Geological Survey of Canada
Commission Geologique du Canada

Open File 1502

GEOCHEMISTRY OF ORGANIC-RICH ORDOVICIAN SEDIMENTS ON AKPATOK AND BAFFIN ISLANDS NORTHWEST TERRITORIES

G. Macauley

Contract Serial #23294-6-0667/01-SG

Geological Survey of Canada (Calgary)
3303 - 33 Street NW
Calgary, Alberta T2L 2A7

1987

TABLE OF CONTENTS

FIGURES

APPENDICES

GEOCHEMISTRY OF ORGANIC-RICH ORDOVICIAN SEDIMENTS ON AKPATOK AND BAFFIN ISLANDS, NORTHWEST TERRITORIES

ABSTRACT

Surface exposures of Ordovician strata on southern Baffin Island and Akpatok Island were searched for potential oil shale-source bed intervals. Immature Type II oil shales were encountered in two apparently separate zones on Baffin Island. On Akpatok Island, slightly organic limestones also contain immature Type II kerogen. An earthy dolostone contains Type II marginal to low (?) maturity kerogen in the Rowley M-04 well on Rowley Island.

Although not an objective of this project, the Ordovician succession on southern Baffin Island has been described in three lithologic units, an upper orange knobby limestone, a middle grey elongate nodular limestone section containing blue-grey shales and the organic-rich intervals, and a lower grey-weathering ledge-forming limestone. These units are correlatable to the sections on Akpatok Island and to the Rowley M-04 well on Rowley Island.

INTRODUCTION

The presence of a sequence of carbonate-dominated Lower to Middle Ordovician rocks on the southern part of Baffin Island has been known since the early paleontological reports describing the macrofauna of the Putnam Highland (Fig. 1) by Gould et al. (1928) and of Silliman's Fossil Mount near the settlement of Iqaluit (Frobisher Bay) (Fig. 1) by Roy (1941). Previous faunal collections by C.F. Hall in 1861 and R.W. Porter in 1897 had established the presence of these strata at Silliman's Mount. Miller et al. (1954) contributed much additional macrofaunal detail. A geological reconnaissance of the southern part of the island (Blackadar, 1967) assessed further the macropaleontology of the area. This prime interest in the paleontology is particularly understandable because of the difficulties in defining the stratigraphic position of many sections within the Middle-Upper Ordovician sequences of North America; consequently, these accounts reported only briefly on the lithologies encountered and recorded the sections as undivided Ordovician. Neither oil shales nor organic-rich (bituminous) beds were reported with any precision to be present within the Ordovician beds of southern Baffin Island; however, Roy (1941) did note the presence of black limestones and limy shales in Foxe Land (probably Putnam Highland) and on Blunt Peninsula (Fig. 1), which he correlated to the Collingwood oil shales of southern Ontario. No Ordovician strata were mapped by Blackadar (1967) on Blunt Peninsula.

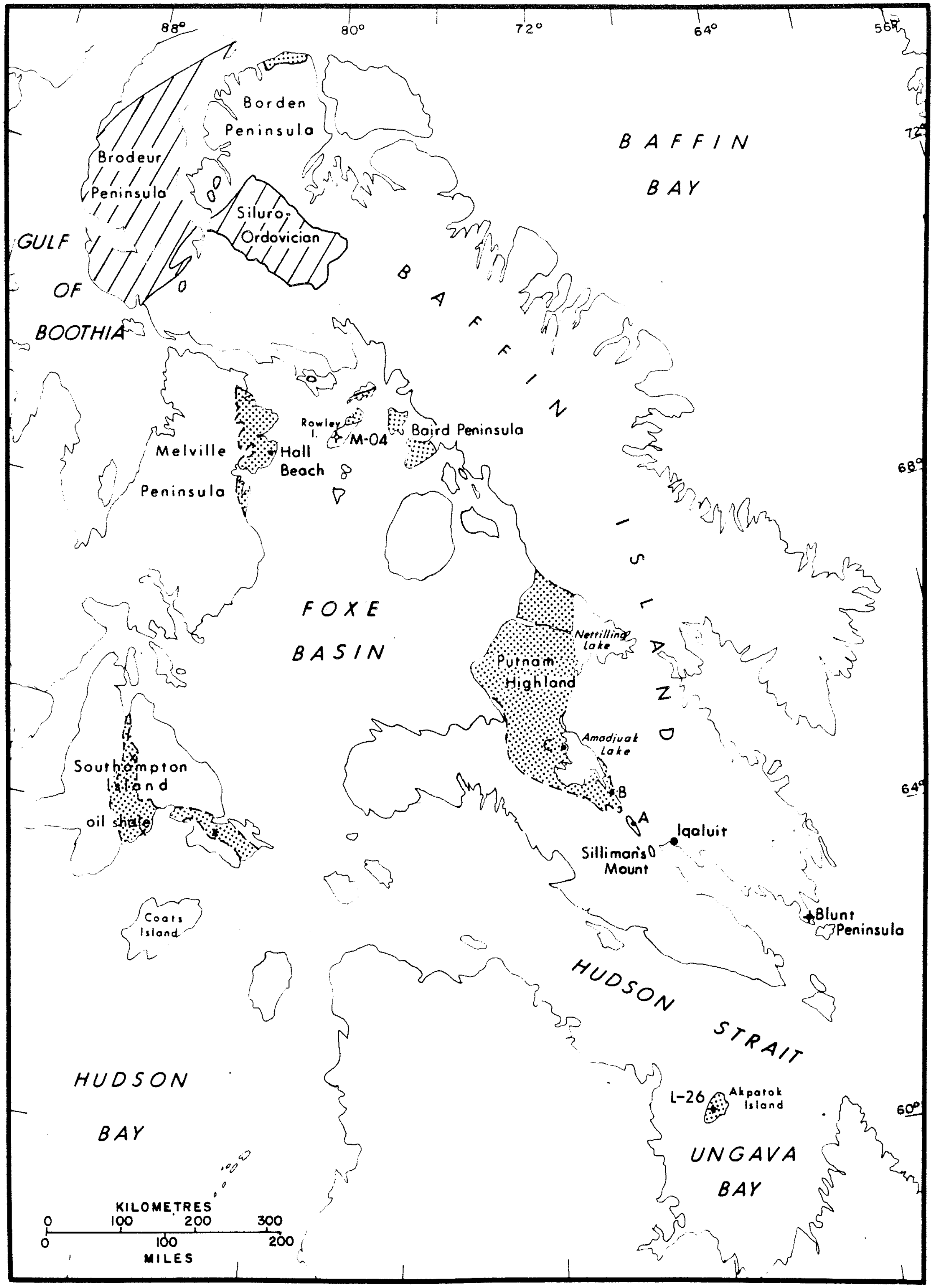

Figure 1: Regional location map.

Brown "bituminous" limestones have been described by Workum et al. (1976) from upper Middle to lower Upper Ordovician beds on Akpatok Island (Fig. 1), located in the northern limits of Ungava Bay, some 400 km south-southeast of the known Ordovician beds on Baffin Island. Oil shales had also been described from Southampton Island (Nelson and Johnson, 1976; Heywood and Sanford, 1976), 400 to 450 km west-southwest of the Ordovician rocks of southern Baffin Island. Workum et al (ibid.) considered these two occurrences of organic-rich beds to be stratigraphically equivalent. After confirming the presence of oil shales on Southampton Island by detailed geochemical analyses (Macauley, 1986), and a review of all published data on the Paleozoic sections of Baffin and Akpatok Islands, the presence of organic-rich beds in the Ordovician exposures on these latter two islands was considered probable. The writer visited the principle Ordovician outcrop locations during August, 1986, and found three obscure exposures of organic-rich beds on southern Baffin Island. The lack of previous recognition of organic-rich intervals is readily understandable from their limited exposure and the paleontological basis for previous investigations.

STRATIGRAPHY

No precise stratigraphic section has been described for the Ordovician beds of southern Baffin Island, nor were detailed sections measured for the purposes of this study. None of the previous reports described a lithologic sequence which is apparent when assessed in the light of the prior studies and with the aerial view afforded by helicopter transport. The observed stratigraphic subdivision, as offered for Baffin Island, can be readily correlated with the Akpatok Island section (Workum et al., 1976), but is made less confidently with the Ordovician of Melville Peninsula (Trettin, 1975; Bolton et al., 1977); however, some comparisons of the southern Baffin Island and Melville Island sections are possible.

Southern Baffin Island

A three-fold stratigraphic sub-division, dominantly carbonate, is based firstly on color and bedding characteristics, and secondly on the presence of shale beds within one specific unit. The section is described top to base commensurate with subsurface procedures as any further clarification will of necessity result from drilling and/or coring rather than further surface studies.

Upper Unit: Ordovician rocks are preserved in hills, or "mounts", capped and preserved by a distinct orange colored limestone which weathers to an equally distinct orange-yellow soft surficial mud. These beds, generally less than 15 m thick, are knobby, with small, lighter colored, cryptocrystalline nodules in the range 2 to 5 cm. The matrix is a slightly darker colored, finely crystalline limestone. Because of the extreme weathering in this Arctic area, exposures are relatively few, and the contact with the underlying unit was not examined in surface beds.

Middle Unit: A medial unit is composed of dominantly light to medium grey cryptocrystalline limestone which occurs as flat elongate nodules, 2 to 5 cm thick, and generally greater than 10 cm in length, within a matrix of slightly darker, finely crystalline limestone. Both the color and the bedding characteristics distinctly separate the middle from the upper unit. In the more southerly exposures, at Silliman's Mount and south of Amadjuak Lake (Fig. 1), the middle unit is approximately 100 to 125 m thick. This rock weathers to a distinct light grey, soft, surficial mud. The difference in color of the surface muds readily allows differentiation of the upper and middle units from the air. Admixing of the muds, especially near the contact, obscures this characteristic when on the ground. Where the hills are viewed from a distance on the ground, the boundary is apparent. Faunal collections from the two units have been lumped together because most were obtained from talus. A close examination of the color of the rock adhering to the fossil detritus, and the color of the fossils themselves (ie. grey or orange), should suffice to define their relative positions in the section.

Blue-grey shale, containing abundant, 2 to 3 cm, carbonate nodules, is distinctive as interbeds within the middle carbonate sequence. An apparently widespread blue-grey shale bed, 1 to 2 m thick, which occurs approximately 8 m below the top of the grey interval, forms a distinct regional marker from the air. Blue-grey shale is more prevalent on the western shores of Amadjuak Lake where the section consists of alternating grey limestone and shale. Gould et al. (1928), described the section on Putnam Highland (Fig. 1) as being composed of 17 m of capping orange (?) limestone underlain by a middle unit of 190 m of grey shale with lesser interbedded limestones.

Organic-rich beds were discovered within this middle unit at three locations.

Lower Unit: A basal unit, probably less than 10 m in thickness, is made up of medium bedded (5 to 15 cm) light grey to greyish-brown resistant limestone which weathers grey to a ledge-like character. Where observed, the zone appears to be non-argillaceous and barren of shale interbeds. The basal unit rests unconformably on the Precambrian.

Regional Distribution: The best exposures occur along a trend of higher hills from Silliman's Mount northward along the Jordan River to Amadjuak Lake (Fig. 1). These hills are the easterly limit of Ordovician beds, and contain the three known oil shale occurrences (Fig. 1, locations A, B ,C). The upper unit caps all the hills along this trend, with the occasional presence of lower unit strata in the deeper river valleys. The Ordovician beds appear to be contained in a large structural graben, very much evident to the west of Silliman's Mount. Although the

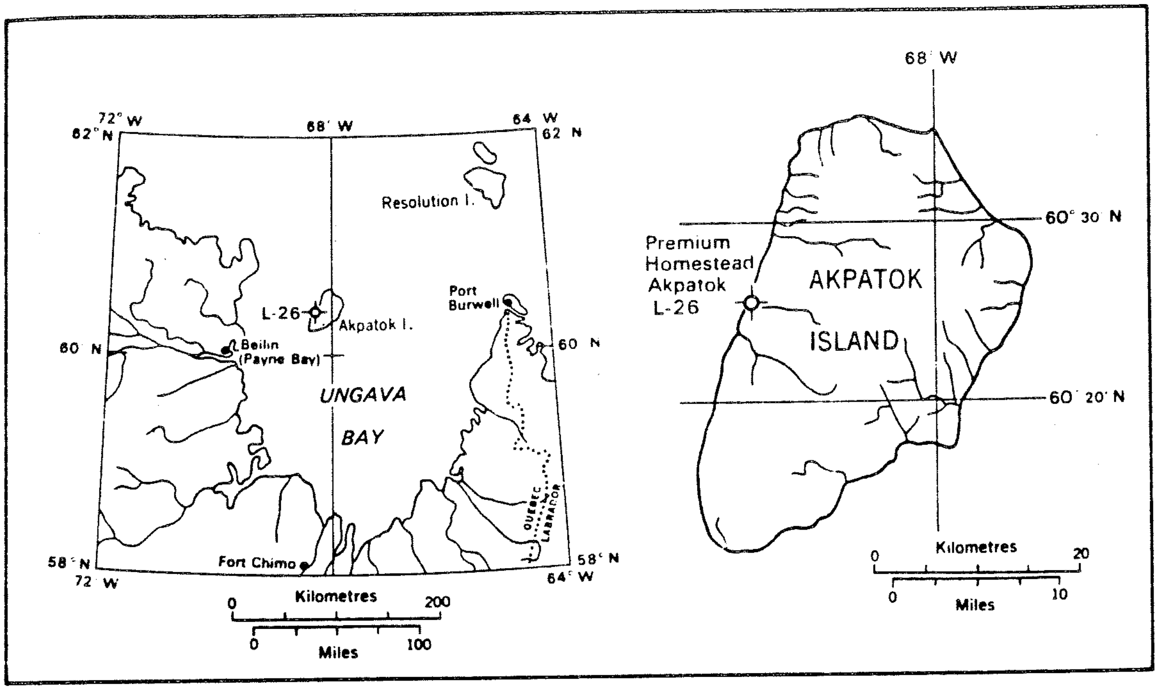

Figure 2: Location map, Akpatok Island (after Workum et al., 1976).

Ordovician - Precambrian contact was not studied, the appearance from the air was that of a stratigraphic rather than a structural contact along some of the more easterly river valleys.

From an air reconnaissance of Ordovician strata preserved westerly of this frontal range of hills, and southerly of Amadjuak Lake, a large geographic area of low-lying hills is variably orange-yellow on the hill tops and grey over the greater part of the slopes. A re-entrant of Precambrian beds at the south end of the continuous surface Ordovician exposures, westerly of section B, follows the Hone River (see Fig. 5). A flight along this river indicated the presence of lower unit carbonates pinching out against Precambrian inliers intermittent along the river bed. These exposures confirmed the limestones to be the oldest Ordovician deposits on southern Baffin Island.

Akpatok Island

Akpatok Island is a flat-topped remnant of Ordovician strata preserved in Ungava Bay (Figs. 1, 2). The nearby mainland area of Quebec contains only Precambrian. Ordovician geology is known from a combination of exposures in massive cliffs which form the shoreline of the island and a single borehole, Premium Homestead Akpatok L-26 (Fig. 2). Workum et al. (1976) have described the geology of both the surface beds and the borehole.

The island is capped by greater than 50 m of orange-brown limestone, much more massive and not so nodular as the upper orange colored unit on Baffin Island, but distinctly a related lithology. Workum et al. (1976, p. 160, Fig. 3) have indicated that the total section of this lithology may approach 160 m. A middle unit, somewhat less massive and much less resistant to erosion, contains light to some medium brown, cryptocrystalline, in part organic limestone, approximately 35 m thick. A basal unit of massively bedded, ledge-forming carbonate, is exposed at low tide. The comparison of these tide-level beds to the lower Ordovician interval on Baffin Island is readily apparent. Their thickness, approximately 60 m from the borehole data, is greater than that on southern Baffin Island. They overlie older beds, roughly 310 m of grey-green and white shales and sandstones assigned by Workum et al. (1976) to the Lower Ordovician. These loosely consolidated clastic beds overlie Precambrian in the well section and are not seen in outcrop. Coring unfortunately did not commence in the L-26 hole until the Lower Ordovician had already been penetrated.

Rowley Island

Siluro-Ordovician strata (Trettin, 1975) form the surface beds on Rowley Island (Fig. 1), but the geology is better known from the Aquitaine et al Rowley M-04 well which cored the entire Ordovician section. The M-04 core, first described by Trettin (ibid.), was re-examined in the light of the surface section recognized on southern Baffin Island to determine if the same stratigraphic sequence could be recognized. Appendix A contains a brief description of the cored intervals most pertinent to this study.

Coring started at a drilling depth of 515 feet. Trettin (1975) has placed beds above 450' into an undivided Siluro-Ordovician section. From 450 to 515', the rocks are similar to those of the uppermost part of the core.

Uppermost beds in the core, to a depth of 551', are orange, mottled, knobby limestone. The nodules are of 2 to 5 cm, light colored, cryptocrystalline carbonate in a slightly darker, finely crystalline matrix. This lithology is identical to that of the exposed upper interval of southern Baffin Island and is compared with confidence to the upper Bad Cache Rapids beds on Melville Island illustrated by Sanford in Bolton et al. (1977, p. 19, Fig. 17). Just over 30 m of the upper lithology is present in the M-04 corehole.

From 551 - 594' (13 m), light grey limestone, comprising elongate, cryptocrystalline, light colored nodules in a slightly darker finely crystalline matrix, are interbedded with lesser amounts of the overlying orange knobby limestone. They represent a transition from the upper orange to the middle grey section. Similar to the Baffin Island surface exposures, the bedding characteristics distinctly reflect the color change.

Grey limestone is the principle lithology from 594' to 1165'. A prominent grey to blue-grey shale bed, 6.1 m thick and containing abundant limestone nodules, occupies the interval 665 to 685', and occurs 21.6 m below the lowest orange bed, or 34.7 m below the first encountered grey limestone. On the basis of the litholgy and its position in the section, this shale interval is tentatively correlated with the regional shale bed occupying a similar position in the Baffin Island sections.

Although not here fully described, the interval 700 - 1000' consists of a continuous sequence of light grey nodular limestone as above.

Light grey to greenish or bluish grey shales again interbed in the interval 1048 - 1165' at the base of the middle grey section. A light grey finely crystalline dolostone, in part earthy textured, was penetrated from 1130 - 1160' (9.1 m thick) just above the base of this stratigraphic interval. The dolostone is included in the middle interval because of its relationship to the underlying shale bed. The total thickness here assigned to the middle grey sequence is 187.2 m.

The lowermost described beds in the M-04 corehole are light brown to grey-brown dolostones, slightly varved with darker brown laminae, but which are obviously more massive and monotonous than the overlying lithologies. These are considered to be the equivalent of the bedded ledge-forming carbonates of the Baffin Island lower unit. All dolostones below 1130' are included in the Lower Ordovician Ship Point Formation by Trettin (1975). The lower carbonates, as seen on both Baffin and Akpatok Islands, are typified by the lower uniformly bedded Bad Cache limestones shown in photograph by Sanford in Bolton et al. (1977, p. 19, Fig. 16). Blackadar (1967) reported a Lower Ordovician (Wilderness) age for fauna collected from Baffin Island locations where the lower unit is possibly exposed.

Regional Correlations

Figure 3 is a diagrammatic north-south cross-section which attempts to illustrate the regional correlations and facies changes described above. The section is distorted by lack of horizontal scale and is vertically to scale only within the generalized thicknesses given for the surface sections on Baffin Island.

The boundary of the orange and grey limestone sections has been arbitrarily selected as the stratigraphic datum. The northward thickening of the interpreted middle unit is pronounced as are the facies changes within the unit. From south to north, the thinnest, light brown, sub-laminated limestones of Akpatok Island grade to grey nodular limestone, then to a dominant grey shale section with lesser limestone, and back to grey limestone at Rowley Island. Following the suggested correlations of Trettin (1975), this middle interval correlates northward on Brodeur Peninsula (Fig. 1) to dominantly cryptocrystalline limestones that are variably dolomitic, fossiliferous, in part cliff-forming, and containing limited zones of argillaceous beds.

The upper grey shale marker bed is slightly organic at the north end of Amadjuak Lake (location C. Fig. 1) and appears to be penetrated slightly lower in the section at Rowley M-04 (Fig. 3). The interbedding of the orange and grey limestones in the M-04

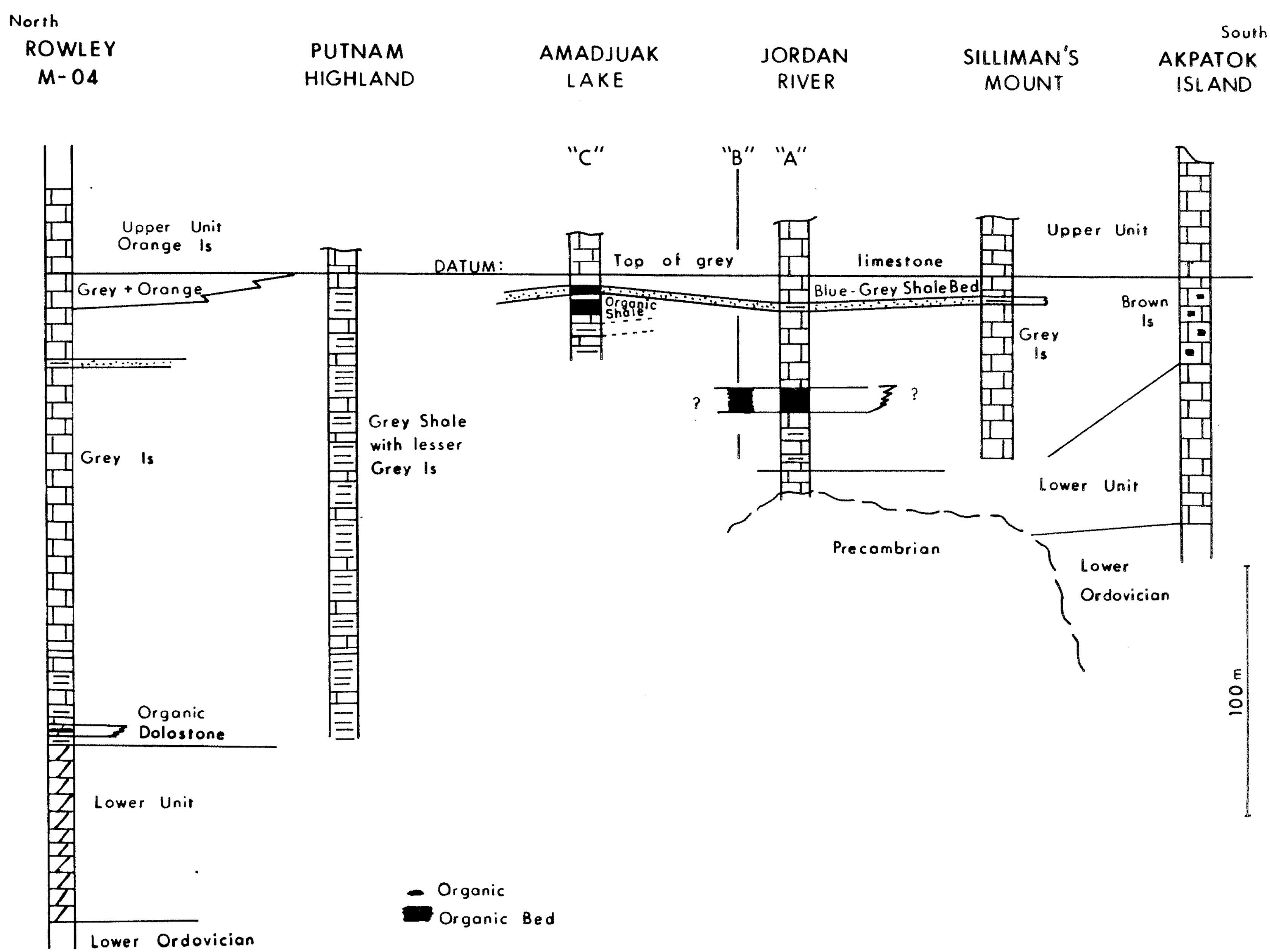

Figure 3: Diagrammatic north-south litho-stratigraphic correlation section.

well, even though grey predominates, may indicate a facies change whereby the stratigraphic datum possibly should be the lowermost occurrence of orange rather than to the uppermost appearance of grey. Lithologic descriptions of the Putnam Highland sections are too vague to permit any specific bed correlations to that area.

Where the lower, massive, ledgy beds overlie Lower Ordovician strata on Akpatok Island and in the M-04 section, the thickness, as here correlated, is fairly uniform, but the unit thins considerably over a Precambrian topographic high on southern Baffin Island. The unit appears to be absent at Silliman's Mount and, if present, is not exposed at the north end of Amadjuak Lake. The lithologic descriptions available for the Putnam Highland exposures are inadequate to determine the nature of the lower part of the section in that area.

OIL SHALES

Beds containing significant organic carbon (>1.5%) were encountered on Akpatok Island, at location A (Jordan River), location B (Nuvungmiut River) south of Amadjuak Lake, location C near the north end of Amadjuak Lake and in a section of dolostone in the lower part of the middle unit as interpreted at the Rowley M-04 well on Rowley Island (Fig. 1). Three different zones contain the kerogen occurrences. Slightly organic beds throughout the middle unit on Akpatok Island are a probable stratigraphic equivalent to all three organic intervals recognized farther to the north.

Miller et al. (1954) first described a large outcropping of Ordovician strata along the Jordan River (Fig. 1, location A), approximately 12 to 13 miles north of the better known Silliman's Mount. Because these hills are essentially buried in their own debris, and exposures are limited in both number and size, an actual section measurement is difficult to make. An estimation of the section present is as follows:

Jordan River Section: (Sections R and S of Blackadar, 1967)

The Jordan River section was examined on the east flank of the large (100 by 20 km) northwesterly trending Ordovician remnant hill located along the Jordan River. Figure 4 outlines the pertinent topography by which the section can be located on the 1:250,000 National Topographic Map Series.

Approximately 20 m of orange weathering knobby mottled carbonate are exposed on the hilltop. In a major stream cut (Fig. 4), 10 m of grey-weathering lenticular mottled carbonate includes minor thin shaly intervals and overlies 2 m of blue-grey beds with a transitional contact at the base. Samples BI-1 and BI-2 of the clay and the limestone nodules within the clay were selected for mineralogy and possible, although not anticipated, organic content. Below this point in this deep stream cut, coarse detritus made determination of the bedrock impossible.

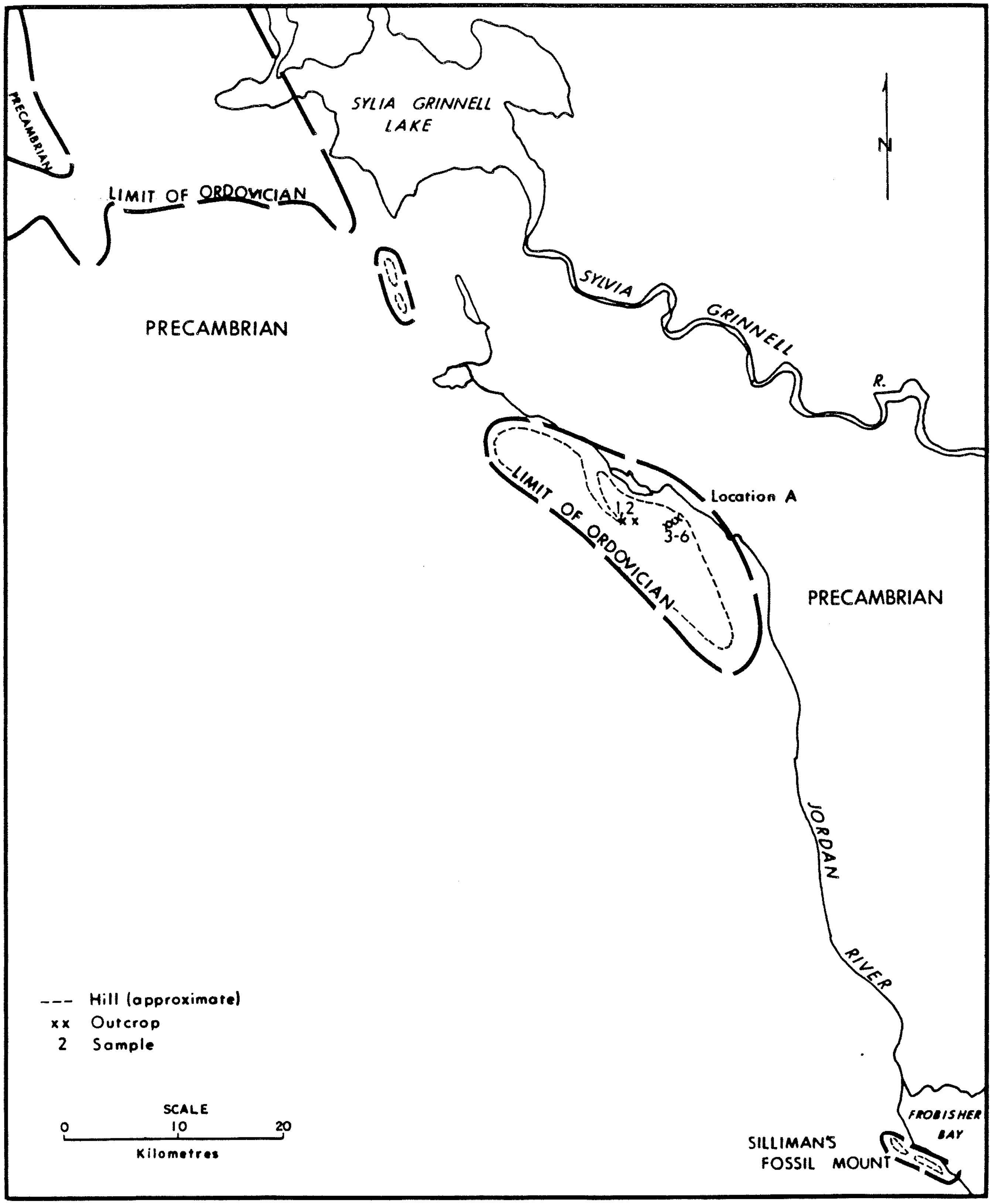

Figure 4: Jordan River location A.

After following the surface color expression of the blue-grey shale bed along the hill face, a small gully was then descended. One to two metres of surface mud, a residual carbonate flour, covers most of the Ordovician bedrock, even on the hillsides. This small gully has cut sufficiently deeply that oil shale beds are exposed at an estimated 30 to 35 m below the blue-grey shale marker, with the intervening interval covered by grey mud. The oil shale was first noticed as laminated detritus on top of the surface mud and then, slightly lower, within the gully bed itself. Samples BI-3 And BI-4 are drift samples of thinly laminated papery oil shale from an approximate 5 m interval: samples BI-5 and BI-6 are from thicker bedded oil shales at the top and base of an estimated 7 to 9 m of bedrock exposure. The occurrence of the uppermost samples in drift higher in elevation than the actual outcropping indicates that a total oil shale section in the minimum range of 12 to 14 m is present. On a flight past this section, a distinct brownish coloration was noted to indicate the top of the oil shale interval.

Below the oil shale exposure, 15 to 20 m of mud-covered interval contains detritus of grey limestones and shales, some orange carbonate and Precambrian debris. The exact nature of the section is indeterminate but interbedded grey limestone and lesser shale is suspected.

Grey-weathering bedded ledges of the lower unit carbonate are exposed along the Jordan River at the base of the hill. Southeastward along the river, carbonate exposures disappear at a series of lakes and swamps at a sharp river bend. Precambrian rocks are exposed in the river bed to the southeast of this small covered area. Although not investigated on the ground, the Ordovician-Precambrian boundary has the appearance of being a stratigraphic rather than a structural contact.

Nuvungmiut River: (Sections M, N of Blackadar, 1967)

A series of Ordovician hills extend parallel to the Nuvungmiut River near the south end of Amadjuak Lake (Fig. 5). All are capped by the orange-weathering upper unit carbonate, with blue-grey shale exposed in the deeper gullies and the orange-grey contact of the upper-middle units apparent on the hillsides. These hills are lower than those at Jordan River, consequently less section is exposed.

Oil shale float, occurring as distinct florets of laminated, papery chips brought to the surface by frost heave, was encountered on a low slope near the base of one of the hillside (Fig. 5, sample 7). No bedrock oil shale was noted as the examined gully was very shallow over a gentle slope. Because the thicker bedded oil shales present at the base of the Jordan River section are obviously much more resistant to erosion than the papery beds, by analogy the lower strata would probably not here be exposed either as detritus or as outcrop at this section. Very specific topographic conditions of slope and gully erosion are required to expose oil shales in the Ordovician beds of southern Baffin Island.

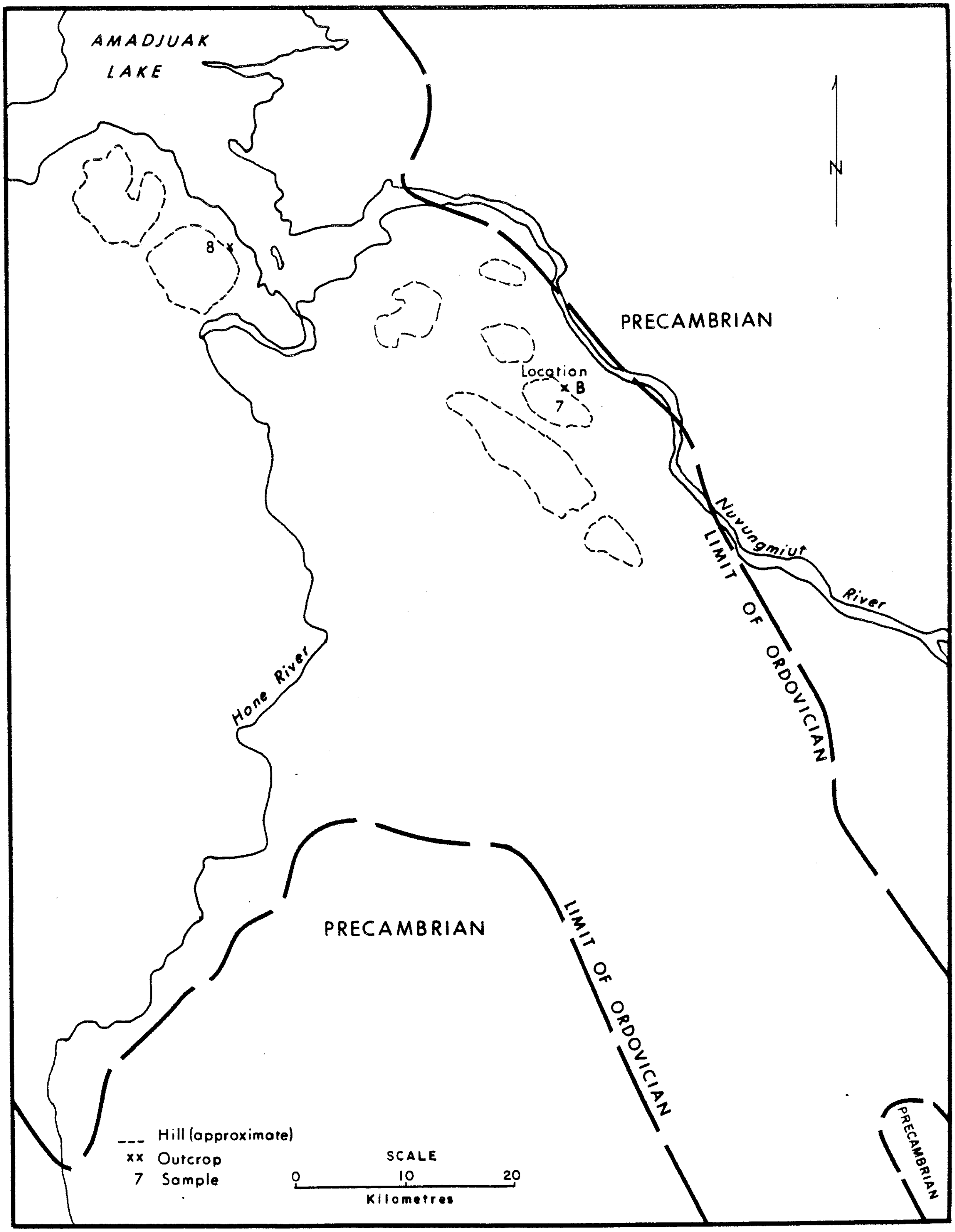

Figure 5: Nuvungmiut River location B.

An additional section was traversed in this area at the south end of Amadjuak Lake (Fig. 5; location J of Blackadar, 1967) where sample 8 was taken of the blue-grey marker shale for mineralogical comparison to the equivalent Jordan River bed.

Amadjuak Lake, north end: (Blackadar, 1967; location E)

A thin section is exposed at location C (Fig. 6) on a steep cliff at the north end of Amadjuak Lake, northward along the shoreline from a landing strip at Black Beach.

Sample BI-9 of blue-grey shale, occurring almost directly beneath the capping orange limestone, was collected in a stream gully north of the cliff exposure. At locality C, orange carbonate overlies approximately 8 m of exposed middle grey unit.

The uppermost 3 m of the grey beds interval are covered by grey talus which overlies 4 m of brown talus, most of which appears to be essentially in place and comprises poor quality oil shale material (sample BI-10 at top, BI-11 at base). When wet, the brown color is much in evidence, but, when dry, a grey color is more pronounced. A thin 0.4 m limestone bed then overlies approximately 7 m of brown oil shale. These beds were extremely difficult to sample because of wet, slippery conditions on a steep cliff face. Sample BI-12 was taken 1 m above the base of this brownish shale interval and BI-13 at the base.

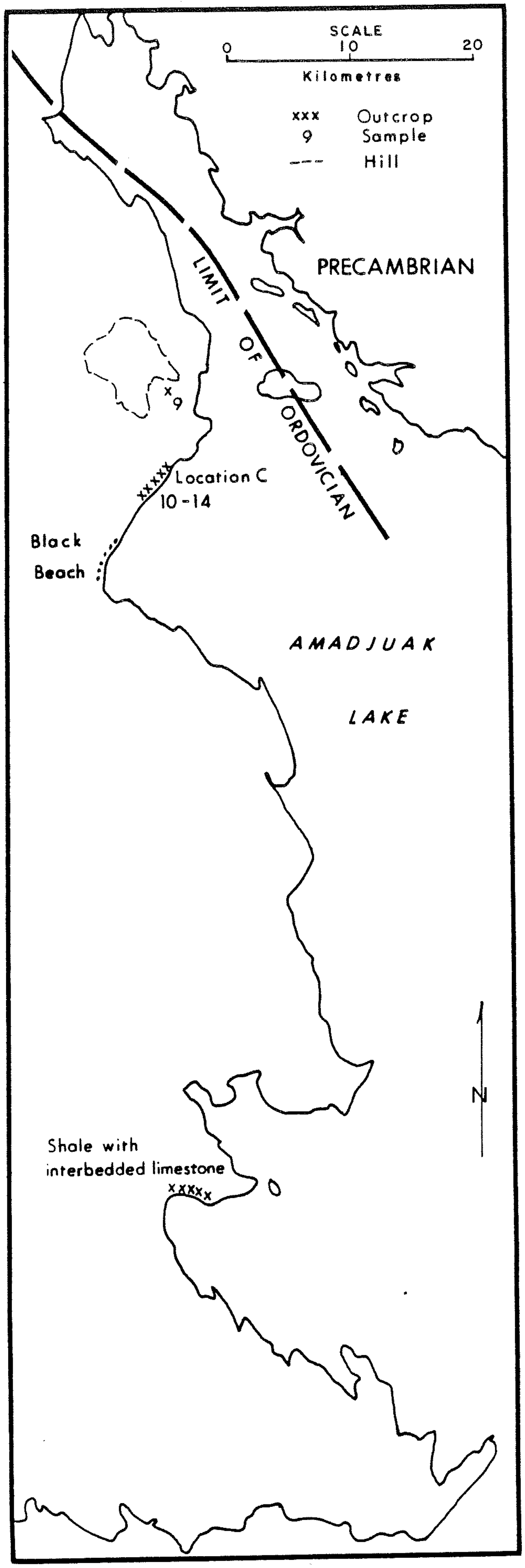

Figure 6: Amadjuak Lake location C

Similarly, much of the brownish color and the apparent hardness were lost as the samples dried. Bedded samples crumbled completely.

Below the organic beds, the downward section comprised 0.2 m non-organic blue-grey shale, 1 m of light brown, aphanitic limestone, 1.3 m of blue-grey shale, 0.7 m of grey elongated knobby limestone and bottomed in 0.2 m of blue-grey shale (sample BI-14).

From a distance, this section is considerably darker than is normal for the blue-grey shales as the organic beds weather with a distinct dark greenish-grey color, almost black from a distance. Perhaps this cliff has given the name to nearby Black Beach as there is no black characteristic to the beach itself.

These organic beds are judged to be higher in the section than those at Jordan River (Fig. 3). The uppermost organic interval appears to be a possible equivalent of, or to occur immediately below, the regional blue-grey shale marker. Rocks equivalent to the oil shales of the Jordan River section then would here occur considerably below lake level.

Sixty kilometres to the south of location C, also on the shore of Amadjuak Lake (Fig. 6), orange limestone overlies about 15 m of interbedded grey limestone and blue-grey shale along shoreface cliffs. No organic beds comparable to the organic shale intervals to the north occur in this section.

Putnam Highland was beyond the range of the helicopter available for the surface sampling. Roy (1941, p.183) stated black limy shales to be present in Foxe Land, although Miller et al. (1954) described the shales of Putnam Highland as blue-grey. A more detailed examination of these shales could be most beneficial to the understanding of the organic shale distribution and the facies relationships of Ordovician beds in the eastern Arctic.

Silliman's Mount:

Because Silliman's Fossil Mount has been so often the basis of paleontological papers, the section was closely scrutinized for oil shale or organic-rich beds. None was encountered even though the surface muds were scanned carefully for frost heaved oil shale florets. Orange limestone caps the mount. The blue-grey shale marker bed, distinctive near the top of the grey section, may represent Bed B of Roy (1941). Sufficient section remains concealed below the marker shale that an interval equivalent to the oil shale zone encountered at the Jordan River section could be present within the hill slope, completely covered by surficial mud deposits. Alternatively, the oil shale may be missing by facies change.

Akpatok Island:

No exposures of good organic-rich limestones were found on Akpatok Island, although medium brown aphanitic limestones appeared to have organic content in contrast to interbedded light brown, aphanitic to cryptocrystalline limestone. Samples were collected along the deep erosional valley of the stream entering the bay immediately south of the L-26 borehole (Fig. 2).

Sample AK-1 was collected from bedrock of medium brown, aphanatic, fairly thick bedded (up to 8 cm) limestone interbedded with lighter carbonate. Samples AK-2 and AK-3 were collected from talus on the cliff slope of carbonate below the orange beds and above the ledge-forming massive carbonate exposed at sea level. AK-1 is the most massive, AK-2 appeared to be the thinnest bedded (<0.5 cm) and AK-3, more massive than AK-2, showed fine darker brown laminations although breakage along the laminae was not possible.

Rowley M-04:

The upper blue-grey shale zone was sampled at 682.5' drilling depth. Light grey calcareous shale with possible black organic detritus was sampled (1079.0') from the shale-bearing sequence in the basal part of the middle grey unit. An earthy organic-appearing dolostone was sampled at 1157.8' and a basal blue-grey shale at 1163.0 feet. Significant organic content was not anticipated for the grey shales which were sampled more specifically for mineral identification.

Analytical Techniques

All samples were subjected to organic geochemical analysis by a standard Rock-Eval Pyrolysis procedure. The S1 peak was obtained at 300°C, and the S2 was measured during hearing at 25°C/min. and collected to a temperature of 600°C. The S3 peak was collected to a temperature of 390°C. TOC content was determined by burning all the carbon in a separate oxidation oven built into the analyzer and operated at 600°C in air. In order to ensure uniform results and that all the organic carbon was burned, samples were ground to a particle size of approximately 150 micrometres. A minimum double run is standard for all samples. A calibration standard had nominal values of S1=0.04, S2=0.87, S3=0.63, Tmax=437°C and TOC=1.65%. Appendix B lists the results of the Rock-Eval pyrolyses.

Inorganic geochemistry was determined by a Philips PW 1700 automated powder diffraction system. Semi-quantitative results were calculated from diffraction peak heights which may vary with degrees of crystallinity, crystal size, and the presence of amorphous material and organic matter. Appendix C contains the results of the X-RD investigations.

Rock-Eval Pyrolyses

As was anticipated, none of the samples of blue-grey shale or of enclosed limestone nodules contained any significant organic carbon component. Total organic carbon (TOC) values are invariably less than than 0.10% (Appendix B) for these beds. The similar beds at the Rowley M-04 contain up to 0.36% TOC, still less than significant.

The laminated papery oil shale beds of the Jordan River (BI-3, BI-4) and Nuvungmiut River (BI-7) sections, containing TOC ranging from 9 to almost 15%, are excellent oil shales and potential source beds. Hydrogen Indices are generally in the mid 500 to high 600 range (Fig. 7), with commensurate yield ratios (Petroleum Potential/%TOC, Fig. 8) ranging from 5 to 7 kg/t/%TOC. Tmax is invariably below 435 °C. These are immature Type II kerogen deposits. Although the more massive oil shale beds (BI-5, BI-6) below the laminated interval at the Jordan River section contain considerably less carbon (3 to 8%), all Rock-Eval indices indicate these beds also to contain immature Type II kerogen.

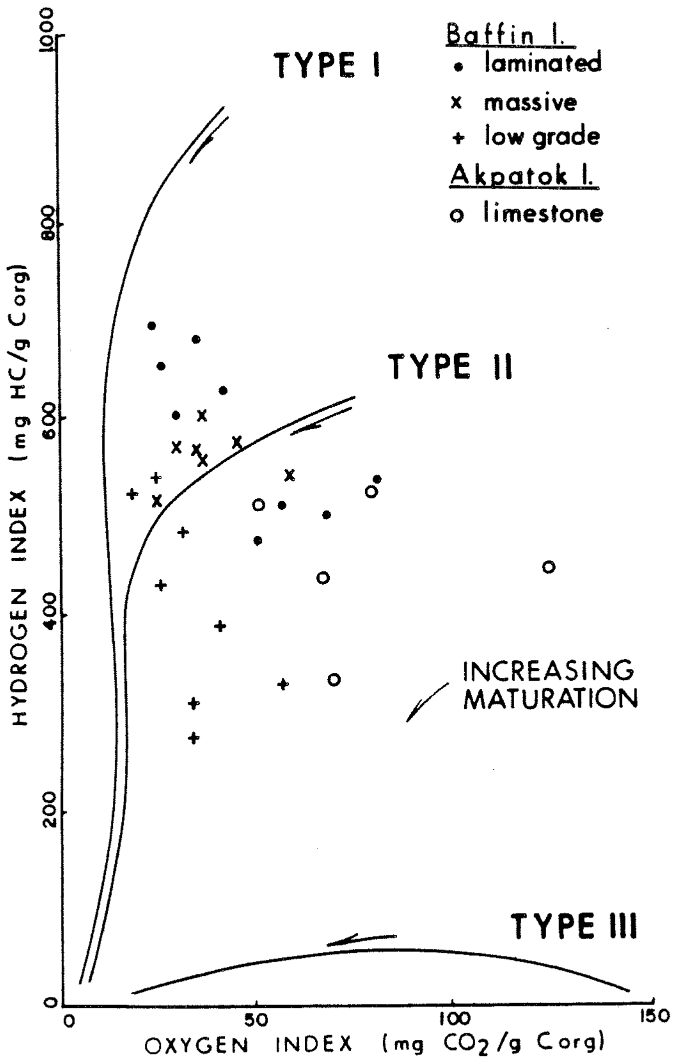

Figure 7: Hydrogen Index versus Oxygen Index.

When collected, the samples (BI-10 to BI-14) from location C at the north end of Amadjuak Lake were believed to contain considerable organic carbon, but this thought was later modified when the brown color diminished as the samples dried and crumbled to unconsolidated mud, losing all aspect of good bedding. TOC for the uppermost two samples (BI-11, -12), in the obviously poorer upper organic interval, are 0.50%. TOC approximates 2.3% in the lower sampled brownish shale interval. These strata do not constitute oil shales but are significant as a potential petroleum source. Although both HI and yield ratio values are considerably lower than for the better oil shales to the south (Figs. 7. 8), these also must be interpreted as immature Type II kerogen deposits.

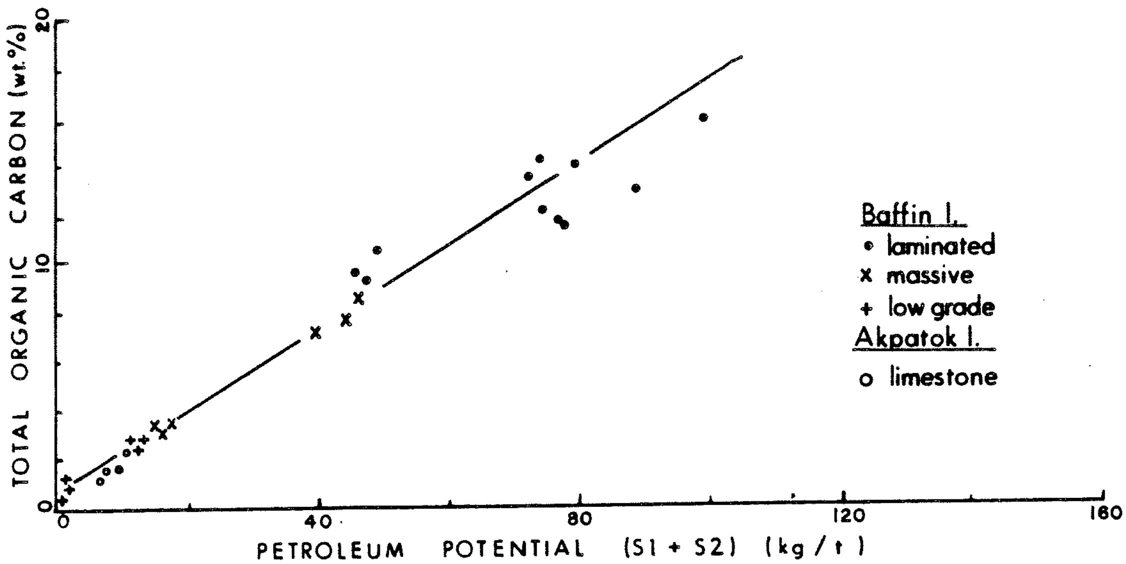

Figure 8: Total organic carbon versus petroleum potential.

TOC content is lower than was anticipated in the Akpatok samples. The range of 0.5 to 2.0% TOC, with Tmax always below 435 C, HI as high as 529, and yield ratios to 5.46, combine to define these beds similarly as immature Type II organic-rich limestones. They will have good potential as a petroleum source where present at higher levels of thermal maturity than observed in the sampled area.

The Transformation Ratios (TR) are low, generally less than further confirmation of the interpreted kerogen classification and level of thermal maturation.

Rock-Eval results are much less definitive for the samples from the Rowley M-04 well where very low yields from negligible TOC content have resulted in low HI values, low yield ratios and a wide range for Tmax and the Production Indices. At an average 1.2% TOC, the organic dolostone exhibits higher HI and yield ratio parameters, but Tmax spans the oil generation window for that sample. Because the TR values are low, marginal to low thermal maturation can be interpreted, but not with confidence. The kerogen is probably Type II as Type III plant-derived terrestrial detritus is not basic to Ordovician beds. Low value Rock-Eval parameters and the marine nature of the deposit negate the presence of Type I lamalginites and torbanites.

X-ray Diffraction Analyses

The laminated and massive oil shale beds of locations A and B (Jordan and Nuvungmiut rivers) are primarily limestone with variable dolomite content. All contain clay (chlorite and illite), minor feldspar (mostly plagioclase) and considerable quartz. Because sand and silt size quartz grains are not readily discernible in the samples, the quartz may have an authigenic chemical origin rather than that of terrestrial detritus.

Clay (mostly chlorite and illite), abundant quartz, and a variable calcite/dolomite content define the organic shales of location C on Amadjuak Lake as argillaceous dolomitic limestones to calcareous dolomitic shale. The term mudstone may be more appropriate as induration has not reached the point where lamination has developed. Samples of the lower of the two exposed organic beds contain alkaline rather than plagioclase feldspar, but no conclusions can be drawn from this minor variation.

All the organic beds are mineralogically similar. They have a clay component, contain significant quartz of unknown origin, and are essentially limestones which become more dolomitic northward over southern Baffin Island.

Although commonly described as blue-grey shale, that lithology has not been sufficiently indurated to be laminated and contains few clay minerals. A strong reaction in cold acid reflects that the beds are properly lime mudstones, with dominant calcite and only minor dolomite content in the Baffin Island samples. All contain a significant amount of quartz, of unknown origin, but likewise thought to be a possible chemical precipitate because no silt or sand size quartz grains are evident. There is no mineralogical difference apparent between the matrix mudstone (BI-1) and an enclosed limestone nodule (BI-2) from the blue-grey shale interval at the Jordan River section.

Chlorite, which is common to the oil shale beds and the blue-grey shale, probably imparts the bluish color to the non-organic shale beds and the greenish tinge to the low grade organic beds at Amadjuak Lake. The brown of the kerogen likely over-rides the green of the chlorite in the organic-rich shales.

Although blue-grey shale is not a precise descriptive term for that lithology, prior usage and the occurrence as distinct color bands, much resembling shale intervals within the grey carbonate sequence, warrants retention of the expression to define those particular beds. Otherwise, differentiation of lithologies and sub-units within stratigraphic descriptions will be obscure to the reader.

The carbonates of Akpatok Island, considered to be correlative with the Baffin Island organic-rich beds, are barren of fine terrigenous clastics and are limestones containing only minor dolomite. Of interest is a significant quartz content which must be present as clay size particles. This is most likely an authigenic chemical precipitate rather than a detrital form of the quartz.

At the Rowley M-04 well, the sampled blue-grey shale is much more dolomitic than on Baffin Island, although this is not evident from visual inspection. Although the Rock-Eval data indicate possible greater thermal maturation at Rowley Island, the shale beds are poorly indurated and are properly mudstones.

Organic Petrology

Detailed reflectance and fluorescence studies are not yet available, but Goodarzi (ISPG, pers. comm.) has provided maceral identifications for these samples. Matrix bituminite is the principle kerogen component, with secondary algal cysts, chitinizoa and graptolites, indicating a marine environment of deposition. Although the beds are indicated to be geochemically immature, non-fluorescing bitumen is present in minor amounts throughout and is more pronounced in the highest TOC beds of the Jordan River section. There is insufficient bitumen present to dispute the geochemical results. These maceral identifications confirm that the kerogen is immature Type II marine sapropelic (amorphous).

SUMMARY

Ordovician strata on southern Baffin Island are divided into three lithologic sub-units, in descending order:

1) an upper unit of orange colored knobby limestone, with cryptocrystalline nodules 2 to 5 cm in a slightly darker finely crystalline matrix, sufficiently resistive to be the cap for the remnant hills of Ordovician beds;

2) a middle unit of grey nodular limestone, with elongate, cryptocrystalline nodules 2 to 5 cm thick and longer than 10 cm in a matrix of slightly darker finely crystalline limestone. The unit contains a regionally correlative blue-grey bed near the top and changes by facies to dominantly blue-grey shale beds at the north end of Amadjuak Lake and in the Putnam Highland. A minimum 12 to 14 m of good quality oil shale beds are present toward the base of the unit, and poor quality organic shales are present near the top of the section in the area of dominant shale development. The unit equates southward to slightly organic brown aphanitic limestone on Akpatok Island and is represented by similar nodular limestone to the north on Rowley Island;

3) the lower unit comprises grey-weathering more massive bedded ledge-forming limestone which rests on Precambrian on southern Baffin Island, on Lower Ordovician clastics on Akpatok Island and on a Lower Ordovician carbonate-clastic sequence on Rowley Island.

Good quality laminated to massive immature marine Type II sapropelic oil shales, possibly 10 to 15 m thick or greater, are present within the middle grey unit at sections on Jordan River and near the south end of Amadjuak Lake, but appear to be missing further south at Silliman's Mount.

The lowest organic bed in the section is a thin, earthy dolostone just above the base of the middle unit in the Rowley M-04 borehole. The maturity level of this Type II kerogen is provisionally placed at marginal to low. Lack of compaction in the blue-grey shale equivalents indicates a minimum depth of burial for these Ordovician beds.

On Akpatok Island, the brown, aphanitic, slightly organic limestones of the middle unit contain thermally immature Type II kerogen.

Acknowledgements

This project was funded under contract with the Geological Survey of Canada, Department of Energy, Mines and Resources, Canada. At ISPG, Calgary, geochemical analyses were carried out under the technical control of R. J. Fanjoy and X-Ray diffraction analyses under the control and interpretation of J. N. Y. Wong. The maceral identifications are courtesy of F. Goodarzi.

N. J. McMillan, ISPG, arranged the logistics for, and accompanied the writer on, the field program. L. R. Snowdon, ISPG, arranged the geochemical investigations. McMillan and Snowdon respectively provided excellent assistance and comments in the preparation of the stratigraphic and geochemical sections of this report. The writer also wishes to express appreciation for the assistance of J. E. Brindle and of the editorial staff at ISPG in the final stages of manuscript preparation.

Mr. Andre Theriault, District Manager, Department of Indian and Northern Affairs, Iqaluit, was a principle benefactor of the project by making available a helicopter contracted by his department.

Mr. R. H. Workum, co-author of the paper on the geology of Akpatok Island, helpfully reviewed his work and thoughts on the area, thereby considerably enhancing the value of the time spent in this project.

RECOMMENDATIONS

This project was carried out for one specific purpose, to determine if the Ordovician sequences on Baffin and Akpatok Islands contained oil shales, and if so, to define the kerogen type, the level of thermal maturation and the potential as oil shale and/or as source beds for the adjacent off-shore hydrocarbon exploration areas. This objective was successfully achieved in 5 working days, requiring less than 10 hours helicopter support on Baffin Island and 3 hours Twin Otter flying time to sample the Akpatok Island section. Within this work schedule, only minimal attention could be paid to the overall stratigraphy of the area and to sample collection for that purpose.

Even with the above constraints, a basic sub-division is proposed in addition to suggested correlations with more northerly areas on the basis of the Rowley M-04 well and published reports. Further investigations for oil shale/source rock beds on Baird Peninsula in central Baffin Island (Fig. 1) and on Melville Peninsula, as well on the intervening islands, may better define the facies distribution within the Ordovician section. Surface geology reports by Trettin (1975) and Bolton et al (1977) provide an excellent background from which to explore for organic-rich zones in these areas. Further investigation, especially Melville Peninsula north of Hall Beach (Fig. 1), is strongly recommended. An investigation of the reported Ordovician outliers on Blunt Peninsula should also be considered.

Macro-fossil studies have not been sufficiently thorough to establish the bio-stratigraphic relationships of Ordovician sequences across eastern North America and the Arctic. Detailed micro-paleontology, especially conodont and graptolite determinations, may be a key to answer this problem. Samples of the blue-grey shale and of the oil shale were collected for conodont determinations and these are currently being processed at the Institute of Sedimentary and Petroleum Geology, Calgary. Although these studies will be a start, they may prove to be insufficient to provide the required solution. On the basis of macro-paleontology, the organic beds on Baffin Island are perhaps older than those described on Southampton Island (Macauley, 1986), although the latter are assigned a wide range of ages by different authors. A thought only, without verification, is that the Southampton Island Boas oil shale may be equivalent to the entire oil-shale-bearing middle grey unit of this study. If this proves true, the Boas beds represent the thin deposit of a starved basin over a long time period, such as described by Williams (1983) for the Middle-late Devonian Horn River Formation. Uplift and erosion would not be necessary to account for an apparent lack of sedimentary record at the Boas interval on Southampton Island.

REFERENCES

Blackadar, R.G.
1967: Geological reconnaissance, southern Baffin Island, District of Franklin; Geological Survey of Canada Paper 66-47, 32 p.

Bolton, T.E., Sanford, B.V., Copeland, M.J., Barnes, C.R. and Rigby, J.K.
1977: Geology of Ordovician rocks, Melville Peninsula and region, southeastern District of Franklin; Geological Survey of Canada Bulletin 269, 137 p.

Heywood, W.W. and Sanford, B.V.
1976: Geology of Southampton, Coats and Mansell Islands, District of Keewatin, Northwest Territories; Geological Survey of Canada Memoir 382, p. 19.

Gould, L.M., Foerste, A.F. and Hussey, R.C.
1928: Contributions to the geology of Foxe Land, Baffin Island; University Of Michigan, Museum of Paleontology Contribution, V. III, No. 3, p. 19-76.

Macauley, G.
1986: Geochemistry of the Ordovician Boas oil shale, Southampton Island, Northwest Territories; Geological Survey of Canada Open File Report OF1285, 15 p.

Macauley, G., Snowdon, L.R. and Ball, F.D.
1985: Geochemistry and geological factors governing exploitation of selected Canadian oil shale deposits; Geological Survey of Canada Paper 85-13, p. 2-5.

Miller, A.K., Younquist, W. and Collinson, C.
1954: Ordovician Cephalopod Fauna of Baffin Island; Geological Society of America Memoir 62, 234 p.

Nelson, S.J. and Johnson, R.D.
1976: Oil shales of Southampton Island, northern Hudson Bay; Bulletin of Canadian Petroleum Geology, v. 24, no. 1, p. 70-91.

Roy, S.K.
1941: The Upper Ordovician fauna of Frobisher Bay, Baffin Island; Field Museum of Natural History Memoir 2, p. 40-45, 177-197.

Trettin, H.P.
1975: Investigations of Lower Paleozoic geology, Foxe Basin, northeastern Melville Peninsula, and parts of northwestern and central Baffin Island; Geological Survey of Canada Bulletin 251, 177 p.

Workum, R.H., Bolton, T.E. and Barnes, C.R.
1976: Ordovician geology of Akpatok Island, Ungava Bay, District of Franklin; Canadian Journal of Earth Sciences, v. 13, p. 157-178

Williams, G. K.
1883: What does the term "Horn River Formation" mean?; Bulletin of Canadian Petroleum Geology, Vol. 31. No. 2, p. 117-122.

APPENDIX A

CORE DESCRIPTION, Aquitaine Rowley M-04

Depths in feet

505 - 551 Limestone, orange mottled, knobby effect, mottle evident by slightly darker inter-nodular color and increased grain size

Middle grey unit

551 - 555 Limestone, grey mottled, nodules creating the mottle are more horizontally lineated and less knobby in appearance

555 - 557 Limestone, orange, as above

557 - 559 Limestone, grey, as above

559 - 563 Limestone, orange, as above

563 - 566 Limestone, orange and grey, as above

566 - 582 Limestone, grey, much as above with elongate lighter grey nodular limestone in wavy irregular essentially horizontal partly discontinuous slightly darker slightly argillaceous limestone, mottling effect distinctly different from that of the orange colored zones above

582 - 585 Limestone, orange, as above, with lesser grey

585 - 587 Limestone, grey, but with minimal argillaceous content, mottled

587 - 588 Limestone, orange with lesser grey

588 - 593 Limestone, grey mottled, minimal argillaceous content

593 - 594 Limestone, orange and grey

594 - 606 Limestone, grey mottled, a few patchy orange zones, inter-nodular material may contain much clay and in part almost grades to a shale bed with limestone nodules

606 - 608 limestone, grey mottled grading down to Shale, light grey, calcareous, mottled with nodular limestone inclusions

608 - 623 Limestone, grey mottled, minimum clay content

623 - 665 Limestone, grey, fair amount of grey clay mottled zones in patchy distribution

Regional shale marker

665 - 685 Shale, grey, with 30 - 60% lighter grey nodular limestone inclusions which are much longer than deep and create a distinct horizontal bedding, shaliest at base, soft, green to blue tinge when wet; sample at 682.5

685 - 700 Limestone, grey, less distinctly mottled than above, very minor argillaceous content, but the presence of platy nodular bedding is still distinct

700 - 1000 not examined

1000 - 1046 Limestone, light grey, mottled along irregular wavy horizontal planes and blebs, cryptocrystalline, slightly darker bones seem to represent solution concentration with traces of stylolite-like surfaces but no distinct stylolites, some possible bioturbation effect, horizontal platy effect evident from the mottling

1048 - 1049 Limestone-Shale, boudinage effect of light grey limestone in slightly darker grey calcareous shale, shale has green to blue tinge when wet

1049 - 1978 Limestone, light grey mottled, with light grey boudinage type limestone and medium brown-grey aphanitic inter-nodular matrix, generally flat-lying structure shown by irregular lineation of the aphanitic material, argillaceous zone 1057-1058

1078 - 1080 Shale-Limestone, elongate nodules light grey cryptpcrystalline limestone in light grey calcareous shale, rare traces black organic fossil detritus (graptolite?); sample at 1079.0

1080 - 1090 Limestone, grey, as above, mottled along irregular horizontal planes

1090 - 1095 Shale-Limestone, limestone nodules in light grey to greenish-grey soft shale as above, scattered shiny black organic detritus, occasional hard slightly calcareous shale bands

1095 - 1130 Limestone, mottled as above, occasional bands with scattered dolomitized fossil detritus in basal seven feet

1130 - 1160 Dolostone, light grey, fine crystalline, hard, replacement of almost solid fossil detritus, debris shows best on etched surfaces, mostly indeterminate, slightly calcareous, irregular but flat-lying distribution of the detritus, some mottling similar to the limestones above, probably a similar initial deposit, a few scattered discontinuous vugs, thin zone medium brown cryptocrystalline earthy textured dolostone with possible organic content and partings 1157.5 - 1180.0 sampled at 1157.8, generally greyer than the limestone above, probably slightly more argillaceous and has a few shale laminae in basal two feet, grades down to

Lower unit

1160 - 1165 Shale, light grey with slight green to blue tinge, especially when wet, sub-laminated to sub-fissile, fairly well indurated, grey streak, laminae to thin beds light grey dolostone replacing fossil detritus; sample at 1163.0, grades down over lower two feet to

1165 - 1200 Dolostone, light brown to zones brownish-grey, finely laminated to almost varved evident from slight color changes and darker brown laminae, aphanitic but with bands to very fine crystalline, some minor cross-beds and slump textures, possibly considerable fine fossil debris, not as coarse as detritus above, gamma zone at 1180 on log not readily evident but could indicate increased clay content, no good shale zones but some greyer argillaceous bands 1178-1183 could cause the log feature

1200 - not examined

APPENDIX B

ROCK-EVAL PYROLYSIS DATA

Sample	TOC Wt%	Tmax °C	S1 mg/g	S2 mg/g	S3 mg/g	HI	OI	S1+S2 kg/t	TR	Ratio kg/t /%TOC
BAFFIN ISLAND										
BI-1	0.07	344	0.00	0.04	0.70	57	1000	0.04	.00	0.57
blgy sh	0.07	429	0.02	0.03	0.36	42	514	0.05	.40	0.71
	0.04	426	0.00	0.04	0.25	100	625	0.04	.00	1.00
	0.10	431	0.00	0.06	0.22	60	220	0.06	.00	0.60
BI-2	0.02	363	0.00	0.02	0.20	100	1000	0.02	.00	1.00
ls nod	0.06	304	0.00	0.01	0.22	16	366	0.01	.00	0.16
	0.12	365	0.00	0.02	0.16	16	175	0.02	.00	0.16
	0.06	329	0.00	0.02	0.58	33	966	0.02	.00	0.33
BI-3	13.31	414	4.33	66.97	7.57	503	56	71.30	.06	5.35
lam OS	13.52	423	3.72	70.75	6.86	523	80	74.47	.05	5.50
	14.76	409	7.13	91.73	6.04	621	40	98.86	.07	6.69
	13.65	411	5.45	74.37	6.16	544	45	79.82	.07	5.84
BI-4	11.75	425	3.72	70.45	3.51	599	29	74.17	.05	6.31
lam OS	11.32	416	4.43	73.15	2.93	646	25	77.58	.06	6.85
	12.26	419	4.52	84.77	2.73	691	22	89.29	.05	7.28
	11.06	426	3.01	74.47	3.84	673	34	77.48	.04	7.00
BI-5	2.89	422	0.45	15.98	1.03	552	35	16.43	.03	5.68
mass OS	2.91	422	0.47	16.58	0.98	569	33	17.05	.03	5.85
	2.94	421	0.48	15.29	0.69	520	23	15.77	.03	5.36
	2.95	427	0.40	15.74	1.46	533	49	16.14	.02	5.47
BI-6	8.09	415	2.02	45.64	2.37	564	29	47.66	.04	5.89
mass OS	7.08	418	1.90	42.30	2.49	597	35	44.20	.04	6.24
	6.76	425	1.34	38.68	2.98	572	44	40.02	.03	5.92
BI-7	10.00	421	2.37	46.28	5.03	462	50	48.65	.05	4.87
lam OS	9.04	428	1.57	44.79	6.07	495	67	46.36	.03	5.12
	8.63	423	2.10	44.88	5.17	520	59	46.98	.04	5.44
BI-8	0.12	428	0.00	0.13	0.18	108	150	0.13	.00	1.08
blgy sh	0.05	424	0.00	0.08	0.46	160	920	0.08	.00	1.60
	0.01	-	0.00	0.01	0.19	100	1900	0.01	.00	1.00
BI-9	0.04	418	0.00	0.07	0.25	174	625	0.07	.00	1.75
blgy sh	0.11	421	0.00	0.08	0.18	72	163	0.08	.00	0.72
BI-10	0.75	427	0.06	2.40	0.43	320	57	2.46	.02	3.28
org sh	0.90	427	0.05	2.41	0.31	267	34	2.46	.02	2.73
BI-11	0.50	429	0.04	1.93	0.20	386	40	1.97	.02	3.94
org sh	0.50	430	0.04	1.75	0.18	312	32	1.79	.02	3.58
BI-12	2.47	425	0.26	10.76	0.60	435	24	11.02	.02	4.46
org sh	2.32	426	0.26	11.16	0.69	481	29	11.42	.02	4.92
BI-13	2.32	426	0.28	12.13	0.42	522	18	12.41	.02	5.34
org sh	2.16	427	0.26	11.60	0.51	537	23	11.86	.02	5.49
BI-14	0.09	418	0.00	0.05	0.25	55	277	0.05	.00	0.55
blgy sh	0.05	421	0.00	0.04	0.30	80	600	0.04	.00	0.80

Sample	TOC Wt%	Tmax °C	S1 mg/g	S2 mg/g	S3 mg/g	HI	OI	S1+S2 kg/t	TR	Ratio kg/t /%TOC
AKPATOK ISLAND										
AK-1	0.51	431	0.06	2.07	0.91	405	178	2.13	.03	4.17
org ls	0.61	433	0.09	2.19	0.42	339	68	2.28	.03	3.73
AK-2	1.23	429	0.21	5.55	1.52	451	123	5.76	.04	4.68
org ls	1.41	429	0.25	6.18	1.06	438	75	6.43	.04	4.56
AK-3	1.82	427	0.34	9.64	1.42	529	78	9.98	.04	5.46
org ls	2.11	424	0.39	10.85	1.11	514	52	11.24	.03	5.32
ROWLEY M-04										
Depth ft.										
682.5	0.36	568	0.02	0.12	0.18	33	50	0.14	.14	0.39
gy sh	0.28	557	0.02	0.12	0.50	42	178	0.14	.14	0.50
1079.0	0.17	444	0.05	0.07	0.16	41	94	0.12	.42	0.71
gy sh	0.13	-	0.13	0.00	0.51	0	392	0.13	1.00	1.00
1157.8	1.22	459	0.16	3.45	0.41	282	33	3.61	.04	2.96
dol	1.18	437	0.17	3.09	0.95	261	80	3.16	.05	2.77
1163.0	0.31	441	0.01	0.19	0.21	61	64	0.20	.05	0.64
gy sh	0.28	424	0.02	0.15	1.66	53	592	0.17	.17	0.61

blgy sh: blue-grey shale
ls nod: limestone nodule
lam OS: laminated oil shale
mass OS: massive oil shale
org sh: organic (low grade) shale
org ls: organic limestone
gy sh: grey shale
dol: dolostone

APPENDIX C

X-RAY DIFFRACTION DATA

Sample	Clays			Quartz	Feld	Calcite	Dol	Py
	Exp/MLC	Kaol/chlor	Illite					
BI-1 blgy sh	-	tr	tr	10	tr	80	9	1
BI-2 ls nod	-	tr	tr	8	-	81	8	3
BI-3 lam OS	-	9 Chl	8 Musc	40	9 P	15	15	4
BI-4 lam OS	-	7 Chl tr K	6	26	6 P	44	8	3
BI-5 lam OS	-	6	4	30	4 P	50	4	2
BI-6 mass OS	-	6	6	32	5	42	6	3
BI-7 mass OS	-	9 Chl	8	38	8 P	30	7	-
BI-8 blgy sh	-	tr	tr	12	-	86	2	tr
BI-9 blgy sh	-	2	2	19	2	59	14	2
BI-10 org sh	-	10 Chl	6	44	5	23	12	tr
BI-11 org sh	tr	6	6	27	3	49	9	tr
BI-12 org sh	5	12 Chl tr K	10	47	9 A	7	10	tr
BI-13 org sh	6	11 Chl	10	41	5 A	10	10	tr
BI-14 blgy sh	-	2	2	18	7 P	61	15	2
AK -1 org ls	-	-	-	25	-	75	-	-
AK -2 org ls	-	-	-	19	-	81	tr	-
AK -3 org ls	-	-	-	21	-	75	4	-
Rowley M-04 682.5 blgy sh	4	2	2	29	4	12	44	3

Exp-MLC: expandable and mixed layer clays
Chlor: Chl: chlorite
K: Kaol: kaolinite
Musc: muscovite
Feld: feldspar
P: plagioclase
A: alkaline
Dol: dolomite
Py: pyrite