvial, lacustrine and deltaic deposits; the Codroy Group is dominated by fluvial red beds, but also contains marine siliclastics, carbonates and evaporates, while the Barachois Group is mostly composed of fluvial clastics with organic-rich oil shale and coal deposits.

According to a report by the Department of Energy (1989), most hydrocarbon shows in the region occurred during drilling relating to the evaluation of gypsum deposits in the Flat Bay area (McKillop, 1957). These were apparently restricted to gas shows, but with one report of an oil show in the Anguille Group. The Barachois Group is the only unit whose potential as a source rock has been investigated (Solomon, 1986). The oil shales are thin but thermally-mature with hydrocarbon yields up to 90 litres/tonne; kerogen is dominantly Type III, with lesser amounts of Type I and Type II. The Barachois Group also contains mature, organic-rich mudstones with TOC's of up to 31.9%, suggesting that it is a potential gas source.

Thermal Maturity Data

1. Vitrinite and Graptolite Reflectance

Methodology

Land plants first evolved during the Lower or Middle Silurian, but did not become abundant until the Devonian Period. Vitrinite in the strict sense does not, therefore exists in sediments deposited before that time. Graptolite workers have, however, realized for some time that the fossilized skeletal remains of these hemichordates differs in appearance between those preserved in relatively undeformed strata and those which have been subjected to low grade regional metamorphism. "Uncooked" graptolites, including the vast majority of examples which may be isolated from carbonates through acid solution techniques, are black with a lustrous sheen (e.g., Williams and Stevens, 1988). In contrast, those occurring in black shales of zeolite or prehnite-pumpellyite facies, such as in central Newfoundland (e.g., Williams, 1991) have a graphitic or metallic lustre. Graptolites from sediments lying between these extremes (such as those in the northern part of the Northern Peninsula of western Newfoundland) are commonly almost indistinguishable from the surrounding matrix due to the destruction of their original organic material and lack of secondary reflectance.

Such observations have now been quantified through the use of reflectance studies of graptolite periderm, of which the maximum reflectance in oil and bireflectance appear to be most diagnostic, and an attempt made to calibrate these Graptolite Reflectance values against Conodont Colour Alteration Indices (CAI's), true vitrinite, and absolute maximum temperatures to which the rocks have been subjected (Goodarzi and Norford, 1985; see Fig. 7).

During the present study, unweathered graptolitic black shale samples were collected for reflectance measurements using sledge hammer, chisel and wrecking bar; slabs were subsequently split in the laboratory and divided into three parts - for reflectance measurements, palynomorph study and TOC testing by MOCAN. Due to the inavailability of adequate facilities in St. John's, reflectance work was subcontracted to Global Geoenergy Research Ltd. of Halifax, N.S., following the advice of F. Goodarzi (I.S.P.G., Calgary). Results are listed in Appendix 1.

The technique of reflectance studies on graptolites is still very much in its infancy compared with other methods of determining thermal maturity; it does, however, seem to be a potentially invaluable technique in understanding the burial and structural history of Lower Paleozoic sediments, and appears to permit greater accuracy than conodont alteration, particularly in sediments which have only been subjected to low temperatures (CAI < 2). Unfortunately, true graptoloids (planktonic graptolites) have a rather restricted stratigraphic range from basal Ordovician to mid Devonian and are only commonly preserved in black shales and limestones deposited under anoxoic conditions; reflectance measurements are restricted, therefore, to such lithologies from this interval. Fortunately, the majority of potential source rocks in western Newfoundland belong to such sediments.

Sample summaries - Port au Port Peninsula

Autochthonous Lower-Middle Ordovician rocks on the Port au Port Peninsula and adjacent mainland have Graptolite Reflectance R_o's varying from 0.67 to 0.85% (Fig. 10); comparison with the true vitrinite R_o values in the chart shown in Figure 7 suggests that these strata are mature; Goodarzi and Norford (1985, p. 1097), however, commented that although a true vitrinite R_o value of 2.5% indicated the semi-antracite stage and a temperature higher than 13O°C, a graptolite R_o value of 2.5% indicated a rather lower temperature of about 1OO°C. By extrapolation it therefore appears that these sediments are only marginally mature to mature, and although probable, it is not possible to state categorically that organic-rich rocks of this age will be potential source rocks. A few kilometres further inland near Cold Pond, to the northeast of Stephenville (Fig. 1), R_o values increase to 1.35%, which by comparison with the above discussion suggests mature sediments.

True vitrinite R_o measurements from Carboniferous sediments of the Codroy Group are 0.58% and 0.65% (Fig. 11); these indicate maximum paleotemperatures indistinguishable from those of the earlier strata, but they may have been affected by Carboniferous hydrothermal systems in the Aguathuna region proposed by von Bitter et al. (1990; see below). Measurements from plant remains in sandstone boulders collected from the beach at Red Island off the west coast of the Port au Port Peninsula were marginally lower at 0.52%, although the exact age of these is uncertain (see section on Red Island).

Authochthonous strata, Northern Peninsula

Graptolite Reflectance results for graptolitic sediments in the Table Point and Port au Choix region vary from 0.96% to 1.90% (Fig. 13); these are, therefore, demonstrably higher than those on the Port au Port Peninsula, but are similar to those from near Cold Pond north of Stephenville. The results indicate that all potential source rocks are mature to overmature.

Allochthonous strata, Cow Head Group

Qualitative observations of periderm preservation made during the study of isolated graptolites from the Cow Head Group in and around the Gros Morne National Park appear to suggest a slight increase in thermal maturity from west to east; similar conclusions were made by Weaver and Macko (1987), based on ^{13}C isotope data. Although not totally conclusive, Graptolite Reflectance R_o data does suggest a slight increase from 0.53-0.57% on the Cow Head Peninsula and at St. Pauls Inlet to the northeast to 0.59-0.63% in more southeasterly thrust slices at Western Brook Pond to the southeast (Figs. 5, 6). Values from Martin Point are 0.55 and 0.56%. This is an exposure of more distal setting, suggesting the presence of a higher thrust slice in similar proximity to the structural base of the Long Range crystalline basement to that of Western Brook Pond; such low R_o values are, therefore, somewhat anomalous, as are the two rather different R_o's of 0.51% and 0.69% at Green Point.

The range of R_o values for the Cow Head Group (0.51-0.69%) suggests that the sediments are marginally mature to mature.

2. Palynomorph and organic particle analysis

Methodology

Because land plants did not appear until the Silurian, it is assumed that any organic material in pre-Silurian rocks is marine in origin. Vitrinite in the strict sense did not exist, nor did other phytoclasts (trachids, cuticle and cortex) or amber. Palynomorphs were predominantly acritarchs; rare trilete spores and tetrads in Ordovician strata were probably derived from advanced algal precursors of land plants.

TAI studies of palynomorphs require a modified preparation technique which reduces or eliminates any acids which may damage the fossil walls. Coarsely crushed 15 g samples are spiked with approximately 25,000 Lycopodium spores to assess whether losses occur during preparation and to establish fossil concentrations. Samples are placed in 250 rml beakers with sufficient 15% HCl to dissolve the tablets containing the Lycopodium spores and to dissolve carbonate minerals in the samples. Following HCl treatment, the samples are washed with distilled water and centrifuged. To remove silicate minerals, the partially digested sample is placed in a 250 ml beaker with about 100 ml of 50% HF. When the silicates dissolve, the black organic sludge is washed and centrifuged with distilled water and a slide of the unsieved residue prepared.

Unsieved organic residues are often cluttered with finely disseminated organic material and partially digested minerals. To obtain a clear indication of the fossil recovery, the residues are sieved with a 10mm screen to remove fine particulate debris and to concentrate the larger organic fossils. Two slides are prepared of the sieved residue. Unsieved and sieved residues are scanned to obtain an indication of the kind and concentration of organic material. A typical count sheet (Appendix 3) is divided into two separate sections separating larger clasts and organic materials from the identifiable palynomorph fossils. Slides are scanned in alternating fluorescence and transmitted light to obtain an indication of the palynomorph TAI and fluorescence properties. Colours are matched with a standardized colour chart of TAI which is calibrated with vitrinite R_o (Fig. 7). Plots of TAI against R_o for the present study (Fig. 8) show anomalously high R_o values in comparison with several previous studies; as reworking of the large graptolite fragments on which the R_o values were determined is unlikely, this may indicate the difference in R_o values between those made on graptolite periderm and those made on true vitrinite.

Palynology descriptions
Sample residues contain several distinctive kinds of organic particles. Some of these particles can be readily identified and relate to known macro- and microfossils (i.e., acritarchs, chitinozoa, scolecodonts and graptolites); other particles, most notably flat sheets of "cuticle", are of uncertain origin. Many samples contain framboidal pyrite, pyritized radiolaria fragments and bitumen (Plate 1).

The most abundant material in the residues is amorphous material (Plate 2). This is by and large similar to the "fluffy" amorphogen reported by Jacobson et al. (1988) for Type II source rocks of the Ordovician of the mid-continent and east-central United States. Other varieties of amorphogen include grey masses, pellets and degraded tissue (Plate 2). None of the samples contain material like the "platy" amorphogen which occurs in Type I source rocks of the Ordovician of the United States (Jacobson et al., 1988).

Zooclasts are dark, chitinous fragments of large invertebrates (graptolites), scolecodonts and chitinozoa (Plate 3). Most of these materials are naturally dark in colour and do not fluoresce; others are shades of red and brown and fluoresce with brilliant red and brown colours. Some zooclasts are rounded in outline and extremely degraded by bacterial and chemical processes. However, the largest proportion of zooclasts is angular.

Acritarchs are crudely divisible into three main types (Plates 4, 5), the acanthomorphs (Veryhachium sp., Micrhystridium sp. and Baltisphaeridium sp.), the sphaeromorphs (very large spheres - Tasmanites?. large leiospheres and small leiospheres) and other palynomorphs (most notably several species of Leiofusa). Some samples have small numbers of Gloeocapsamorpha sp., an algal cyst characteristic of Type I source rocks of the U. S. (Jacobson et al., 1988). In general, acritarch abundances tend to correspond with samples containing bitumen possibly pointing to other unknown source rocks.

Sample summaries - Port au Port Peninsula
Autochthonous Middle Cambrian sediments of the Port au Port Group at Degras and March Point (Fig. 9; samples 91044, 91028 and 91027) apparently contain two distinctive macerals. The sample from the Petit Jardin Formation (91044) contains little or no dispersed organic matters and abundant pyrite. In contrast, the underlying March Point Formation has more dispersed organic matter and relatively abundant acritarchs, including Tasmanites sp. and Gloeocapsamorpha sp. The TAI's of 2.22 and 2.9 and brown fluorescence suggests a mature and relatively productive Type I or Type II source rock.

The single sample from the St. George Group has a TAI of 2.33 and fluorescence of 3.2. The Lower to Middle Ordovician Table Head and Goose Tickle groups on the Port au Port Peninsula have TAI's-of 1.01-1.77 and mostly blue fluorescence (Fig. 10); those on the mainland around Black Cove show, however, rather higher TAI values of 1.87-2.5 and fluorescences of 2.69-3.63 (see below). This suggests that the majority of the Table Cove, Black Cove and Cape Cormorant formations on the Port au Port Peninsula, which are here considered to have the greatest source rock potential in this area, are only marginally mature, but that thermal maturity increases from west to east.

The Winterhouse Formation with a TAI of 1.02 and blue fluorescence is apparently immature (Fig. 11). TAI's from Red Island are 2.47 with fluorescence of 2.87 in sandstone clasts within conglomerate and 4.0 with green fluorescence from overlying cross- bedded sandstones. By comparison with older autochthonous sediments on the adjacent mainland, this strongly suggests that the organic matter within these Devonian or Carboniferous sediments is highly oxidized and of no use in determining original burial depths in the area. The Carboniferous Codroy Group near Aguathuna has TAI's of 2.03- 2.4 and blue fluorescence; these higher than expected values are in agreement with the presence of the Carboniferous hydrothermal system hypothesized by von Bitter et al. (1990).

Autochthonous and allochthonous strata, Stephenville area
Samples of the Black Cove and Mainland Sandstone formations at Black Cove just northeast of the Port au Port isthmus (Fig. 10) contain fluffy and pyritic organic matter. In addition, Black Cove samples contain diverse and relatively abundant palynomorphs, including Tasmanites? sp., whereas the Mainland Sandstone has a small, low diversity assemblage. The TAI's of 1.87-2.5 and red to brown fluorescence colours indicate these samples are mature. The Black Cove Formation in this area is probably a relatively productive Type I or Type II source rock; the Mainland Sandstone would apparently be less productive.

Sample 92001 from the Humber Arm Allochthon south of Point au Mal is a bituminous siltstone with a strong petroliferous odour, before processing for fossils, the oil had to be removed with solvents. After processing the sample was seen to contain relatively abundant amorphogen. However, there were no other fossils. The oil in this rock is thought to have migrated from another source.

The Goose Tickle Group at Cold Pond (Fig. 1; 91057) contains dispersed "fluffy" organic material, pyrite and a low diversity assemblage of sphaeromorph acritarchs. The TAI of 2.6 and black fluorescence indicates that these rocks are near the bottom of the oil window. The amorphous matter in the sample suggests that this was once a relatively productive Type II source rock.

Samples 91055 and 91058 from near Gallants and Georges Lake northeast of Stephenville respectively (Fig. 1) contain carbonized organic material. Both samples are metamorphosed with TAI's of 4.0 and are unlikely candidates for source rocks.

The increased thermal maturity passing eastwards from the Port au Port Peninsula to St. Georges Lake (Fig. 1), indicated by higher TAI values from 2.6 to 4.0, is as would be expected from the more intense structural deformation experienced towards the Long Range Mountains.

Autochthonous strata, Northern Peninsula
Samples from the Lower Cambrian Hawkes Bay and Forteau formations in the southerly part of the Northern Peninsula between Wiltondale and Rocky Harbour are largely barren (Fig. 1); the one sample with limited organic matter has TAI and fluorescence values of 4.0, indicating overmature sediments.

Those from the Lower-Middle Ordovician St. George, Table Head and Goose Tickle groups in the Daniel's Harbour to Port au Choix region (Fig. 13) have TAI's of 2.95-3.8 and fluorescences of 4.0, samples 85278, 85280 and 91051 containing very small numbers of acritarchs. This evidence suggests that these sediments, including the Catoche and Black Cove formations, lie just below the oil window in the transition to overmature and metamorphosed rock, and unlikely to be oil-bearing.

Allochthonous strata, Cow Head Group
Samples from the Cow Head Group of the Northern Peninsula (85235, 85238, 85242, 85245, 91052, 91054) typically have abundant and fluorescing bitumen. Dispersed "fluffy" organic matter also fluoresces brightly in yellow and blue. Palynomorph diversity and abundance is relatively high; most samples have Tasmanites? sp., and sample 91054 has Gloeocapsamorpha sp. No systematic variation is apparently demonstrated by TAI values in the Cow Head Group, which are 1.25-2.29; these and the fluorescence colours of blue and bright yellow suggest, however, that the samples come from transition to mature

source rocks. With burial these are likely to be excellent candidates for productive Type I or Type II source rocks.

Macauley (1987a), Weaver and Macko (1987) and Weaver (1988) considered the Green Point Formation of the Cow Head Group to be the likely source of oil recovered from Parsons Pond and St. Pauls Inlet. The fact that most Cow Head Group samples processed during the present study yielded copious quantities of crude oil suggests that the sediments are mature and in all probability lie near to the level of thermal maturity required for optimum oil production. The rather low paleotemperatures indicated by TAI and R_o values suggest that the generally accepted thermal norms for oil production should be revised when dealing with Lower Paleozoic rocks, and that full thermal maturity may occur at temperatures of 3O°C or less.

3. Conodont Colour Alteration Index (CAI)
The change in conodont colour from transluscent or clear to amber, brown, black and finally white has been used widely in determining the maximum temperatures experienced by Paleozoic sediments since the study by Epstein et al. (1977). CAI's are useful in permitting quick and ready determination from new and existing conodont samples. The recognizable divisions are, however, rather crude in comparison to paleotemperature determinations made using particulate organic matter and reflectance techniques, particularly with regard to sediments in and around the oil window. Conodonts have an advantage over graptolites in terms of their longer stratigraphic range and preservation in a greater variety of rock types, but similar disadvantage in being largely absent from pre- Ordovician strata. Both groups are invaluable for local and global biostratigraphic correlation.

Following a preliminary report by Stouge (1986), a comprehensive summary of CAI's throughout eastern Canada and their application in determining thermal histories of Lower Paleozoic strata was made by Nowlan and Barnes (1987a, b). Most of the CAI data recorded on maps within the present study is taken from these publications. They recorded a clear increase in CAI from 1 in the southwest on the Port au Port Peninsula to 5 or more on the northwestern tip of the Northern Peninsula (Fig. 1); Nowlan and Barnes (1987b) acknowledged that much of this would have been due to increased structural burial and tectonic activity, but also considered it to be related in part to the passing of the area over a hotspot during the Mesozoic.

Barnes and Nowlan (1987b) found little evidence of thermal alteration on the Port au Port Peninsula, with CAI's from the autochthonous Ordovician consistently measuring 1. They recorded CAI's of 4.5 to 5 in Ordovician autochthonous and allochthonous strata in the Bonne Bay area of the Northern Peninsula (Fig. 5), clearly related to intense structural deformation. The Cow Head Group yielded uniform values of 1.5; these marginally higher values than those found on the Port au Port Peninsula contrast with the lower R_o, TAI and fluorescence data which suggest roughly similar temperatures in the two regions. CAI's from the Lower-Middle Ordovician authochthonous St. George, Table Head and Goose Tickle groups of the Daniel's Harbour-Port au Choix region (Fig. 13) are 2 and 2.5, in broad agreement with the TAI and R_o values determined here.

4. Fluid inclusion temperatures
Fluid inclusion temperatures have been calculated for the platform carbonates by the Geological Survey of Canada (Saunders et al., in press). In addition, the Newfoundland Zinc Mine at Daniels Harbour has completed a detailed thermal analysis of fluid inclusions in and around the ore body (Lane, 1990). These data (incorporated into thermal maturity maps within the present report) suggest that the rocks of the Northern Peninsula north of Gros Morne National Park were heated to temperatures in excess of 1OO°C. In contrast, the rocks of the Port au Port Peninsula show temperatures below 1OO°C (Figs. 10, 11). One anomalous locality in the Aguathuna-Lead Cove area in the eastern Port au Port Peninsula (Fig. 11) with values of 65-187°C is thought to be a Carboniferous hydrothermal system (von Bitter et al., 1990).

5. Controls on thermal maturity
Possible controls that might have had an influence on thermal maturities of rocks examined during the present study include sedimentary burial, structural burial, duration of heating, hydrothermal systems and hotspots. On the Port au Port Peninsula, low R_o and TAI values indicate that sediment burial depths for

the late Ordovician to Carboniferous strata were probably never much more than 1 km. This somewhat surprising figure suggests that sedimentation during the Carboniferous was almost entirely restricted to fault- bounded basins such as the Deer Lake Basin and St. George Subbasin and also that only a relatively thin structural allochthon slice was ever present. Earlier Cambrian sediments have TAI's of 2.22-2.9, in contrast to those of Middle Ordovician age which yield values of 1.01-1.77; if a typical geothermal gradient of about 2.5°C per 100 m of burial is adopted, such a change falls broadly within the range that would be expected.

Higher thermal maturity values in autochthonous strata east of the Port au Port Peninsula and on the Northern Peninsula are probably due more to structural control than sedimentary burial, and indicate the subsequent emplacement of overlying allochthonous thrust sheets. On a smaller scale, the anticipated increase in thermal maturity from west to east within the Cow Head Group passing across thrust sheets towards the Long Range Mountain is not conclusively demonstrated by either R_o or TAI values. It is interesting to note that allochthonous strata structurally overlying the autochthonous units on the Port au Port Peninsula can never have been more than 1 km in thickness, and most probably less.

It is well known that older sediments can be oil producing at considerably lower temperatures than more recent units. Strata 100 million years old may be thermally mature at temperatures of 3O°C or less (Fig. 7), but little work has been carried out to compare oil producing rocks of Lower Paleozoic age, such as the 450-500 Ma sediments involved in the present study. Evidence from the Cow Head Group suggests that organic rich sediments of this age with TAI's as low as 1.25 and Graptolite Reflectance R_o's of 0.53-0.57% are thermally mature, and evidently at the optimum conditions for oil generation, despite having been subjected only to paleotemperatures of less than 3O°C. Further detailed study is evidently required to investigate such findings.

Von Bitter et al. (1990) documented the presence of hydrothermal vent communities in the Aguathuna region of the eastern Port au Port Peninsula; this apparently explains the anomalously high TAI and fluid inclusion values found in that area (Fig. 11), and implies the existence of higher than normal heat flows at that time.

The final control reported to have had an effect on thermal values was the presence of a Mesozoic hotspot hypothesised by Nowlan and Barnes (1987b), which they employed in order to explain anomalous gradients in CAI values in both Quebec and western Newfoundland. It is here, however, considered unnecessary to invoke such mechanisms to explain thermal maturity data in western Newfoundland.

Thermal Maturity and Organic Content of Potential Lower Paleozoic Autochthonous Source Rocks In Western Newfoundland

A discussion of possible autochthonous sources was given by Sinclair (1990, pp. 27- 31), but his study lacked thermal maturity data. The section here includes reference to his discussion, but incorporates thermal maturity results based on reflectance, TAI and CAI studies. Additional results from samples collected during the present study and submitted to Mobil Oil Canada for TOC testing should add to these conclusions.

The early Cambrian Labrador Group sediments of the Bradore, Forteau and Hawkes Bay formations generally comprise coarse siliciclastics and subordinate carbonates deposited under well oxygenated conditions, although a few finer grained, darker lithologies occur locally. An over mature sample of deformed black shale from the Forteau Formation collected by Sinclair (1990) from Highway 430 near Gros Morne Mountain (Fig. 1; also see sample # 91031 of this study) proved to be thermally overmature and to have a very low organic content (0.01-0.05% TOC). Corkin (1965) recorded bituminous black shales and dark brown limestones from the Forteau Formation immediately east of the Table Mountain anticline, but his observations have not since been rechecked. Samples from the Hawkes Bay and Forteau formations collected from roadcuts along Highway 430 between Wiltondale and Rocky Harbour during the present study were generally devoid of organic material; the only sample to yield useable particulate matter confirmed that the rocks in this area are overmature.

According to Sinclair (1990, p. 29), the overlying March Point Formation of the Port au Port Group has low TOC's varying from 0.12-0.15% at the base to 0.08% at the top, with even lower TOC levels in the following Petit Jardin Formation (0.03-0.04%). These data are somewhat at odds with our own observations on samples collected during the present study, which appear to contain appreciable amounts of particulate organic matter in the March Point Formation. TAI and fluorescence data indicate that this units fans within the oil window, suggesting that it might form a potential Type I or Type II source rock should sufficient organic material be present. Unlike most other potential units, it stratigraphically underlies possible reservoir rocks in the St. George Group.

The remainder of the Port au Port Group, including the Berry Head Formation, comprises pale grey carbonates and dolostones and appears likely to be totally devoid of organic material based on field observations, as do the Watts Bight and Boat Harbour formations of the St. George Group.

Sinclair (1990, pp. 30-31) suggested that based on work by Knight (1977), the Laignet Point member of the Catoche Formation in the Port au Choix area might have potential as a source rock, but included no TOC data. The presence of several graptolitic horizons throughout the Catoche Formation (Williams et al., 1987) perhaps indicates somewhat more anoxic conditions during the deposition of this unit. Several samples were collected from this interval for TOC analysis during the present study (Fig. 13); a TAI of 2.95 and Graptolite Reflectance R_o of 1. 11% suggests mature organics. An equivalent organic-rich interval does not appear to have been recorded from the Port au Port area, although a 50 m petroliferous dolostone interval is widespread (Knight and Cawood, 1991, p. 309).

Although dark, fine-grained, graptolitic dolostones occur at the base of the Aguathuna Formation just north of Table Point (Williams et al., 1987), almost all of the unit is composed of very pale grey dolomitic carbonates and is unlikely to have any measurable organic content either on the Northern Peninsula or the Port au Port Peninsula. The overlying Table Point Member of the Table Point Group is composed of slightly darker, less dolomitic carbonates, but the rich shelly macrofauna and sediment types clearly point to deposition in a shallow, well-oxygenated environment. One graptolitic lamina was, however, located at Point Riche on the Port au Choix peninsula, and the unit may possibly have some organic content.

The level of organic material clearly increases upwards through the Table Head Group, with dark grey to black, graptolitic shales making up much of the Table Cove Formation on both the Northern Peninsula and Port au Port Peninsula. Sinclair (1990, p. 27) recorded an average TOC of 0.82% for this unit, which is marginally mature in much of the latter area. The transition into the overlying Black Cove Formation represents a continued increase in proportion of black shale, TOC s up to 1.25% (Sinclair, 1990, p. 28). The Black Cove Formation varies from marginally mature to mature passing from west to east across the Port au Port Peninsula and adjacent areas (Fig. 10); along with the laterally equivalent Cape Cormorant Formation, which contains similar black shales as a major component, it is here considered to have the best potential as a source rock in the Port au Port area. In the Daniel s Harbour-Port au Choix region, TAI s, graptolite reflectances and CAI s suggest that the units are overmature.

The remaining Goose Tickle Group (of which the Black Cove Formation is the basal unit) and the Mainland Sandstone Formation are composed predominantly of green-grey sandstones, which although locally graptolitic do not appear to contain appreciable organic material. The Middle Ordovician Lourdes Formation of the parautochthonous Long Point Group comprises a series of pale grey carbonates with little potential for organic preservation; the overlying Winterhouse Formation, composed of medium to fine-grained siliciclastics does, however, contain some darker, apparently organic-rich intervals, some of which are graptolitic (Bergstrom et al., 1974). One sample was submitted for TOC analysis during the present study (#91056) but the TAI of 1.02 suggests only immature organics, and it is thus doubtful that this unit represents a potential source rock.

The remaining Clam Bank Formation, and predominantly fluvial late Devonian- Carboniferous Red Island formation and Codroy Group in the Port au Port region are unlikely to contain sufficient organic material for them to be considered as potential source rocks, although rare palynomorphs and other organic matter were recovered from both the latter units during the present study.

In summary, the highest TOC levels appear to occur in the Black Cove and Cape Cormorant formations, and these are marginally mature to mature on the Port au Port Peninsula, suggesting a potential hydrocarbon source. The Forteau and March Point formations may represent locally developed Cambrian sources, but their potential has yet to be demonstrated in terms of TOC data, as has that of the Catoche and Winterhouse formations.

Age and Stratigraphy of Red Island

Red Island has received scant attention in previous geological studies on the Port au Port Peninsula; in fact, the only published record appears to be by Riley (1962, p. 33) who stated merely that the beds at Red Island and at Cape St. George to the south were comprised of red and green conglomerate containing porphyry clasts and unfossiliferous, cross-bedded sandstone. He remarked that such lithologies differed from those of the Codroy Group, but included them within that unit pending further study.

The island is only 1 km in breadth at its widest point, and surrounded by largely inaccessible cliffs some 30 m high. The centre of the island is an almost flat, grassy plateau. The strata dip at about 5° to the north or NNW. The oldest sediments, on the shore facing the mainland just under 2 km to the southeast, are composed of poorly consolidated conglomerates, dominated by well-rounded, cobbles of siliceous igneous rock. Rare clasts of other material include green sandstone; a few pebbles of similar composition retrieved from the shingle beach directly below the cliff, which had almost certainly been derived from the conglomerates, contained fragmentary fossil plant material which yielded R_o values of 0.57%, and palynomorphs with TAI s varying from 1.5 to 3.5. The conglomerate matrix is composed of iron-rich sandstone, and is channelled by sands with ferrous basal lag deposits at several horizons. No organic material appears to be present in the matrix. Although not entirely age-diagnostic, palynomorphs from the sandstone clasts suggest a likely Devonian age and have a bimodal distribution of TAI values, perhaps indicating fresh and reworked material (see Appendix 5).

The conglomerates are overlain by red and green, heavily channelled and cross-bedded sandstones; a locally developed, narrow, finer-grained, grey interval was located on the westernmost part of the island some 8 m above sea level. This yielded organic matter with TAI of 4.0 and green fluorescence.

A thorough stratigraphic study on the sediments of Red Island is evidently needed; unfortunately, most of the strata are inaccessible due to the steep but poorly consolidated nature of the cliffs, and it is likely that no more than photographic reconaissance will ever prove possible. The brief study made for the present report, however, confirms the lithologically distinct nature of the conglomerate from other stratigraphic units present on the Port au Port Peninsula, and we therefore here assign the strata to an informal Red Island formation. H. Williams (pers. comm., 1992) points out that shingle beaches on the foreshore of the Port au Port Peninsula in that area are dominated by similar silicic igneous clasts to those seen on Red Island, despite a total lack of exposure of such rocks except on the island. He considers that the unit probably extends almost to the foreshore near Mainland, and makes up the shoals which occur just below normal sea level between that community and Red Island. It is thus likely that the sediments were deposited during the late Devonian in a discrete basin distinct from those elsewhere in western Newfoundland, which may have considerable lateral extension offshore in the Gulf of St. Lawrence. The source of igneous clasts within the conglomerates, however, remains an enigma.

Correlation of The Western Newfoundland Sequence With Anticosti Island

The stratigraphy of Anticosti Island was first defined in modern terms by Twenhofel (1928), who divided the sequence into several formations; the oldest of these was the Macasty Shale, which he based entirely on erratic blocks of graptolitic shale found on the northwest of the island. Since that time, a program of drilling has revealed this unit at depth, and earlier formations are now known from both Anticosti and the neighbouring Mingan Islands (Fig. 14; Desrochers, 1985; Desrochers and James, 1988). Although some of these units were deposited at similar times to others in western Newfoundland, they are not, for the most part, readily correlatable, and the presence of major hiatuses at different times generally suggests a lack of close linkage between the two sequences.

The middle part of the Winterhouse Formation correlates broadly with the organic-rich Macasty Formation of Anticosti (Fig. 14; Riva, 1969; Macauley, 1984; Sinclair, 1990, p. 24). The revision of both lithostratigraphy and graptolite biostratigraphy of the Macasty Formation by Riva (1969) indicates that it encompasses a range equivalent to part of the British Caradoc Series and although much thinner, is basically equivalent to the widely developed Utica Formation of the northeastern Appalachians. It is thus evident that the Winterhouse Formation is unrelated to the Macasty or Utica formations, which were deposited in a continually subsiding, anoxic basin extending southwards from Quebec into New York State.

Sedimentary equivalents to the succeeding thick succession of platform carbonates spanning the Upper Ordovician and Lower Silurian on Anticosti Island are lacking in western Newfoundland.

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Appendix 1: Thermal Maturity Values of Mocan Samples

Autochthonous rocks, Port au Port Peninsula

Samp#	Field#	Lithostrat.	Age	Location	Toc	TAI	Flu	Ro% (s.d.)
84091	RH278	Codroy Gp.	Visean	Aguathuna		2.10	2.43(B)	0.65
84092	RH279	Codroy Gp.	Visean	Aguathuna		2.03	2.30(B)	
84093	RH280	Codroy Gp.	Visean	Boswarlos		2.40	2.54(B)	0.58
91056	26/6/91-6	Winterhouse Fm	Caradoc	Lourdes		1.02	Blue	

	26/6/91-3	Cape Cormorant Fm	Llanvirn	Mainland	*			
91042	6/6/91-5	Cape Cormorant Fm	Llanvirn	Mainland	*	1.35	Blue	
V91003	6/6/91-5	Cape Cormorant Fm	Llanvirn	Mainland				0.72 (0.09)
91025	6/6/91-6	Cape Cormorant Fm	Llanvirn	Mainland	*	1.01	Blue	
V91002	6/6/91-6	Cape Cormorant Fm	Llanvirn	Mainland				0.74 (0.06)
	26/6/91-4	Cape Cormorant Fm	Llanvirn	Mainland	*			
V91001	26/6/91-5	Cape Cormorant Fm	Llanvirn	Mainland	*			0.70 (0.07)
91043	6/6/91-4	Black Cove Fm	Llanvirn	West Bay Quarry	*	1.48	Blue	
V91004	6/6/91-4	Black Cove Fm	Llanvirn	West Bay Quarry				0.73 (0.12)
91026	6/6/91-3a	Table Cove Fm	Llanvirn	West Bay Quarry	*	1.49	Blue	
V91005	6/6/91-3a	Table Cove Fm	Llanvirn	West Bay Quarry				0.67 (0.10)
91041	6/6/91-3b	Table Cove Fm	Llanvirn	Shore below WBQ	*	1.77	2.19	
V91006	6/6/91-3b	Table Cove Fm	Llanvirn	Shore below WBQ				0.85 (0.08)
91029	5/6/91-7	Boat Harbour Fm	Tremadoc	Isthmus Bay	*			
91030	5/6/91-6	Watts Bight Fm	Tremadoc	Isthmus Bay	*	2.33	3.20	
91046	5/6/91-5	Port au Port Gp?	Ur Cambrian	Isthmus Bay	*			
91044	6/6/91-2	Petit Jardin Fm	Mid Cambrian	March Point	*	2.90	4.00	

91028	6/6/91-1	March Point Fm	Mid Cambrian	Degras	*	2.59	3.73	
91027	6/6/91-1a	March Point Fm	Mid Cambrian	Degras	*	2.22	3.61	
91038	26/6/91-1	ss boulders on beach	?	Red Island		2.47	2.87 reworked?	
V91007	26/6/91-1	ss boulders on beach	?	Red Island				0.52 (0.09)
91053	26/6/91-2	silt interbeds in situ	?	Red Island		4.00	Green	

Autochthonous (& allochthonous?) rocks, Stephenville area

Samp#	**Field#**	**Lithostrat.**	**Age**	**Location**	**Toc**	**TAI**	**Flu**	**Ro% (s.d.)**
91045	5/6/91-8a	Black Cove Fm	Lanvirn	Black Cove oil tanks	*	2.00	2.69	
V91008	5/6/91-8a	Black Cove Fm	Lanvirn	Black Cove oil tanks				0.54 (0.11)
91049	5/6/91-8b	Black Cove Fm	Lanvirn	Black Cove oil tanks	*	2.50	3.63	
V91009	5/6/91-8b	Black Cove Fm	Lanvirn	Black Cove oil tanks				0.70 (0.11)
91037	5/6/91-8b	Mainland Sandstone	Lanvirn	Black Cove oil tanks	*	1.87	3.49	
91057	26/6/91-9	Goose Tickle Gp	Lanvirn	Cold Pond	*	2.60	4.00	
V91010	26/6/91-9	Goose Tickle Gp	Lanvirn	Cold Pond				1.35 (0.16)
91058	27/6/91-1	?	?	Road to Gallants		4.00	4.00	
91055	26/6/91-2	Table Cove Fm?	?Lanvirn	TCH, Georges Lake	*	4.00	4.00	
	26/6/91-8a	bituminous ss	?	Point au Mal	*			
92001	26/6/91-8b	bituminous silt/shale	?	Point au Mal	*	2.70	3.40	

Autochthonous Rocks, Northern Peninsula

Samp#	**Field#**	**Lithostrat.**	**Age**	**Location**	**Toc**	**TAI**	**Flu**	**Ro% (s.d.)**
	27/6/91-4a	Black Cove Fm	Lanvirn	Spundgells Cove	*			
V91011	27/6/91-4a	Black Cove Fm	Lanvirn	Spundgells Cove				0.96 (0.15)
	27/6/91-4b	Black Cove Fm	Lanvirn	Spundgells Cove	*	2.50	3.63	
	27/6/91-4c	Black Cove Fm	Lanvirn	Spundgells Cove	*			
85280		Black Cove Fm	Lanvirn	US Borax DD #2-55m		3.14	4.00	
85278		Black Cove Fm	Lanvirn	Dn.H.DD #1382-170'		>3.0	4.00	ca. Barren
V91012		Table Cove Fm	Lanvirn	Table Point	*			1.39 (0.14)
85272		Table Cove Fm	Lanvirn	Table Cove		//	//	Barren
91034	4/6/91-3	Table Cove Fm	Lanvirn	Point Riche	*	3.80	4.00	ca. Barren
V91013	4/6/91-3	Table Cove Fm	Lanvirn	Point Riche				1.77 (0.05)
V91014	will etal ‘87	Aguathuna Fm	Lr Arenig	Table Point	*			1.90 (0.15)
91035	4/6/91-2a	Catoche Fm	Lr Arenig	Laignet Point	*			
91051	4/6/91-2b	Catoche Fm	Lr Arenig	Laignet Point	*	2.95	4.00	
V91015	will etal ‘87	Catoche Fm, Hor. H	Lr Arenig	Laignet Point	*			1.11 (0.08)
	will etal ‘87	Catoche Fm, Hor. H	Lr Arenig	Laignet Point	*			
	will etal ‘87	Catoche Fm, Hor. H	Lr Arenig	Laignet Point	*			
91050	4/6/91-1a	Boat Harbour Fm	Tremadoc	Barbace Cove	*			
91036	4/6/91-1b	Boat Harbour Fm	Tremadoc	Barbace Cove	*	3.40	4.00	ca. Barren

91031	5/6/91-4	Forteau Fm	Lr Cambrian	Highway 430	*			
91047	5/6/91-3	Forteau Fm	Lr Cambrian	Shoal Cove Brook	*	//	//	Barren
91032	5/6/91-2	Hawkes Bay Fm?	Lr Cambrian	Shoal Cove Brook	*			
91033	5/6/91-1a	Hawkes Bay Fm?	Lr Cambrian	S of Mill Brook	*	4.00	4.00	ca. Barren
91048	5/6/91-1b	Hawkes Bay Fm?	Lr Cambrian	S of Mill Brook	*	4.00	4.00	ca. Barren

Allochthonous rocks, Northern Peninsula

Samp#	**Field#**	**Lithostrat.**	**Age**	**Location**	**Toc**	**TAI**	**Flu**	**Ro% (s.d.)**
91052	4/6/91-4a	Cow Head Gp	Ur Cambrian	Green Point	*	1.25	Blue	
	4/6/91-4b	Cow Head Gp	Ur Cambrian	Green Point	*			
V91016		Cow Head Gp	Tremadoc	Green Point, GP26	*			0.51 (0.06)
85245		Cow Head Gp	Arenig	Green Point, GP47A	*	2.07	Blue	
V91017		Cow Head Gp	Arenig	Green Point, GP47A				0.69 (0.08)
	27/6/91-3c	Cow Head Gp	Ur Cambrian	Martin Point, MPS36B	*			
91040	27/6/91-3b	Cow Head Gp	Ur Cambrian	Martin Point, MPS36B	*			
91054	27/6/91-3a	Cow Head Gp	Ur Cambrian	Martin Point, MPS36D	*	1.44	Blue	
85237		Cow Head Gp	Ur Tremadoc	Martin Point, MPS42B	*			
V91018		Cow Head Gp	Ur Tremadoc	Martin Point, MPS42B				0.56 (0.10)
		Cow Head Gp	Ur Arenig	Martin Point, MPS58	*			
V91019		Cow Head Gp	Ur Arenig	Martin Point, MPS58				0.55 (0.08)
85238		Cow Head Gp	Ur Tremadoc	W. Brook Pd., WBN4	*	2.10	2.49	(faint blue)

V91020		Cow Head Gp	Ur Tremadoc	W. Brook Pd., WBN4				0.59 (0.06)
85232		Cow Head Gp	Ur Arenig	W. Brook Pd., WBS52A	*			
V91021		Cow Head Gp	Ur Arenig	W. Brook Pd., WBS52A				0.63 (0.05)
		Cow Head Gp	Tremadoc	Broom Point, BPN77	*			
85242		Cow Head Gp	Ur Tremadoc	St. Pauls, SPN43A	*	2.29	3.21	
V91022		Cow Head Gp	Ur Tremadoc	St. Pauls, SPN43A				0.53 (0.11)
85224		Cow Head Gp	Ur Arenig	St. Pauls, SPS 7 or 10	*			
V91023		Cow Head Gp	Ur Arenig	St. Pauls, SPS 7 or 10				0.53 (0.05)
85235		Cow Head Gp	Ur Tremadoc	Cow Head, CHN32	*	1.73	2.36 (Blue)	
V91024		Cow Head Gp	Ur Tremadoc	Cow Head, CHN32			0.57 (0.04)	
		Cow Head Gp	Ur Arenig	Cow Head, CHS13.6	*			
V91025		Cow Head Gp	Ur Arenig	Cow Head, CHS13.6			0.56 (0.07)	

nb. Samples marked as "ca.Barren" have been assigned TAI values from amorphous material * in TOC column indicates TOC sample sent to MOCAN
Figures in parentheses in Ro% column indicate standard deviations

Appendix 2: Sample Locations and Stratigraphy

V91001 Top of Cape Cormorant Fm., 200 m above base, north of Caribou Brook, Mainland, Port au Port Peninsula (see Knight and Cawood, 1991 stop 26, fig. 81). Black graptolitic shale.

V91002 Cape Cormorant Fm., 146 m above base, north of Caribou Brook, Mainland, Port au Port Peninsula (see Knight and Cawood, 1991 stop 26, fig. 81). Black graptolitic shale.

V91003 Cape Cormorant Fm., 139 m above base, north of Caribou Brook, Mainland, Port au Port Peninsula (see Knight and Cawood, 1991 stop 26, fig. 81). Black graptolitic shale.

V91004 Black Cove Fm. at top end of West Bay Centre quarry, Port au Port Peninsula (see Knight and Cawood, 1991 stop 25). Black graptolitic shale.

V91005 Table Cove Fm. in West Bay Centre quarry, Port au Port Peninsula (see Knight and Cawood, 1991 stop 25). Black graptolitic shale.

V91006 Table Cove Fm. along shoreline below West Bay Centre quarry, Port au Port Peninsula (see Knight and Cawood, 1991 stop 25). Black graptolitic shale.

V91007 Grey-green, laminated, plant-bearing sandstone cobbles on beach; probably derived from neighbouring conglomerate cliffs in Red Island fm. Shingle beach on east shore of Red Island, west of Mainland, Port au Port Peninsula.

V91008 Black Cove Fm. in quarry adjacent to old oil tanks at Black Cove, 3 km north along Highway 462 from junction with main Stephenville-Port au Port road (see Knight and Cawood, 1991 stop 28). Black graptolitic shale.

V91009 Top of Black Cove Fm. in quarry adjacent to old oil tanks at Black Cove, 3 km north along Highway 462 from junction with main Stephenville-Port au Port road (see Knight and Cawood, 1991 stop 28). Silty, black graptolitic shale.

V91010 Black, graptolitic silt in Goose Tickle Group from quarry alongside forest track north of Cold Pond and 5 km ENE of Stephenville Airport (fossil locality marked on Williams, 1985).

V91011 Black Cove Fm., Spudgells Cove, 6 km NNE of Daniel s Harbour (see Stenzel et al., 1990, fig. 3). Black shale.

V91012 Table Cove Fm., Table Point (see Knight and Cawood, 1991 stop 8, fig. 55). black shale.

V91013 Table Point Fm., Point Riche, Port au Choix peninsula (see Knight and Cawood, 1991, fig. 51). Dark grey, graptolitic mudstone laminae in limestone.

V91014 Aguathuna Fm., Table Point (see Knight and Cawood, 1991 stop 8, fig. 55). Dark grey, graptolitic dolostone.

V91015 Catoche Fm., 103 m above base, Laignet Point, Port au Choix peninsula (horizon H of Williams et al., 1987, fig. 2; see Knight and Cawood, 1991 stop 6, fig. 53). Dark grey, graptolitic mudstone laminae in limestone.

V91016 Basal Broom Point Member (unit GP26 of James and Stevens, 1986), Green Point Fm., Cow Head Group, Green Point (see Knight and Cawood, 1981 top 12, fig. 65). Black graptolitic shale.

V91017 Low St. Pauls Member (unit GP47 of James and Stevens, 1986), Green Point Fm., Cow Head Group, Green Point (see Knight and Cawood, 1981 stop 12, fig. 65). Black graptolitic shale.

V91018 Top Broom Point Member (unit MPS42B of James and Stevens, 1986), Green Point Fm., Cow Head Group, Martin Point (see Knight and Cawood, 1981 stop 11, fig. 64). Black graptolitic shale.

V91019 High St. Pauls Member (unit MPS58 of James and Stevens, 1986), Green Point Fm., Cow Head Group, Martin Point (see Knight and Cawood, 1981 stop 11, fig. 64). Black graptolitic shale.

V91020 Top Broom Point Member (unit WBN4 of James and Stevens, 1986), Green Point Fm., Cow Head Group, north side of Western Brook on Western Brook Pond (see James and Stevens, 1968, fig. 10). Black graptolitic shale.

V91021 High St. Pauls Member (unit WBS52 of James and Stevens, 1986), Green Point Fm., Cow Head Group, south side of Western Brook on Western Brook Pond (see James and Stevens, 1968, fig. 10). Black graptolitic shale.

V91022 Top Broom Point Member (unit SPN43 of James and Stevens, 1986), Green Point Fm., Cow Head Group, North Tickle, St. Pauls Inlet (see James and Stevens, 1968, fig. 14). Black graptolitic shale.

V91023 High St. Pauls Member (unit SPS10 of James and Stevens, 1986), Green Point Fm., Cow Head Group, North Tickle, St. Pauls Inlet (see James and Stevens, 1968, fig. 14). Black graptolitic shale.

V91024 High Stearing Island Member (unit CHN32 of James and Stevens, 1986), Shallow Bay Fm., Cow Head Group, The Ledge, Cow Head Peninsula (see Knight and Cawood, 1981 stop 10, loc. 4, figs. 60, 61). Black graptolitic shale.

V91025 High Factory Cove Member (unit CHS13.6 of James and Stevens, 1986), Shallow Bay Fm., Cow Head Group, Jim s Cove, Cow Head Peninsula (see Knight and Cawood, 1981, figs. 60, 62). Black graptolitic shale.

84019 Codroy Gp., Aquathuna, Port au Port Peninsula (see Knight and Cawood, 1981, fig. 77).

84092 Codroy Gp., Aquathuna, Port au Port Peninsula (see Knight and Cawood, 1981, fig. 77).

84093 Codroy Gp., Boswarlos, Port au Port Peninsula.

85224 High St. Pauls Member (unit SPS 10 of James and Stevens, 1986), Green Point Fm., Cow Head Group, North Tickle, St. Pauls Inlet (see James and Stevens, 1968, fig. 14). Black graptolitic shale.

85232 High St. Pauls Member (unit WBS52 of James and Stevens, 1986), Green Point Fm., Cow Head Group, south side of Western Brook on Western Brook Pond (see James and Stevens, 1968, fig. 10). Black graptolitic shale.

85235 High Stearing Island Member (unit CHN32 of James and Stevens, 1986), Shallow Bay Fm., Cow Head 'Group, The Ledge, Cow Head Peninsula (see Knight and Cawood, 1981 stop 10, loc. 4, figs. 60, 61). Black graptolitic shale.

85237 Top Broom Point Member (unit MPS42B of James and Stevens, 1986), Green Point Fm., Cow Head Group, Martin Point (see Knight and Cawood, 1981 stop 11, fig. 64). Black graptolitic shale.

85238 Top Broom Point Member (unit WBN4 of James and Stevens, 1986), Green Point Fm., Cow Head Group, north side of Western Brook on Western Brook Pond (see James and Stevens, 1968, fig. 10). Black graptolitic shale.

85242 Top Broom Point Member (unit SPN43 of James and Stevens, 1986), Green Point Fm., Cow Head Group, North Tickle, St. Pauls Inlet (see James and Stevens, 1968, fig. 14). Black graptolitic shale.

85245 Low St. Pauls Member (unit GP47 of James and Stevens, 1986), Green Point Fm., Cow Head Group, Green Point (see Knight and Cawood, 1981 stop 12, fig. 65). Black graptolitic shale.

85272 Table Point Fm., Table Point (see Knight and Cawood, 1991 stop 8, fig. 55). black shale.

85278 Black Cove Fm., Daniels Harbour zinc Mine DD hole # 1382, at 170, north of Daniels Harbour.

85280 Black Cove Fm, US Borax DD hole #2, at 55 m, north of Daniels Harbour.

91025 Cape Cormorant Fm., 146 m above base, north of Caribou Brook, Mainland, Port au Port Peninsula (see Knight and Cawood, 1991 stop 26, fig. 81). Black graptolitic shale.

91026 Table Cove Fm. in West Bay Centre quarry, Port au Port Peninsula (see Knight and Cawood, 1991 stop 25). Black graptolitic shale.

91027 Basal March Point Fm. (unit 1 of Chow and James, 1987), 1 km west of Degras, Port au Port Peninsula (see Knight and Cawood, 1991 stop 23, fig. 78). Grey siltstone.

91028 Basal March Point Fm. (unit 1 of Chow and James, 1987), 1 km west of Degras, Port au Port Peninsula (see Knight and Cawood, 1991 stop 23, fig. 78). Grey siltstone.

91029 Boat Harbour Fm., 17 m above base, Isthmus Bay, Port au Port Peninsula (see Knight and Cawood, 1991 stop 21, fig. 74). Grey mudstone.

91030 Watts Bight Fm., 15 m above base, Isthmus Bay, Port au Port Peninsula (see Knight and Cawood, 1991 stop 21, fig. 74). Grey mudstone.

91031 Devil s Cove Mbr., Forteau Fm., Road cut along Highway 430 midway between Wiltondale and Rocky Harbour (see Knight and Cawood, 1991 stop 1). Grey siltstone.

91032 Dark grey silty shale in Hawkes Bay Fm.?, roadcut along Highway 430 at Shoal Cove Brook, 10 km southest of Rocky Harbour.

91033 Dark grey silty shale in Hawkes Bay Fm.?, roadcut along Highway 430, 100 m south of Mill Brook, 11.5 km southest of Rocky Harbour.

91034 Table Point Fm., Point Riche, Port au Choix peninsula (see Knight and Cawood, 1991, fig. 51). Dark grey, graptolitic mudstone laminae in limestone.

91035 High in Catoche Fm., Laignet Point, Port au Choix peninsula (see Knight and Cawood, 1991 stop 6, fig. 53). Dark grey limestone.

91036 Low Barbace Cove Mbr., Boat Harbour Fm., Barbace Cove, Port au Choix peninsula (see Knight and Cawood, 1991 stop 6, fig. 52). Grey algal boundstone.

91037 Base of Mainland Sandstone in quarry adjacent to old oil tanks at Black Cove, 3 km north along Highway 462 from junction with main Stephenville-Port au Port road (see Knight and Cawood, 1991 stop 28). Silty, black graptolitic shale.

91040 Basal Martin Point Member (unit MPS36B of James and Stevens, 1986), Green Point Fm., Cow Head Group, Martin Point (see Knight and Cawood, 1981 stop I 1, fig. 64). Dark grey shale.

91041 Table Cove Fm. along shoreline below West Bay Centre quarry, Port au Port Peninsula (see Knight and Cawood, 1991 stop 25). Black graptolitic shale.

91042 Cape Cormorant Fm., 139 m above base, north of Caribou Brook, Mainland, Port au Port Peninsula (see Knight and Cawood, 1991 stop 26, fig. 81). Black graptolitic shale.

91043 Black Cove Fm. at top end of West Bay Centre quarry, Port au Port Peninsula (see Knight and Cawood, 1991 stop 25). Black graptolitic shale.

91044 Campbells Mbr., Petit Jardin Fm. at base of boat ramp, Big Cove, 1.4 km from March Point (see Knight and Cawood, 1991, stop 24). Dark grey siltstone.

91045 Black Cove Fm. in quarry adjacent to old oil tanks at Black Cove, 3 km north along Highway 462 from junction with main Stephenville-Port au Port road (see Knight and Cawood, 1991 stop 28). Black graptolitic shale.

91046 Top of Port au Port Gp., Isthmus Bay, Port au Port Peninsula just west of Knight and Cawood, 1991 stop 21). Algal boundstone.

91047 Dark grey mudstone in Forteau Fm., roadcut along Highway 403 at Shoal Cove Brook 10 km, southeast of Rocky Harbour.

91048 Dark grey silty shale in Hawkes Bay Fm.?, roadcut along Highway 403 100 m south of Mill Brook, 11.5 km southeast of Rocky Harbour.

91049 Top of Black Cove Fm. in quarry adjacent to old oil tanks at Black Cove, 3 km north along Highway 462 from junction with main Stephenville-Port au Port road (see Knight and Cawood, 1991 stop 28). Silty, black graptolitic shale.

91050 Low Barbace Cove Mbr., Boat Harbour Fm., Barbace Cove, Port au Choix peninsula (see Knight and Cawood, 1991 stop 6, fig. 52). Grey algal boundstone.

91051 High in Catoche Fm., Laignet Point, Port au Choix peninsula (see Knight and Cawood, 1991 stop 6, fig. 53). Dark grey limestone.

91052 High Martin Point Member, Green Point Fm., Cow Head Group, Green Point (see Knight and Cawood, 1981 top 12, fig. 65). Grey silty shale.

91053 Grey-green, cross-laminated siltstone/sandstone in middle part of Red Island fm. Lower part of cliff on west shore of Red Island, west of Mainland, Port au Port Peninsula.

91054 Basal Martin Point Member (unit MPS36D of James and Stevens, 1986), Green Point Fm., Cow Head Group, Martin Point (see Knight and Cawood, 1981 stop 11, fig. 64). Dark grey shale.

91055 Table Cove Fm.?, exposure on southeast side of TCH at inlet on Georges Lake, 22 km SSW of Cornerbrook. Deformed, dark grey mudstone.

91056 High Winterhouse Fm., top of waterfall along shoreline at Lourdes, 400 m northwest of school.

91057 Black, graptolitic silt in Goose Tickle Group from quarry alongside forest track north of Cold Pond and 5 km ENE of Stephenville Airport (fossil locality marked on Williams, 1985).

91058 Grey mudstone in cliff exposure on east side of road from TCI-L to Gallants, 2 km south of Gallants and 6 km southwest of Georges Lake. Table Head or St. George Gp.?

92001 Bituminous silt/shale from exposure in allochthon along shoreline near Point au Mal, southwest of Two Guts Pond and 9 km NNE of junction between Highway 462 and main Stephenville-Port au Port road (bitumin locality marked on Williams, 1985).

Appendix 3: Thermal Alteration Index Data

Appendix 3a (pdf - 199kb)	Appendix 3b (pdf - 192kb)	Appendix 3c (pdf - 202kb)
Appendix 3d (pdf - 66kb)	Appendix 3e (pdf - 215kb)	Appendix 3f (pdf - 108kb)
Appendix 3g (pdf - 192kb)	Appendix 3h (pdf - 159kb)	Appendix 3i (pdf - 62kb)
Appendix 3j (pdf - 172kb)	Appendix 3k (pdf - 153kb)	Appendix 3l (pdf - 143kb)
Appendix 3m (pdf - 172kb)	Appendix 3n (pdf - 186kb)	Appendix 3o (pdf - 134kb)

Appendix 4: Vitrinite Ro Data

Data of Mean Reflectance (with Standard Deviation) Measured on Graptolite or VLM (Vitrinite-Like Materials) Grains

Sample Number	Graptolite/VLM Reflectance		
	Mean (% R_o)	Std. Dev.	Number of Measured Points
V91001	0.70	0.07	46
V91002	0.74	0.06	51
V91003	0.72	0.09	60
V91004	0.73	0.12	50
V91005	0.67	0.10	50
V91006	0.85	0.08	51
V91007	0.52	0.09	56
V91008	0.54	0.11	22
V91009	0.70	0.11	37
V91010	1.35	0.16	28
V91011	0.96	0.15	10
(Doubtful data, limited grains)			
V91012	1.39	0.14	50
V91013	1.77	0.05	5
(Doubtful data, limited grains)			
V91014	1.90	0.15	5
(Doubtful data, limited grains)			
V91015	1.11	0.08	4
(Doubtful data, limited grains)			
V91016	0.51	0.06	50
V91017	0.69	0.08	50
V91018	0.56	0.10	28
V91019	0.55	0.08	21
V91020	0.59	0.06	50
V91021	0.63	0.05	50
V91022	0.53	0.11	50
V91023	0.53	0.05	52
V91024	0.57	0.04	50
V91025	0.56	0.07	51

Reflectance Histograms

91001-91002 (pdf - 155kb) 91003-91004 (pdf - 164kb) 91005-91005 (pdf - 163kb)

91007-91008 (pdf - 148kb) 91009-91010 (pdf - 141kb) 91011-91012 (pdf - 138kb)

91013-91014 (pdf - 109kb) 91015-91016 (pdf - 128kb) 91017-91018 (pdf - 146kb)

91019-91020 (pdf - 142kb) 91021-91022 (pdf - 156kb) 91023-91024 (pdf - 159kb)

91025 (pdf - 84kb)

Appendix 5: Red Island Palynology (With Plate)

Red Island is a prominent island located about two kilometres off Cape Cormorant. Physically, the island is a flat plateau surrounded by red sea cliffs 25 m high. Strata in the sea cliffs are predominantly pebble and cobble conglomerate beds; red sandstone and siltstone beds are far less common (Plate 6).

Two samples of siltstone collected from Red Island were processed for palynomorphs and slides scanned for species composition and thermal maturation indices. Sample 91053 was barren, whereas sample 91038 contained fossils.

The assemblage identified in sample 91038 consists of Anapiculatisporites sp., Deltoidospora sp., Emphanisporites sp. Retusosporites sp. and scattered and corroded palynomorph debris (Plate 7). Thermal maturation indices for this sample suggests a broad bimodal TAI (mean 2.47; standard deviation 0.81) in the mature zone of hydrocarbon production. The bimodality of the assemblage calls into question the accuracy of the TAI value. The sample may be a mixed assemblage of thermally mature and immature material or an in situ deposit which has become oxidized from groundwater flow.

The species in this sample are by and large Devonian and Carboniferous taxa. This indicates that these beds can be no older than Devonian. If the hypothesis suggesting reworking is rejected and the beds are considered to be an oxidized rock unit which has no mixed and recycled palynomorphs, then the identification of Emphanisporites with the other morphologically simple spores is very significant. Emphanisporites in association with spores lacking grapnel shaped spines is typically found in early and middle Devonian strata. This has broad implications for the interpretation of Acadian structures formed in this area.

Appendix 6: Mining Cores Which Penetrated Possible Autochthonous Sources on The Port Au Port Peninsula

The Newfoundland Department of Mines and Energy has a core repository in Pasadena which is used to house representative materials from mineral exploration and development projects in western Newfoundland. The local contact in Pasadena is Stuart Cochrane (Phone 709-686-2054). In addition, a summary of all Newfoundland drillholes is held by the Newfoundland Department of Mines and Energy in St. John s (contact Janet Gillespie or Norm Mercer, Phone 709-729-6193). For this study, a summary of cores through autochthonous strata on the Port au Port Peninsula which record oil showings is here provided (see Fig. 3 for locations).

Brinex, Victors Brook (1974)
Brinex Open File Report 12B/11 (211). All cores are stored in Springdale. Map sheet 12B/11, DD-Holes 74-24 to 74-33.

Core description in the report refers to the Humber Arm Allochthon, which overlies the autochthonous Table Head Group.

Core	Total Depth	Interval
74-23	120 ft	0-49.5 ft Humber Arm 49.5-120 ft Table Head 57-59 ft Crude oil found in calcite veining - contamination from drilling??
74-25	129 ft	0-91 ft Humber Arm 91-129 ft Table Head, contains crude oil staining in joint at 104.5 ft.
74-32	60 ft	0-7 ft Overburden 7-60 ft Table Head, contains bitumen staining in the upper 7-15 ft.

Brinex, Victors Brook (1978)
Brinex-Freeport Canadian Exploration Ltd. Riofinex Joint Venture. Report on the 1978 Port au Port

Diamond Drilling Program Brinex Doc. No. H78001. Open File Report 12B/11 (227). Cores are stored at Springdale.

Cores which show oil staining:

Core	Total Depth	Interval
78-1	245.7 m	Oil at 32.5 m and 46 m in the lower Table Head.
78-2	236.8 m	Scattered oil showing between 34-157 m in the Table Head.
78-3	267.3 m	Scattered oil showing between 20-46 m in the lower Table Head.
78-4	267.3 m	Scattered oil showing between 54-65 m in the lower Table Head.
78-5	255.1 m	Scattered oil showing between 15-60 m in the lower Table Head.
78-6	264.3 m	Oil at 14 m in the lower Table Head.
78-8	272.5 m	Scattered oil showing between 63-102 m in the lower Table Head.
78-9	239.3 m	Scattered oil showing between 16-94 m and between 158-180 m in the lower Table Head.
78-10	285.6 m	Scattered oil showing between 35-66 m in the lower Table Head.
78-11	267.3 m	Scattered oil showing between 7-263 m in the lower Table Head.

Brinex, Table Mountain
Brinex-Freeport Open File Report 12B (196).
Map sheet 12B/10, core is stored at Springdale

Core	Total Depth	Interval
WK-75-1	189 ft	0-0.1 ft Surface bitumen Core is in limestone of the St.George and Table Head groups.