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PROTEROZOIC AND PALEOZOIC GEOLOGY OF BANKS ISLAND, ARCTIC CANADA

by

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PREFACE

Banks Island is located in the southwest corner of the Canadian Arctic Archipelago, and is situated between three major Paleozoic geological provinces, Franklinian Geosyncline, the northern Cordillera and the Central Stable Region. For this reason the subsurface Paleozoic geology of the area is of special interest, for it provides a means of comparing and correlating the stratigraphic and tectonic history of these three regions in a way that is not possible from surface evidence alone. In particular, evidence is provided which suggests a southward extension of the deep, axial basin of the Franklinian Geosyncline and a possible link with Richardson Trough in northern Yukon.

Most of the publications of the Geological Survey of Canada dealing with the Arctic Islands have been based on work carried out in the field; the present report is the first to be based primarily on subsurface data. As petroleum and mineral exploration in the Arctic Islands continues, studies of this nature will become more and more important in furthering out understanding of this complex and intriguing area.

PROTEROZOIC AND PALEOZOIC GEOLOGY

OF BANKS ISLAND, ARCTIC CANADA

ABSTRACT

Banks Island is the southwesternmost island of the Canadian Arctic Archipelago, comprising an area of 60100 square kilometres (23,200 sq miles). Proterozoic rocks crop out along the south coast and Upper Devonian strata are exposed in the northeast portion of the island. The remainder of Banks Island is covered by Mesozoic and Cenozoic sediments.

This report is concerned primarily with the subsurface stratigraphy, based on data obtained from the first four wells to be drilled in the area. A limited amount of surface data is also included as a result of the writer's field work in 1973 and 1974.

The oldest rocks exposed in the area are Late Proterozoic cherty dolomites and quartzose sandstones of Glenelg Formation comprising part of a craton sequence of mainly shallow marine origin.

A sequence of Cambrian to Middle Devonian strata 1200 metres (4,000 ft) thick overlies the Precambrian in Victoria Island. Cambrian to Silurian rocks are not exposed at the surface on Banks Island and have not been penetrated by any wells drilled to date; the succession in Banks Island is assumed to be similar to that of Victoria Island except that a westward transition from cratonic to geosynclinal facies may occur in the western part of Banks Island, similar to that which is now known to characterize the overlying Devonian rocks. The latter range in age from Lower to Upper Devonian and total an estimated 2400 metres (8,000 ft) in thickness.

Early and Middle Devonian strata display abrupt lateral facies changes. Blue Fiord Formation represents sedimentation on a shelf area which was confined mainly to the southern and eastern part of the island. The rocks are mainly carbonates. They pass laterally westwards and northwards into a basin slope facies, the calcareous shales of Orksut Formation, and these in turn pass laterally into siliceous shales comprising a deep basin facies, Nanuk Formation. The deep basin represents a southward extension of Hazen Trough and it probably linked to a similar basin in the northern Yukon area, Richardson Trough.

The facies belts underwent a southward migration during the Early and Middle Devonian. Commencing in the late Middle Devonian a clastic wedge (Melville Island Group) spread southward into the Banks Island area. The source of the detritus was probably a tectonic landmass to the west and north of the report area.

Rocks of Late Paleozoic age are not known in Banks Island. However, several lines of evidence suggest that strata of this age may have been deposited, but that they were removed in pre-Jurassic time. For example, the level of hydrocarbon maturation in the Devonian sediments is everywhere considerably greater than that of the Mesozoic deposits, suggesting deep burial before Mesozoic sedimentation commenced.

There is no evidence of any significant structural deformation of the Proterozoic and Paleozoic rocks other than normal faulting. Dips are generally less than 10°.

Hydrocarbon potential in the Paleozoic strata is considered to be fair. Stratigraphic traps may be present at the carbonate-shale facies change. In view of the high degree of maturity exhibited by these rocks, any hydrocarbons present are likely to be dry gas. The carbonate-shale facies change also has potential as a locus for sulphide ore enrichment.

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CHAPTER I

INTRODUCTION

Source of Data

Banks Island is the southwesternmost island of the Canadian Arctic Archipelago; it comprises an area of 60100 square kilometres (23,200 sq mi) and is the fifth largest island in Canada.

This report is concerned primarily with the subsurface Paleozoic stratigraphy of the island, as revealed by the first four wells to be drilled in the island. These four wells are as follows: Elf *et al.* Storkerson Bay A-15, rig release date 10 December, 1971; Elf Nanuk D-76, rig release date 4 March, 1972; Elf Uminmak H-07, rig release date 7 May, 1972; Deminex GGDC FOC Amoco Orksut I-44, rig release date 28 March, 1973. Locations are shown in Figure 1. In order to facilitate early release of the report, no information has been included from the later wells drilled in the area.

The four wells have all been logged by the author, using the chip samples and cores stored at the Institute of Sedimentary and Petroleum Geology, Calgary. Very few cores were cut in the Paleozoic portions of these wells (or, indeed, any portions) and the lithologic descriptions and age determinations must suffer, as a result. Chip samples are necessarily small, and owing to the different densities of the various lithologies, they rise to the surface in the mud stream at different rates. Depth determinations are thus imprecise unless they are coupled with interpretations of geophysical log character, as has been done in the present study.

A limited amount of new surface information is also included in this report, based on field work carried out by the author during the remapping of the island in 1973 and 1974. These new data include an incomplete section measured through the Weatherall Formation at Cape Crozier, a re-examination of the Early and Middle Devonian rocks of Princess Royal Island, new age information on the "Eids-like" outcrops of northwestern Victoria Island, and a stratigraphic and sedimentologic study of the Proterozoic sediments exposed at Cape Lambton and Nelson Head. Apart from the two sections through the Proterozoic, virtually all the new data presented herein pertains to the Devonian System. Only one well (Orksut I-44) penetrated strata that are possibly pre-Devonian in age.

Previous work

The only Paleozoic rocks exposed at the surface on Banks Island are Upper Devonian sediments, mainly clastics, comprising the Melville Island Group. They outcrop throughout the northeastern portion of the island and also in small inliers between Cape Crozier and Cape Wrottesley (Fig. 1). These rocks were first mapped and described by Thorsteinsson and Tozer (1962) and were later studied in more detail by Klovan and Embry (1971), Hills, Smith and Sweet (1971) and Harrington (1971). The biohermal reef tract near Mercy Bay received considerable attention at this time (Embry and Klovan, 1971). The first information on the Paleozoic rocks as they occur in the subsurface was published by Miall (1974a, c).

The Paleozoic succession of Banks Island is similar in many respects to that of northwestern Victoria Island (Thorsteinsson and Tozer, 1962). The strata of both areas were grouped into a single structural unit, Prince Albert Homocline, by Thorsteinsson and Tozer (1962). The present study shows that marked lateral facies changes appear in this homoclinal succession, proceeding westwards into the subsurface beneath Banks Island, none of which can be detected from any of the rocks now exposed.

The Hadrynian sediments of Victoria Island are similar to those exposed at Nelson Head. They have been described in detail by Young (1974).

Post-Paleozoic sediments of Banks Island are under study by the writer (Miall, 1974b, 1975a) and will be the subject of detailed reports to be published at a later date. At the time of going to press a summary account of the Jurassic to Tertiary history of the area had been made available (Miall, 1975b).

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Regional geological setting

The structural setting of Banks Island is shown in Figure 2, which is derived from the work of numerous authors, notably Thorsteinsson and Tozer (1960), Kerr (1974), Christie (1972) and Lerand (1973). As with all such maps, much is, of necessity, omitted in order to improve clarity. Tectonic units of different ages overlap one another, and attempts to provide all the relevant information lead only to confusion. A brief summary of the features shown in Figure 2 follows.

In the southeast corner of the map is the edge of the Canadian Shield. The Shield also projects northwards along a linear feature named Boothia Uplift, the northern end of which is shown at the right hand edge of Figure 2. Marginal to the Shield are large areas occupied by Proterozoic rocks. Some of these rocks are geosynclinal in origin and have been strongly deformed, for example those of Coronation Geosyncline. Others are cratonic in origin and have remained essentially undisturbed except for gentle regional tilting and block faulting. Coppermine Homocline, Brock Inlier, Minto Uplift, Duke of York High and Wellington High are characterised by rock sequences of this type. Rocks of widely varying age are included in the Proterozoic category, the details of which are not relevant to the present study (*see* Christie, 1972 and Young, 1974 for further discussions). It is sufficient to record that the cratonic sequences listed above are mainly of younger Proterozoic (Helikian and Hadrynian) age and reach many thousands of feet in thickness. The thickest is that of Coppermine Homocline, where Baragar and Donaldson (1973) estimated a maximum of 8500 metres (28,000 ft) of sedimentary and volcanic rocks. Minto Uplift, which is the closest of these areas of Proterozoic rocks to the present report area, is underlain by 3700 metres (12,000 ft) of youngest Proterozoic (Hadrynian) rocks (Thorsteinsson and Tozer, 1962).

Christie (1972, p. 45) grouped all the cratonic Proterozoic sequences of the western Arctic into a single depositional assemblage, and he interpreted them all as having been deposited within the same depositional basin which he named Amundsen Basin. However, the unity of the Basin has been partly obscured by later sedimentary and tectonic events. As Young (1974) pointed out, the basin was bounded on the south and east by the Shield but, during Proterozoic times, was probably open to the west and north. He renamed the basin Amundsen Embayment.

Large areas of the craton along the borders of the exposed Shield are now underlain by Cambrian to Devonian rocks, comprising the Central Stable Region. Epeirogenic movements of uncertain, but probably in part post-Devonian, age have divided the Central Stable Region into broad basins, platforms and highs, and erosion on the highs subsequently revealed the Proterozoic rocks beneath. Structural units made up of Paleozoic cratonic sequences include Mackenzie Platform, Wollaston Basin, Prince Albert Homocline, Melville Basin and M'Clintock Basin. Part of Banks Island is underlain by the rocks of Prince Albert Homocline, which was estimated by Thorsteinsson and Tozer (1962) to comprise at least 2400 metres (8,000 ft) of Cambrian to Devonian strata. The present study shows that on Banks Island the Devonian succession, alone, is at least this thick.

The cratonic sequences pass laterally into geosynclinal rocks in the Cordillera west of the Mackenzie River and in the central Arctic Islands. The Cordilleran Orogen has had a complex stratigraphic and tectonic history spanning the late Proterozoic and most of Phanerozoic time (Lenz, 1972; Norris, 1973). Geosynclinal conditions in the Arctic Islands were, however, confined as far as is known to the Late Proterozoic to Devonian time interval (Trettin *et al.*, 1972). The shallower water, miogeosynclinal portions of the geosyncline were deformed during Early to Late Devonian times giving rise to Cornwallis Fold Belt, and again in the Late Devonian or Early Mississippian Ellesmerian Orogeny, creating Parry Islands Fold Belt and Central Ellesmere Fold Belt (not shown on Fig. 2). The deeper water, axial portion of the geosyncline has been named Hazen Trough by Trettin (1971a). Its sediments are now largely covered by Late Paleozoic to Tertiary deposits.

Evidence will be presented in this report to suggest that deep water, geosynclinal conditions also extended along the west side of Banks Island during the Paleozoic and possibly connected with a similar paleogeographic environment in northern Yukon. Whether a deformed belt similar to that of the Parry Islands also extends along this alignment remains to be demonstrated.

Sverdrup Basin is a successor basin which partly overlaps the Franklinian Geosyncline (Trettin *et al.*, 1972); the rocks within it are of Late Paleozoic to Early Tertiary age and reach thicknesses as great as 12000 metres (40,000 ft). Of similar age is Beaufort-Mackenzie Basin, which contains approximately 9000 metres (30,000 ft) of Jurassic to Late Tertiary sediments (Lerand, 1973). Thinner sequences accumulated in several relatively small pericratonic basins and troughs adjacent to these two major depocentres; they include Anderson Basin, Banks Basin and Eglinton Graben. Post-Paleozoic sediment thicknesses here probably do not exceed 3000 metres (10,000 ft). Part of this area is described by Miall (1975b).

Overlapping all these regions of Late Paleozoic, Mesozoic and Tertiary sedimentation is the Arctic Coastal Plain. This comprises a thin wedge

of Miocene sediments, which thickens markedly offshore and probably includes younger units of Pliocene to Recent age.

CHAPTER II

STRATIGRAPHY

Introduction

In order to place the rocks underlying Banks Island in their proper context it is necessary to include in this introductory discussion some descriptions of these rocks as they occur on Victoria Island, for the reason that some of the units are much more completely exposed in the latter area.

The Precambrian rocks of Minto Uplift (Fig. 2) have been divided into nine map units by Thorsteinsson and Tozer (1962). These are, from the base, or oldest, upwards:

1. A formation of metasediments consisting predominantly of quartzite and probably of Archean age (McGlynn, *in* Stockwell *et al.*, 1970, p. 84).
2. A granodiorite body which is thought to intrude the rocks of map unit 1. It has yielded a potassium-argon age of 2405 million years (Thorsteinsson and Tozer, 1962, p. 25).

Overlying these rocks is a series of five sedimentary formations which were grouped by Thorsteinsson and Tozer into the Shaler Group. The individual units are:

3. Glenelg Formation: sandstone, carbonate rocks.
4. Reynolds Point Formation: limestone, minor clastic rocks.
5. Minto Inlet Formation: evaporites, minor clastics and carbonates.

6. Wynniat Formation: carbonate rocks, minor clastics.

7. Kilian Formation: evaporites, minor clastics and carbonates.

The Shaler Group is followed by:

8. Natkusiak Formation: basalts flows, minor agglomerate.

The remaining unit constitutes:

9. Gabbro dykes and sills.

Map unit 9 represents rocks which intrude Shaler Group sediments. The gabbros have been dated as 635-640 m.y. (Christie, 1964, p. 10) indicating a Late Proterozoic (Hadrynian) age. Shaler Group is also believed to be of Hadrynian age although there is no conclusive evidence for this interpretation. The five formations comprising Shaler Group include approximately 3350 metres (11,000 ft) of strata, and the Natkusiak Formation is in the order of 300 metres (1,000 ft) in thickness.

The inliers of Precambrian rocks in southern Banks Island were assigned by Thorsteinsson and Tozer (1962, p. 28) to the Glenelg Formation, on the basis of lithologic similarity to the rocks of the type area. This correlation is followed in the present report (Table 1). It is unknown whether any of the other Precambrian units described above are present beneath Banks Island.

Two members may be recognised in the Glenelg Formation of Victoria Island. The lower member consists of sandstone, shale, siltstone and dolomite totalling 610 metres (2,000 ft) in thickness, and the upper member comprises 370 metres (1,200 ft) of sandstone plus stromatolitic dolomite. A similar subdivision may be made in the Glenelg of southern Banks Island, although the formation is incompletely exposed. A lower unit 87 metres (285 ft) in thickness is exposed at Cape Lambton and consists primarily of dolomite and chert. Much of the dolomite is stromatolitic. An upper unit, consisting of sandstone plus minor siltstone and shale is exposed in the sea cliffs of Nelson Head. A thickness of 393 metres (1,289 ft) of sedimentary rocks is exposed in this area, and several tens of metres of gabbro sills are also present. Detailed descriptions of these rocks are given in Appendix II of this report and a graphic log is provided in column 7 of Figure 3.

The Paleozoic rocks on the northwest flank of Minto Uplift form a gently dipping structural unit named Prince Albert Homocline. Approximately 2400 metres (8,000 ft) of Cambrian to Upper Devonian strata were estimated by Thorsteinsson and Tozer (1962) to be present in this unit. The present study shows that on Banks Island the Devonian succession, alone, is at least this thick. Rocks of Late Devonian age are the only part of this succession exposed at the surface in Banks Island, but the wells described in this report penetrate strata as old as Early Devonian, or possibly Silurian, in age. Cambrian to Silurian rocks on Victoria Island have been subdivided into three units (Thorsteinsson and Tozer, 1962). As very similar strata

TABLE I. TABLE OF PROTEROZOIC AND PALEOZOIC FORMATIONS, BANKS ISLAND

Period	Stage	Group	Formation	Subsurface Thickness (feet), surface thickness in brackets where known	Lithology
Devonian	early to middle Famennian	Melville Island Group	Griper Bay Fm.	640+ (910+)	Fine to very fine grained, quartzose sandstone; siltstone; medium grey, silty shale; dark grey, carbonaceous shale, minor coal.
	late Frasnian		Hecla Bay Fm.	140(140)	Fine-grained sandstone; minor shale, siltstone.
	Givetian Frasnian		Weatherall Fm.	1930+ (2610+)	Fine to very fine grained quartzose sandstone, siltstone, shale, minor coal, minor dolomite.
	Emsian, Eifelian		Nanuk Fm.	650	Siliceous shale; chert, minor calcareous shale; minor silty shale.
	Emsian, Eifelian, Givetian, ?Frasnian		Orksut Fm.	50-1300	Calcareous shale; silty shale; minor argillaceous limestone, minor siltstone.
	?Siegenian Emsian Eifelian		Blue Fiord Fm.	500-2270	Fossiliferous limestone; dolomite; minor shale; minor siltstone.
?Silurian-Devonian			Unnamed dolomite-shale formation	160	Fine-grained dolomite, grey shale.
			Unnamed dolomite formation	320	Fine grained, argillaceous dolomite.
UNCONFORMITY					
Proterozoic			Glenelg Fm. upper member	(1300+)	Fine to medium-grained sandstone, minor siltstone, shale.
			Glenelg Fm. lower member	(290+)	Dolomite, chert.

may be present in the deep subsurface of Banks Island a brief description of the Victoria Island succession is included below.

The oldest Paleozoic unit comprises a maximum of 120 metres (400 ft) of sandstone, shale, siltstone and dolomite, dated as Upper Cambrian on the basis of chitinoid brachiopods. The formation, which is unnamed, infills topographic lows in the Precambrian erosion surface. Overlying the Cambrian rocks and cropping out over wide areas of Victoria Island is a texturally monotonous dolomite unit of Middle Ordovician to Middle Silurian age. Complete sections through this succession are not available but Thorsteinsson and Tozer (1962, p. 19) estimated the thickness at 900 metres (3,000 ft). Elsewhere in the Arctic Islands, notably in the Franklinian Miogeosyncline, rocks of this age range and general lithologic character have been subdivided into Cornwallis Group of Middle and Upper Ordovician age (Kerr, 1967) and Allen Bay Formation, of Upper Ordovician and Silurian age (Thorsteinsson and Fortier, 1954).

On Victoria Island and Stefansson Island the unnamed dolomites are succeeded by Read Bay Group. The Read Bay was first defined as a formation by Thorsteinsson and Fortier (1954) from their work in Cornwallis Island, and the name has subsequently been used in many parts of the Arctic Islands. The formation consists predominantly of limestone, with minor sandstone and shale, and is Wenlockian to Gedinnian in age. On Stefansson Island a different situation prevails, in that rocks of Read Bay age were subdivided by Thorsteinsson and Tozer (1962) into three units, each of formation status. For this reason Thorsteinsson and Tozer redefined the Read Bay as a Group for local usage, although no names were assigned to the three formations.

The lowest of the three units is a limestone and dolomite formation 120 metres (400 ft) thick, containing an *Atrypella* fauna which was interpreted as indicating an Upper Wenlockian to Ludlovian age range and a correlation with the lowest member of the Read Bay on Cornwallis Island. The second unnamed formation on Stefansson Island consists of shale that is variably calcareous and which has yielded a graptolite fauna of lower Ludlovian age. The shales are 38 metres (125 ft) thick. The youngest unit in Read Bay Group is a grey, thin-bedded dolomite at least 46 metres (150 ft) thick, which has yielded no fossils. Its stratigraphic position would suggest a correlation with the upper part of Read Bay Formation of the type area.

The oldest rocks yet penetrated by drilling on Banks Island are interpreted to be of Upper Silurian or Lower Devonian age. The unnamed dolomite formation in the Orksut I-44 borehole, of which 98 metres (320 ft) were penetrated, may be equivalent to either the oldest or youngest of the three formations within Read Bay Group. If the former, then the overlying dolomite-shale formation in the Orksut section may correlate with the graptolitic shale unit of Stefansson Island. These correlations are purely speculative as no fossil evidence is available at the time of writing. In age and general lithology a partial correlation between the two oldest units at Orksut and the Gossage Formation (Tassonyi, 1969) of the Arctic Mainland is also indicated.

Blue Fiord Formation is the youngest unit that was positively identified by Thorsteinsson and Tozer (1962) on Victoria Island. The formation was originally defined by McLaren (1963a) from limestone exposures at Blue Fiord in southwestern Ellesmere Island, where it is 1160 metres (3,800 ft) thick and was dated by McLaren as Eifelian. However, subsequent work has shown that, in fact, the rocks in the type section are probably Emsian in age (Harper *et al.*, 1967, p. 430; T. T. Uyeno, pers. com. 1974). The Blue Fiord has been shown to be Emsian to Eifelian in age on Bathurst Island (Kerr, 1974) and also on Melville Island (McGregor and Uyeno, 1972). Limestone outcrops yielding an Eifelian fauna were recorded by Thorsteinsson and Tozer from the northwest coast of Victoria Island and were duly assigned to Blue Fiord Formation. This correlation is probably correct, in spite of the changes that have been made in the interpretated age range of the type section.

On Banks Island Blue Fiord Formation has been penetrated in two wells: at Storkerson Bay, where a late Emsian conodont fauna was recovered 20 metres (66 ft) from the top of the formation; and at Orksut, where a late Emsian conodont fauna was recovered 526 metres (1,725 ft) from below the top of the formation. The unfossiliferous strata overlying the dated horizon at Orksut probably range up into the Eifelian. If this is the case then the top of the formation in Banks Island is diachronous. As shown in Figure 4 it indicates a gradual southward migration of facies belts during Early and Middle Devonian time.

Diachroneity is a problem that has hindered our understanding of much of the Early and Middle Devonian stratigraphy of the Arctic Islands. In no case is this more true than in the example of the Eids Formation. A discussion of Eids stratigraphy is very relevant to the present report as strata similar in "lithological and faunal facies" to the Eids Formation of the type area have already been identified in Victoria Island (Thorsteinsson and Tozer, 1962, p. 51), and the name has been applied informally by industry geologists to certain of the beds which overlie the Blue Fiord Formation in the subsurface in Banks Island. The name is not used in this report, for reasons that will be explained below.

The Eids Formation was first defined by McLaren (1963a) in south-western Ellesmere Island, where it consists of calcareous shale, calcareous siltstone, black calcareous mudstone, minor dolomitic limestone and minor bioclastic limestone, and was dated by McLaren (1963a, p. 318) as Early or Middle Devonian. The formation underlies the Blue Fiord in the type area. As noted above, the Blue Fiord is now known to be itself largely Emsian in age in Ellesmere Island. The Eids is thus older, and recent work by Trettin (1974) has shown that the formation is probably entirely Lower Devonian in age in Ellesmere Island.

The Eids Formation has also been recorded on Bathurst Island. It was first recognised there by McLaren (1963b), and consists of grey limy mudstone and shale, with some beds of argillaceous limestone. Gypsum is present in places. Kerr (1974, p. 40) has shown that the age range of the formation varies from place to place; it is partly overlain by and partly a lateral equivalent of Blue Fiord Formation, and includes beds as old as Emsian and as young as Eifelian.

It is thus known now that in two different localities the age ranges of the Eids outcrops are so different as to barely overlap one another. As a stratigraphic unit the Eids is thus very poorly defined.

As well as being given a time connotation (however contradictory the evidence) the name Eids has also been used in a facies sense. Thus Kerr (1974, p. 38) stated that the Eids is "the basinal equivalent of nearly all of the Disappointment Bay and Blue Fiord Formations of the shelf". Trettin (1974, p. 358) described an Eids mudstone facies in central Ellesmere Island which he regards as "the last phase in the filling of the Hazen Trough". This facies passes eastwards into a carbonate facies for which various shallow water environments have been interpreted.

The lithofacies and the paleogeographic environment of the beds overlying Blue Fiord Formation on Banks Island immediately suggest an allocation of these strata to the Eids. However, there are two reasons for not using this name. The diversity in age that has been demonstrated for the Eids of the central and eastern Arctic indicates that a redefinition of the term Eids is now necessary. Secondly, nowhere in the Arctic has the Eids Formation been mapped as overlying Blue Fiord Formation. To introduce this sequence of names in Banks Island would only add to the confusion. For these reasons a new name, Orksut Formation, is erected in this report. The Orksut consists of calcareous shale, silty shale, minor argillaceous limestone and siltstone. The formation reaches its thickest development in the Orksut I-44 well, where it includes 392 metres (1,285 ft) of beds. It ranges in age from Emsian to late Givetian or early Frasnian, although owing to lateral facies changes the formation does not span this entire time interval in any one locality (Fig. 4).

The Orksut is analogous to the Prongs Creek Formation (Norris, 1968) of northern Yukon. The lithologies are similar, and the Prongs Creek also shows a variable age range (Gedinnian to Eifelian) and a lateral transition into shelf carbonates (Lenz, 1972, p. 346).

Contemporaneous strata in the axial portions of the Franklinian Geosyncline are of several facies. The Ibbett Bay Formation of Melville Island is of Lower Ordovician to late Lower Devonian age and consists of graptolitic shale, argillite, minor chert and dolomite (Tozer and Thorsteinsson, 1964). This unit is overlain by the precursors of a major clastic wedge which subsequently filled the entire axial trough of the geosyncline. The clastic rocks are named Melville Island Group (Tozer, 1956; Tozer and Thorsteinsson, 1964), and the oldest unit on Melville Island is Weatherall Formation of Eifelian and Givetian age.

The Nanuk Formation, as herein defined, represents the deeper water environment on Banks Island. It consists of siliceous shale, chert, minor calcareous shale and minor silty shale, and is assigned an Emsian and Eifelian age range. As such the formation is similar in lithology to the Ibbett Bay, but is partly or even entirely younger than that formation. In paleogeographic terms the Nanuk represents an extension southwards of Hazen Trough, and it would seem likely that the formation represents a tongue (a diachronous tongue) of the Ibbett Bay. However, until this relationship can be conclusively demonstrated, the radically different age ranges of the two units precludes the use of a common name for these beds.

As in the case of the Orksut Formation, a deposit analogous to the Nanuk Formation is to be found in northern Yukon. These are black, siliceous shales similar to the Canol Formation of Mackenzie Platform (Bassett, 1961; Tassonyi, 1969). The type Canol Formation is mainly Frasnian in age, but it probably represents a relatively thin tongue of a deposit that had a much greater age range in Richardson Trough of northern Yukon. As Lenz (1972, p. 351) stated: "it is virtually impossible at any one locality to distinguish the lithologic character of Middle Devonian from Upper Devonian black, siliceous shales; that is, between 'true' Canol shale and possibly other black, siliceous, bituminous shales." According to Lenz (1972, p. 349) the base of these shales varies in age from Emsian or Eifelian to late Givetian from locality to locality.

The Melville Island Group overlies Nanuk Formation and is represented by at least 1800 metres (6,000 ft) of beds in Banks Island. The unit was first defined as a formation by Tozer (1956, p. 14) for a thick sequence of Devonian clastic sediments that outcrop on the west coast of Melville Island. Later work by Tozer and Thorsteinsson (1964) resulted in the elevation of the unit to group status and the recognition of three formations within the group. These were named the Weatherall, Hecla Bay and Griper Bay Formations. The Weatherall of the type area in eastern Melville Island consists of 1400 metres (4,600 ft) of thin bedded, marine sandstone, siltstone and shale, and is dated by McGregor and Uyeno (1972) as late Eifelian and Givetian. The Hecla Bay Formation comprises 550-790 metres (1,800-2,600 ft) of nonmarine sandstone of late Givetian to early Frasnian age. The Griper Bay Formation consists of at least 910 metres (3,000 ft) of marine sandstone, shale, siltstone and thin coal seams, dated as early Frasnian to early Famennian in age.

The Melville Island Group is the only Paleozoic rock unit exposed at the surface on Banks Island. The outcrops were described by Thorsteinsson and Tozer (1962) before the Group was formally subdivided into three formations. However, Thorsteinsson and Tozer made tentative lithologic comparisons between the Banks and Melville Island areas, most notably that between a prominent sandstone unit 43 metres (140 ft) in thickness exposed in the sea cliffs facing M'Clure Strait, and map unit 7 of Thorsteinsson and Tozer (1959). The latter was the unit subsequently renamed the Hecla Bay Formation. This correlation was followed by Klovan and Embry (1971) who studied the stratigraphy and sedimentology of the Banks Island outcrops in greater detail. They recognised the three formations, Weatherall, Hecla Bay and Griper Bay in a composite section 1116 metres (3,660 ft) thick, measured along the coastline of northeastern Banks Island.

However, work by Hills *et al.* (1971) showed that the Banks Island section measured by Klovan and Embry ranges in age from early Frasnian to middle Famennian, which falls almost entirely within the age range of the Griper Bay Formation of the type area, on eastern Melville Island (McGregor and Uyeno, 1972). The use of the three formation names on Banks Island is therefore appropriate only in the sense that they imply certain facies characteristics, as will be discussed below. Recent work by Embry and Klovan (1974) has shown that the ages of the various facies vary markedly across the Parry Islands, and that a major stratigraphic revision is necessary. However, the terminology of Klovan and Embry (1971) is used in the present discussion in order to facilitate comparisons between the surface and subsurface in the project area. Beds of Givetian age which have been assigned to the Weatherall Formation occur in the Storkerson Bay well, and in outcrop along the west side of Prince of Wales Strait. Above the Hecla Bay sandstone there is a significant break in megaspore flora which Hills *et al.* (1971) interpreted as a regional unconformity.

Melville Island Group is part of a wedge of Upper Devonian clastic sediments that extends through the entire North American side of the Arctic, from Ellesmere Island, west through Parry Islands Fold Belt, Banks Island, northern Yukon, northern Alaska and Wrangel Island, which is located off the north coast of Siberia. Most regional interpretations (Tailleur and Brosgé, 1970; Miall, 1973; Trettin *et al.*, 1972) assumed a northerly source area for the detritus, in the form of a landmass that has now disappeared. However, Embry and Klovan (1974) proposed that the major source area for the Canadian portion of the clastic wedge was located in Greenland. This controversy will be discussed at greater length in Chapter IV.

Rocks of post-Devonian, pre-Jurassic age have not been identified in the Banks Island area, but as discussed in the latter part of this chapter there is evidence that strata of this age may have been deposited and subsequently eroded prior to Jurassic time.

Description of Formations

Proterozoic

Glenelg Formation

Definition, distribution and thickness. Glenelg Formation was first defined by Thorsteinsson and Tozer (1962, p. 26). It is the oldest of five units which comprise a conformable sedimentary succession named Shaler Group (op. cit., p. 25). The Glenelg has a widespread area of outcrop within Minto Uplift on Victoria Island, and the type area for the formation was established at Glenelg Bay, near the northeast end of the Uplift. Two members are present (though only the upper member is exposed at Glenelg Bay, according to Thorsteinsson and Tozer, 1962, p. 26). The lower member is 610 metres (2,000 ft) thick and consists of red, white and grey, fine- to medium-grained sandstone and orthoquartzite; dark grey shale; red and grey, thin-bedded siltstone and grey, aphanitic dolomite. The upper member of the formation is at least 366 metres (1,200 ft) thick and consists predominantly of light grey to red, fine- to medium-grained sandstone. A unit of stromatolitic dolomite 18-38 metres (60-125 ft) thick occurs at the top of the formation. Sills intruding these rocks at Glenelg Bay have yielded dates of 635 and 640 m.y. (Christie, 1964, p. 10), indicating that Shaler Group is not younger than Late Proterozoic in age. No other direct evidence for the age of the group is available. At present it is assigned a latest Proterozoic (Neohelikian or Hadrynian) age by McGlynn (in Stockwell *et al.*, 1970, p. 84).

The outcrops at Nelson Head were tentatively assigned to the Glenelg Formation by Thorsteinsson and Tozer (1962, p. 28) on the basis of lithologic similarity with the rocks of the type area. This correlation is tentatively followed in the present report, and the same subdivision into two members is also retained.

The lower, cherty dolomite member is exposed at Cape Lambton (Fig. 5, Plate IA) where it is 87 metres (285 ft) thick, and the upper sandstone member was studied at Nelson Head (Plate IB) where a section 393 metres (1,289 ft) thick was measured. Both the sections are incomplete, and the full thickness of the two members may thus be considerably greater. As shown in Figure 5, the upper member of the Glenelg is exposed along the coast north of Cape Lambton as far as the mouth of Rufus River. Exposures of Precambrian rocks are also present inland, on Rufus River and Pass Brook, where they occur as inliers beneath Cretaceous and glacial cover. The inland exposures are all of diabase gabbro and are presumed to represent the sills which intrude the Glenelg.

The Glenelg is probably also present at depth beneath the Paleozoic rocks in central and northern Banks Island, but has yet to be reached by exploratory drilling. The Orksut well bottomed at 3,060 metres (10,040 ft) in Late Silurian (?) rocks, an estimated 600 ± metres (2,000± ft) above the Precambrian.

The Glenelg and the overlying Reynolds Point Formation have recently received attention by Young (1974), who has studied their stratigraphy, paleocurrents and stromatolites in various parts of Victoria Island. The present work confirms and amplifies many of Young's conclusions regarding sedimentary environments and paleogeography, as discussed below.

Lithology. The lower member of the Glenelg, as studied at Cape Lambton (Fig. 5), consists of approximately 80% dolomite and 20% chert. The dolomite consists primarily of microspar, interlocking rhombs 10-50μ in diameter, with occasional larger rhombs, many of them of fracture-infill origin. On the macroscopic scale the dolomite is medium grey in colour and thin to massive bedded; few primary sedimentary textures are preserved (Plate IA). Flat-pebble dolomite breccia is the only texture that has been observed at Cape Lambton. Chert is present in blebs, lenticles and persistent strata-bound seams (Plate IIA). Many of the more laterally persistent chert beds are stromatolitic, the stromatolites occurring as low amplitude ripple-like undulations or small, well formed, laterally linked domes (Plate IIB). In detail the chert beds are commonly vuggy and contain patches of clear quartz showing a mosaic or spherulitic texture. The latter may represent replaced ooliths.

Numerous fractures are present in these cherty dolomites, many are filled with pyrite. Minute traces of copper mineralization are also present.

The upper member of the Glenelg, at Nelson Head, consists predominantly of thick units of sandstone. Approximately 15% of the section comprises interbedded very fine sandstone, siltstone and silty mudstone, and at the top of the Nelson Head section there is a shale unit 12 metres (40 ft) thick.

The sandstones are very fine to medium grained and pink to medium reddish brown in colour, with the exception of a unit 58 metres (190 ft) thick near the top of the section (the pale unit near the top of the cliff in Plate IB) which is cream in colour and yellowish weathering. Bedding varies from fine lamination to massive. Heavy mineral concentrations are commonly present, in most cases as laminae a few grains thick, repeated over a few decimetres of section at the rate of up to 15 laminae per centimetre. The petrography of five typical sandstone specimens is shown in Table 2. The three specimens from the lower part of the section (15, 75 and 94 m levels) are regarded as typical of the red sandstones; the sample from 125 metres is a sandstone containing heavy mineral laminae, and the sample from 325 metres is from the pale coloured unit near the top of the section. All the sandstones are silica cemented; the extent of the cementation varies in inverse proportion to the amount of clay matrix present. In the pure quartz sandstone from the 325 metre level the quartz grains display an interlocking mosaic texture with abundant stylolitic contacts. In those sands containing more clay matrix clay films on grain surfaces are common. In these cases the grains rarely display interpenetrating relationships. They have preserved their original outlines, which vary from subangular to well rounded. The strongly silica-cemented sandstones must have undergone considerable pressure solution and authigenic growth, but very little trace of this is left in the form of ghost grain outlines. Porosity in every case is very low to nil. In terms of Okada's (1971, Fig. 5) sand classification, the 325 metre sample is a quartz arenite and the remaining samples indicate a gradation from quartzose arenite to quartzose wacke.

The units of interbedded sandstone, siltstone and mudstone (Plate IIIA) show a colour-banded appearance, the finer grained lithologies being dark red-brown in colour, and the sandstones pink. Most of the sandstones are lenticular in nature, reaching maximum thicknesses of 10 centimetres and showing undulating top surfaces, reflecting their origin as low amplitude mega-ripples with wavelengths of approximately 1 metre. The petrography of all these lithologies is assumed to be similar to that of the sandstones described above although it has not been studied in detail. The siltstones and mudstones commonly contain a scattering of detrital muscovite readily visible to the naked eye.

The shale at the top of the Nelson Head section is medium greenish grey in colour and contains thin lenticles of white, quartzose, fine-grained sandstone extending laterally for a distance of from less than 1 metre to more than 30 metres.

Sedimentary Structures and Paleocurrents. Planar crossbedding is very common in the sandstones; the example shown in Plate IIIB is typical. The cross-sets have non-erosional lower surfaces and eroded

TABLE II. SANDSTONE PETROGRAPHY, GLENELG FORMATION, NELSON HEAD

Per Cent Clastic Grains (Approximately 200 Grains Counted Per Section)

Position in Section	Quartz	Chert	Orthoclase[x]	Plagioclase	Microcline	Muscovite	Ilmenite*	Sphene	Zircon	Detrital Limonite	Detrital Clay	Per Cent Clay Matrix	Notes
325 m	100	-	-	-	-	-	-	-	-	-	tr	3	
125 m	73	tr	7	-	tr	tr	9	5	1	5	-	21	Heavy mineral laminae present. tr aegirine?
94 m	73	1	18	tr	-	-	-	-	-	8	-	13	Some limonites are decomposed ferromags.
75 m	85	-	13	tr	tr	1	-	-	-	1	-	23	
15 m	93	1	4	tr	-	tr	1	-	-	1	-	5	tr aegirine?

*Probably includes some magnetite
[x]Identified by staining with sodium cobaltinitrite using Chayes's method (Allman and Lawrence, 1972, p. 107)

upper surfaces. They range in thickness from 6.5 to 54 centimetres with an average (arithmetic) of 20.4 centimetres. Foreset dip ranges from 7 to 25 degrees, except where the cross-sets have been deformed, as discussed below. This type of crossbedding conforms to the description of alpha-cross-stratification of Allen (1963, p. 101) and it is thought to have been formed by the migration of low amplitude sand waves or by prograding avalanche faces at the down-current ends of sand bars.

Many of the planar cross-sets are deformed, such that the upper portion of the foresets is overturned in a downcurrent direction (Plate IVA). The deformation is cylindrical, i.e. the dip of the overturned foresets is oriented at 180° to the dip of the non-overturned foresets. Similar structures have been observed by Young (1974, p. 23) in the upper clastic unit of the Glenelg, near Hadley Bay. Such structures are not uncommon in cross-bedded sands. Experimental work by McKee *et al.* (1962) and field observations on some Tertiary-Cretaceous examples by Rust (1968) have led to the interpretation that the deformation is caused by the shear stresses induced in soft, water-saturated sediments by the passage of a sediment-laden current. Allen and Banks (1972) show that liquefaction of the sediments is important, and they suggest that the most likely cause of this condition is repeated shocks induced by earthquakes.

Other sedimentary structures of value as paleocurrent indicators in the sandstone units include abundant parting lineations (Plate VB) and rare trough crossbeds (theta-cross-stratification of Allen, 1963). Non-directional features include load structures, caused by the density differential between quartzose sands and heavy mineral laminae in unconsolidated sands (Plate IVB). Dendritic growths of pyrite(?) along bedding planes are rarely present; they are a diagenetic feature.

In the finer grained sandstones and the interbedded siltstones and mudstones, small-scale ripples are the dominant sedimentary structure. These vary in form from straight-crested to sinuous and bifurcating (Plate VA). Amplitudes vary from a few millimetres to a few centimetres. The strongly asymmetric nature of most of the small-scale ripples suggests that they are current-formed rather than of wave-origin. In addition to solitary ripple trains, climbing ripples of kappa type (Allen, 1963) are also rarely present. The larger scale, low amplitude sand waves in this lithofacies have been referred to earlier. Desiccation cracks and load casts are also rarely present.

Measurements of foreset dip direction and set thickness were made on 35 planar crossbed sets and measurements of lineation orientation were made on 18 examples of parting lineation in order to determine sediment transport directions. Both sets of measurements indicate unimodal current directions, with a mean indicating transport from southeast to northwest. Parting lineation is ambiguous as a paleocurrent indicator. Thus in the example shown in Plate VB there is nothing to indicate whether flow was to the left or to the right. However, where other data are available, as in the present case, the correct alternative may be assumed to be that which is closest to the independently derived mean azimuth. The data are shown in detail in Table III and in Figure 5. Vector mean azimuth, vector strength and the Rayleigh probability test were calculated according to the method of Curray (1956). Weighting was carried out using the method of Miall (1974d), whereby each reading is weighted according to the cube of crossbed set thickness. Variance (S^2) was derived from vector magnitude per cent (L) using the graph of Curray (1956, Fig. 3).

Age and Correlation. A Neohelikian or Hadrynian age for the Glenelg is assumed on the basis of stratigraphic relationships observed on Victoria Island and comparisons with the Arctic mainland (McGlynn, *in* Stockwell *et al.*, 1970, p. 84). Two whole-rock K-Ar dates of 635 and 640 m.y. were obtained on samples of the diabase sills (Christie, 1964, p. 10). The Glenelg is the lowest of five units comprising Shaler Group (Thorsteinsson and Tozer, 1962).

According to Christie (1972, p. 45) these rocks may be correlated in a general way with other Late Precambrian sediments occurring in the Brock River, Coppermine River and Bathurst Inlet regions. These rocks are all thought to have been deposited within a single sedimentary province, to which Christie assigns the name Amundsen Basin. The southern margins of the basin are located within the Canadian Shield. The eastern margin

TABLE III. PALEOCURRENT DATA, UPPER GLENELG FORMATION, NELSON HEAD

Structure Type	n	Unweighted u Weighted w	$\bar{\theta}$	L	S^2	P	Rose diag. no. in Fig. 5
Planar CB	35	u	337	64.2	2920	$<10^{-6}$	1
Planar CB	35	w	358	43.2	5780	.001	2
Parting lin.	18	u	295	80.7	1430	$<10^{-5}$	3
Combined data	43	u	321	65.2	2810	$<10^{-9}$	4

n = Number of observations, $\bar{\theta}$ = vector mean azimuth, L = vector strength, per cent, S^2 = variance, P = probability of randomness (Rayleigh test) is Wellington High, a northwesterly trending inlier of Precambrian rocks located in southern Victoria Island. The northern and western margins of Amundsen Basin are not known.

Depositional Environment

The stromatolites in the cherty dolomite member indicate a marine, probably shallow water depositional environment. Very little other evidence is available concerning the depositional environment of the cherty dolomite member of Banks Island. The stromatolites studied by Young (1974) in the Glenelg of Victoria Island almost invariably contain a flat pebble conglomerate at the base which also suggests that growth was initiated under shallow water conditions. On Victoria Island stormatolite orientations provide evidence of tidal currents and of fluvially controlled current directions (Young, 1974).

The thick sandstone units of the upper member of the Glenelg Formation are believed to have been deposited under a fluvial or proximal deltaic regime. This is indicated by several lines of evidence:

1. The relative textural and mineralogical immaturity of the pink sandstones (moderate abundance of feldspar grains and clay matrix) suggests the inhibition of mechanical weathering and current winnowing processes by fairly rapid deposition.

2. Paleocurrent directions are virtually unimodal (Fig. 5), which is a strong indicator of a fluvial or deltaic environment.

3. Alpha-type cross-stratification and parting lineation are typically formed under fluvial conditions. Planar cross-sets of alpha type commonly develop as prograding avalanche faces at the down-current ends of fluvial sand bars, as illustrated by Potter and Pettijohn (1963), Williams (1971) and Picard and High (1973). Parting lineation is caused by grain alignment during a certain type of flow condition when bed morphology is virturally planar. This occurs at low velocity during the upper flow regime, as defined by Harms and Fahnestock (1965). Parting lineation is common in fluvial environments (see same references as for planar crossbedding).

The sand units of the upper Glenelg consist of tens of metres of fine- to medium-grained sand with negligible quantities of interbedded siltstone or shale. Such assemblages are typical of braided, bed-load stream systems which, according to Schumm (1968) were the predominant stream type in pre-vegetation geological time. The lack of vegetation meant that sediment was not trapped for chemical weathering but tended to be transported as soon as it was capable of movement. Sheet-like piedmont deposits composed predominantly of sandy sediment were thus the characteristic fluvial deposit.

The units of interbedded sandstone, siltstone and mudstone probably represent intertidal deposits. They resemble the "tidal bedding" deposits of Wünderlich (1970) and the "mid-tidal flat" environment of Klein (1971). The resemblance includes the rapid alternation of lithologies of widely varying grain size, the predominance of small-scale ripple crossbedding, and the presence of sand lenticles of megaripple origin. Paleocurrent measurements were not made to check this interpretation.

The sandstone facies and the facies of interbedded sandstone, siltstone and mudstone alternate with one another and appear to have gradational contacts with each other. Only in one instance was an unmistakeable erosion surface observed; a unit of red-brown, silty sandstone rested on a medium grained pink sandstone with an erosional cut-and-fill, showing a maximum vertical relief of 7 centimetres. But for this one exception the upper member of the Glenelg therefore appears to represent a gradual alternation of tidal flat and fluvial-deltaic conditions. The alternation may have been brought about by lateral migration of deltaic distributaries or by contrasts between rate of subsidence and rate of sediment supply. Environments of this type have been described as fan-deltas by McGowen and Scott (1974).

The clean quartz arenite near the top of the Nelson Head section may represent a higher energy deposit, as suggested by its relatively greater textural and mineralogical maturity. A low tidal flat (Klein, 1971) or offshore bar environment may have been the origin. This unit passes up into a shale, of probable open marine origin. The upper 100 metres of the Nelson Head section thus appears to represent a gradual marine transgression. Regional comparison with the Glenelg of Victoria Island will be discussed in Chapter IV.

?Silurian and Devonian

Unnamed dolomite formation

Definition, distribution and thickness. The provisional name "unnamed dolomite formation" is applied to a unit that has been penetrated by one well, Orksut I-44, which bottomed in the formation. The section in this well is 98 metres (322 ft) thick, and is incomplete. The distribution of this formation is unknown at the present time.

Lithology. The formation is composed primarily of very fine grained, medium to dark brown-grey, argillaceous dolomite. Occasional crystals of rhombic dolomite are present. Sparry calcite and pyrite are minor accessories, generally as cavity infillings. No porosity is visible.

Age and correlation. No paleontologic evidence for the age of this formation is available. A sample from the overlying formation was processed for conodonts by T. T. Uyeno, but the result was inadequate for accurate correlation as it yielded a Middle Ordovician to Middle Devonian age range.

A tentative interpretation, based on a regional synthesis, is that the unnamed dolomite formation correlates with part of the Read Bay Group of Thorsteinsson and Tozer (1962). The dolomites at the base of the Orksut section may equate with either the oldest or the youngest of the three formations comprising Read Bay Group. If the former, then the unnamed dolomite-shale formation may correlate with the shale unit of the Read Bay.

Unnamed dolomite-shale formation

Definition, distribution and thickness. The formation is present only in the Orksut well, where it is 50 metres (164 ft) in thickness. The top and bottom of the unit are at depths of 2913 metres (9,554 ft) and 2963 metres (9,718 ft) respectively.

Lithology. The formation consists of interbedded dolomite and shale. The dolomite is medium brown-grey, argillaceous and very fine grained, and contains occasional rhombic crystals up to 0.3 millimetres in diameter. Shale is interbedded with the dolomite, as clearly shown by geophysical log characteristics, but most of the shale has been lost from the well chip samples.

Traces of bitumen and pyrite are present in the dolomite, which shows poor pinpoint porosity.

Age and Correlation. Chip samples from this formation were analysed for conodonts by T. T. Uyeno with little success. A channel sample from the 2896 to 2927 metre (9,500-9,600 ft) level in the Orksut well (which includes the upper 14 metres of the dolomite-shale formation) yielded fragmentary remains of *Panderodus* spp. (GSC catalogue number C-29858). According to T. T. Uyeno they indicate a Middle Ordovician to Middle Devonian age range.

The problem of correlation of this formation was discussed above briefly, in connection with the underlying unnamed dolomite formation.

It is tentatively suggested that the lowermost 150 to 200 metres of the section at Orksut I-44 may correlate with the Read Bay Group of Stefansson Island. In this interpretation the unnamed dolomite-shale formation may correlate with map unit 11b of Thorsteinsson and Tozer (1962, p. 48), i.e. the middle unit of the Read Bay Group. On Stefansson Island this unit consists of grey shale that is variably calcareous. It is approximately 38 metres (125 ft) thick and contains a graptolite fauna indicating a lower Ludlovian age.

Lower and Middle Devonian

Blue Fiord Formation

Definition, distribution and thickness. The Blue Fiord Formation was first defined by McLaren (1963a) as a succession of limestone and minor shale which is widely exposed in southern Ellesmere Island. The formation reaches its maximum known thickness of 1160 metres (3,800 ft) in the type area, at Blue Fiord. An Eifelian age was assigned by McLaren (op. cit.) but recent revisions in age assignments of certain brachiopod species has led Johnson (*in* Harper *et al.*, 1967, p. 430) to suggest that at least part of the Blue Fiord in the type area is of Emsian age.

The formation is also present on Melville and Bathurst Islands. On Melville Island the formation is more than 600 metres (2,000 ft) thick, consists predominantly of limestone (Tozer and Thorsteinsson, 1964, p. 68-71), and has been assigned an Eifelian age by McGregor and Uyeno (1972).

Kerr (1974) describes the occurrences of the Blue Fiord on Bathurst Island. As on Melville and Ellesmere Islands the formation is composed predominantly of limestone; it ranges in thickness from 180 to 520 metres (600-1,700 ft), and is Emsian to Eifelian in age.

On Banks Island a complete section through the formation has been penetrated only in the Orksut well, where it is 692 metres (2,269 ft) in thickness. The Storkerson Bay well bottomed in this unit, penetrating only the uppermost 103 metres (339 ft) of the succession. The detailed stratigraphic section shown in Figure 3 and the simplified, restored section shown in Figure 4 show that strong lateral facies changes are present in the Lower and Middle Devonian strata. The thickness of the Blue Fiord Formation therefore is expected to be highly variable. Reconstructions suggest a thickness of approximately 300 metres (1,000 ft) at Storkerson Bay and 200 metres (700 ft) at the Nanuk location.

Lithology. A complete section through this formation is present at the Orksut location. Detailed lithologic descriptions are contained in an appendix to this report, but the succession may be summarised as follows, from the base up.

1. Dolomite, pale to medium grey, mean grain size 0.03 millimetres, occasional pelletoid and coated grains, occasional mud intraclasts, trace of pinpoint porosity, trace of calcite and pyrite -- 93 metres (304 ft)

2. Dolomite, pale to medium grey, grain size typically 0.02 to 0.08 millimetres, no visible porosity, minor interbeds of siltstone ------------ -- 76 metres (250 ft)

3. Dolomite, white, microcrystalline, average grain size 0.04 millimetres, plus occasional finer grained dolomite interbeds, mean grain size 0.02 millimetres, occasional thin shale interbeds, trace of gypsum and pyrite, trace of sparry calcite, low pinpoint porosity -- 280 metres (920 ft)

4. Dolomite - limestone transition beds. Base of unit similar to unit 4, top similar to unit 5. Limestone is pale to medium brownish grey, occasionally dark grey and argillaceous, microcrystalline. Dolomite is pale or medium brownish grey to white, microcrystalline. Occasional shale interbeds, rare pyrite, rare *Tentaculites*. Dolomite present as silt-sized rhombs which increase in abundance downwards, from less than 5% at top to more than 95% at base of unit ---------------- 143 metres (470 ft)

5. Limestone, pale to medium brownish grey, occasionally dark grey or white, microcrystalline, occasionally argillaceous, with occasional interbeds of black, bituminous shale. Rare pyrite. Brachiopod spines, *Tentaculites*, *Styliolina* ------------------------------ 99 metres (325 ft)

The total section is 692 metres (2,269 ft) in thickness. Unit 4 represents a zone of recrystallisation, within which calcite is (or was) undergoing pervasive replacement by dolomite.

An incomplete section 103 metres (339 ft) thick through the formation is present in the Storkerson Bay well. Lime mudstone is the predominant lithology; it is white or pale to medium grey, cryptocrystalline, normally very dense, variably argillaceous, becoming more argillaceous at the top of the unit. Greenish grey shale interbeds are rarely present. Most of the section is pelletoid and much of it contains corals and stromatoporoids. Authigenic quartz needles are present in the lower 12 metres of section. Brachiopods, gastropods, pelecypods and ostracodes are present throughout.

A core 8.5 metres (28 ft) in length is available from near the top of the Storkerson Bay limestone section. This shows that in detail the limestone lithologies are highly variable. Lime mudstones are interbedded with lime wackestones and lime packstones (in the terminology of Dunham, 1962). Some intervals are richly fossiliferous while others contain no fossils. Scattered silt-sized grains are present and are probably of eolian origin. Most of these variations are illustrated in Plates VI and VII. An unusual lithology of uncertain origin is illustrated in Plate VIA. It consists of lime mudstone showing a rod-shaped mottling texture. The mottling is a reflection of varying argillaceous content, but the origin of the fabric is unknown.

Fossils present in the core include syringoporid and favositid corals, *Amphipora-*, *Stachyodes-* and *Atelodictyon*-type stromatoporoids, crinoid ossicles, brachiopod fragments, orthocone nautiloids and ?ostracodes. Some of the stromatoporoid fragments, as in Plate VIIA, show thecal cavities partially infilled with micrite, a feature that is useful for indicating the stratigraphic top of rock outcrops and cores (and photomicrographs).

The two Princess Royal Islands both expose approximately 60 metres (200 ft) of light grey, very coarse grained, thick bedded to massive, bioclastic, in part vuggy limestone (Thorsteinsson and Tozer, 1962, p. 52). Much of the rock is composed of crinoid columnals up to 2 centimetres (0.8 in) in diameter (Plate VIIIB). A lateral transition into shales of Orksut lithology is visible, the bioclastic limestone tapering out westwards into beds a few centimetres or decimetres in thickness interbedded with dark shales (Plate IX). This interfingering lithology is interpreted as the talus slope of a reef. Depositional dips of up to 30° are clearly visible in the southeastern cliffs of the larger of the two islands (Plate IXA). The position of this interesting outcrop in the regional scheme is shown in Figure 4 (where it is numbered as section 7).

<u>Age and Correlation</u>. Samples of core number 2 at Storkerson Bay were processed for conodonts and yielded the following assemblage (identifications by T. T. Uyeno, GSC No. C-23944):

> *Ozarkodina* n. sp. A of McGregor and Uyeno 1972
> P (7), O_1 (3), N (2), A_1 (1), A_2 (1), A_3 (1)
> *Panderodus* spp. (sensu formae) (74)
> *Scolopodus* sp. (sensu formae) (1)
> indet. simple cone (M_2 element) (1)

Figures in brackets indicate number of specimens recovered.

Uyeno states: "*Ozarkodina* n. sp. A occurs in the upper part of the Stuart Bay Fm. at Young Inlet and in the Eids Fm. at Twilight Creek, both on Bathurst Island (Uyeno *in* McGregor and Uyeno, 1972). At these localities it occurs with *Polygnathus perbonus* (Philip) which is a late Emsian indicator. The P elements of this species have also been noted from the Gossage Formation at Powell Creek in the Mackenzie Mountains, west of Norman Wells (Uyeno *in* Lenz and Pedder)." Uyeno concludes that the assemblage is late Emsian in age.

Three channel samples from the Blue Fiord Formation were taken from the unwashed cuttings of the Orksut section. Two of these samples, at 2226-2256 metres (7,300-7,400 ft) and 2408-2438 metres (7,900-8,000 ft), yielded no conodont recovery. The third sample, from the 2747-2777 metre (9,010-9,110 ft) interval, yielded the following conodont type (identification by T. T. Uyeno, GSC no. C-29857):

Ozarkodina exigua (Philip) to
O. expansa Uyeno and Mason (P elements)

Uyeno states: "The platform element in GSC loc. C-29857 is a transitional form between *Ozarkodina exigua* and *O. expansa*. The former was reported from Emsian strata at Royal Creek, Yukon (Klapper, 1969), whereas the latter has been found at several localities in the Arctic Islands, Yukon and the western District of Mackenzie, in strata of late Emsian age (Uyeno and Mason, in press)."

The two samples from this formation which have been reliably dated are thus of closely similar age. However, the Storkerson Bay sample is from near the top of the formation whereas the Orksut sample is 526 metres (1,725 ft) from the top.

Dates obtained from chip samples may be viewed with a certain amount of doubt because of the nature in which the cuttings were obtained. Cavings from the wall of the drill hole can contaminate the mud stream so that anomalously young material may be included in the samples labelled as originating at any given depth. This is a serious problem with unconsolidated rocks, for example caved Cretaceous foraminifera were recovered from the Paleozoic samples in the Orksut well down to a depth of 2180 metres (7,150 ft) which is 350 metres (1,150 ft) below the Devonian-Cretaceous unconformity. However, in well lithified rocks such as the Devonian carbonates, caving is likely to be of minimal importance. The dating of the 2747-2777 metre (9,010-9,110 ft) interval of the Orksut well is therefore regarded as being virtually as reliable as any date obtained from core material.

If the foregoing argument is accepted, a markedly diachronous formation top is indicated. Approximately 518 metres (1,700 ft) of post-late Emsian carbonate rocks appear in the section moving southeastwards from Storkerson Bay to Orksut, a distance of 84 kilometres (52 miles). As shown by later sections of this report, and as shown in Figure 4, most of the formation boundaries in the Paleozoic rocks of Banks Island display similar diachronism, indicating that the stratigraphy is dominated by marked lateral facies changes and that all the major depositional environments migrated with time. The table of formations at the beginning of this chapter (Table 1) should be read with these qualifications in mind.

No information is available to date the top of the Blue Fiord Formation at Orksut. It is probably Eifelian or Givetian in age, i.e. Middle Devonian. The base of the formation is 135 metres (444 ft) below the base of the late Emsian channel sample at Orksut, and is probably Early Devonian or Late Silurian in age. The underlying dolomite-shale formation is tentatively correlated with map unit 11b of Thorsteinsson and Tozer (1962) which is dated as lower Ludlovian.

The limestone exposures on the larger of the Princess Royal Islands have yielded the following fauna (identifications by D. J. McLaren, in Thorsteinsson and Tozer, 1962, GSC no. 40798):

Favosites sp. L,
dalmanellacid indet.,
Gypidula sp. C,
rhynchonellid, n. sp.?,
Atrypa spp.
Spinatrypa sp. F
"Reticularia" ex gr. *R. curvata* (Schlotheim)

The age of this fauna is given as Eifelian and the rocks were assigned to the Blue Fiord Formation by Thorsteinsson and Tozer.

A collection made by geologists of Elf Oil Canada Ltd. from the same locality has also been assigned an Eifelian age. The assemblage is as follows (GSC no. C-12537, identifications by A. W. Norris):

Cortezorthis sp.
Gypidula sp.

Atrypa sp.
Spinatrypa sp.
Carinatina sp. cf. *C. dysmorphostrota* (Crickmay)
Emanuella sp.
Leiorhynchus sp. cf. *L. manetoe* McLaren - a thin, flattened form
"*Camarotoechia*" sp. - a small, f. costate form
Conocardium sp.
small echinoderm ossicle with single axial canal
very large echinoderm ossicle with single axial canal

Norris states:"Sample C-12537 contains a mixture of faunal elements characteristic of both the Cordilleran and Arctic faunal provinces. Forms closely related to *Carinatina dysmorphostrota* and *Leiorhynchus manetoe* are present in the sample. These occur typically in the Hume Formation and equivalent beds of the Cordilleran faunal province of northwestern Canada, and suggest an early Middle Devonian (Eifelian) age for the containing beds."

Samples were collected from these outcrops by the writer and have been processed for conodonts by T. T. Uyeno. The following assemblage has been obtained (GSC nos. C-30544, C-30545):

Polygnathus perbonus perbonus (Philip) (late form)
Pandorinellina cf. *P. optima* (Moskalenko)
Panderodus spp.
"*Belodella*" spp.
"*Neopanderodus*" spp.

Uyeno assigns a mid-Emsian age to this collection. Ormiston (1967, p. 18) dated a trilobite assemblage collected at the same locality from the interbedded shales (now included in the Orksut Formation) as latest Emsian to earliest Eifelian.

The age of the base of the formation on Banks Island is unknown. The late Emsian date at Orksut was obtained on a sample collected 150 metres (500 ft) above the base of the formation. An Emsian or Siegenian age, therefore seems probable for the lowermost strata at this locality. The age of the underlying strata is not known either at Orksut or in the outcrops of laterally equivalent rocks on Stefansson and Victoria Islands.

As shown in the restored stratigraphic section (Fig. 4) the Blue Fiord Formation of Banks Island is laterally equivalent to the Nanuk Formation and parts of the Orksut and Weatherall Formations. Similar lateral transitions are displayed elsewhere in the Arctic Islands. On Bathurst Island, for example, the formation passes laterally into the Eids Formation (Kerr, 1974). Similar facies changes are also shown in the Emsian and Eifelian rocks of Yukon Territory, for example between the fine clastics of Prongs Creek Formation and the shelf carbonates of Ogilvie Formation (Lenz, 1972).

Depositional environment of Blue Fiord and underlying unnamed formations. The fauna in the Blue Fiord Formation is benthonic, including corals, brachiopods and trilobites, and this suggests a shallow-marine depositional environment. There is at present no reason to doubt that similar conditions prevailed during the accumulation of the two earlier unnamed formations, although the presence of shale in the dolomite-shale formation would suggest temporary water deepening at that time.

The predominantly micritic texture of the Blue Fiord Formation in the Storkerson Bay core indicates a generally low energy depositional environment. Allochems are rarely present in sufficient abundance to provide a grain framework (indicative of higher energy conditions in which fine-grained matrix components have been removed by winnowing). In all these cases the framework is formed by stromatoporoid remains. None of the fossil remains show signs of much erosive wear or breakage, which would indicate considerable transportation distances from the point of growth. This again points to quiet water conditions. The breakage which is apparent, as in Plate VIIB, may probably be attributed to the activity of scavenging organisms.

Several of the Storkerson Bay limestone types illustrated in Plates VI and VII show well developed fenestral or birdseye fabric. These are defined as irregular shaped cavities larger than grain-supported interstices (Tebbutt *et al.*, 1965, p. 4). In the present case they are filled with twinned calcite crystals. As discussed by Choquette and Pray (1970, p. 246) there are many possible origins for this fabric. They include decay of sediment-covered algal mats, shrinkage during drying, and accumulation of pockets of gas or water. Localisation of the fenestral fabric along laminae may be interpreted as indicators of intertidal or supratidal algal mat sedimentation (Tyrrell, 1969, p. 90). In the absence of other supporting evidence no final conclusions can be drawn concerning the origin of this fabric in the present case. Certainly there is no other evidence to indicate intertidal or supratidal environments, such as well developed laminations. With this qualification in mind an analogy is proposed between the limestones in the Storkerson Bay core and those interpreted as originating in a "mixed shelf" environment by Tyrrell (1969, p. 89-91). According to Tyrrell this environment is characterised by deposition at or close to sea level.

No other core is available for study of the Blue Fiord and underlying carbonates, and thus further environmental interpretations must be regarded as tentative. The upper part of the section at Orksut, that between 2221 and 2320 metres (7,285-7,610 ft), which is undolomitized, is interpreted as being transitional between a shelf deposit and one formed on a basin slope. Indicators for this are the mixed benthonic and pelagic elements in the fauna, and the presence of minor shale interbeds in the limestone. These beds grade upwards into the typical basin margin deposits of the Orksut Formation. The limestone grades down into a partially dolomitized section 470 feet thick, and this in turn into a section containing scattered gypsum crystals. The presence of a minor evaporite component suggests a restricted, lagoonal or intertidal environment.

The partially dolomitized interval between the restricted dolomite and the outer shelf limestone is of unknown origin. In a higher energy carbonate environment this stratigraphic position would probably be occupied by shelf edge reef deposits or barrier island carbonate sands. The absence of clear evidence for either suggests that at Orksut the transition between shelf and basin was very gradual. This is consistent with the interpretation of low energy conditions for most of the Blue Fiord and older carbonate formations.

At Princess Royal Island a very different condition prevails. The limestones are bioclastic and show steep depositional dips, suggesting that they comprise talus slopes at the edge of biohermal banks (Plate IXA). They are similar to deposits of the "basin slope" facies of Tyrrell (1969). Clearly, higher energy conditions and abrupt facies changes did develop, but the lateral extent of the resulting shelf-edge reef developments is impossible to determine with the limited evidence available. Their absence at Storkerson Bay and Orksut suggests that their development may have been quite localised. This subject will be discussed further in the discussion of history and paleogeography (Chapter IV).

The origin of the dolomitization of the Blue Fiord and underlying units will not be considered in detail in the present study owing to a paucity of evidence. Several major dolomitization theories have been proposed by previous workers, including the brine-refluxion idea of Adams and Rhodes (1960) and Deffeyes *et al.* (1965), the Dorag model of Badiozamani (1973) and the theory of post-depositional dolomitization due to the lateral movement of brines during differential compaction (Illing, 1959;Jodry, 1969). According to this third model where there is a limestone-shale facies change, compaction, which tends to be greater in the shales, will cause interstitial waters to be expelled laterally across the facies boundary, causing the limestone bodies to be dolomitized from the sides and the base upwards. The situation in the Orksut well, with its progressive downward increase in dolomite content, would appear to suggest this second model.

In conclusion, the Blue Fiord Formation and the underlying, unnamed strata were deposited under shallow marine, generally quiet water conditions. The Blue Fiord, at least, contains evidence of considerable benthonic organic activity. These rocks are a typical shelf or platform association and pass laterally into a deeper water shale facies with the localised development of bioherms at the shelf margins.

Orksut Formation (original description)

Definition, distribution and thickness. The name Orksut Formation is applied to a succession of calcareous shale and silty shale with minor interbeds of argillaceous limestone and siltstone, that overlies the Blue Fiord Formation throughout Banks Island. The black calcareous shale at the southwest tip of the larger of the two Princess Royal Islands, and the shale and argillaceous limestone of Victoria Island that were tentatively correlated with the Eids Formation by Thorsteinsson and Tozer (1962, p. 50-51), are also assigned to the Orksut Formation.

The thickest and most complete section through the Orksut is present in the Orksut I-44 well (Figs. 3, 4) where the formation is 392 metres (1,285 ft) thick, hence the choice of the name. This is designated as the type section;a detailed log is provided in Appendix II. The formation is markedly diachronous, as will be discussed below. At the Nanuk well the Orksut-Nanuk contact is arbitrarily drawn at 1262 metres (4,140 ft). It is impossible to pick a precise boundary owing to a lack of distinctiveness in the geophysical log character of the two formations. There may be, in any case, a gradational contact. With the top of the Orksut placed at 1262 metres (4,140 ft) the formation is at least 115 metres (378 ft) in thickness, this being the interval from 1262 metres to total depth. In the stratigraphic reconstruction shown in Figure 4 it is suggested that the base of the Orksut may be within a few metres of the base of the Nanuk well section.

At the Storkerson Bay well it is again necessary to draw a somewhat arbitrary boundary between the Orksut and the Nanuk Formations. The top of the highly calcareous shale occurs at 1930 metres (6,330 ft) in the chip samples (no geophysical logs are available at this depth to provide accurate control). Fifteen metres (50 ft) of beds, between 1930 and 1945 metres (6,330-6,380 ft) are thus assigned to the Orksut Formation.

Lithology. The Orksut Formation in the Banks Island area consists primarily of dark grey calcareous shale. The shale is occasionally micaceous or bituminous and contains occasional silty interbeds in the Orksut well. Pyrite is a minor accessory. Fossil remains, including *Tentaculites*, *Styliolina*, small orthocone nautiloids, and crinoid ossicles are present at certain levels in the formation, in the top 46 metres (150 ft) at Orksut and in the top 30 metres (100 ft) at Nanuk.

Carbonate stringers are also present in the succession. At Nanuk a dolomite approximately 4.6 metres (15 ft) thick occurs 27 metres (90 ft) above the base of the section (the well bottoms in the Orksut and thus an unknown thickness is present below total depth). The dolomite is dark grey and very argillaceous, fine grained to microcrystalline. At Orksut several limestone stringers occur in the top 18 metres (60 ft) of the formation. They are also dark grey and very argillaceous. Similar thin limestones are present in the lower 61 metres (200 ft) of section at Orksut, suggesting a transitional contact with the underlying limestone-dolomite unit. They contain scattered calcispheres 0.1 to 0.2 millimetres in diameter of unknown, possibly radiolarian origin.

A single specimen of calcareous Orksut shale has been analysed by X-ray diffraction. The specimen was taken from chip samples in the 1277-

1290 metre (4,190-4,230 ft) interval of the Nanuk well and contains the following minerals with approximate percentages: silica 32%, calcite 48%, dolomite 18%, pyrite 1%. Clay minerals were not recorded in this sample, but this may be a reflection of the inaccuracies of the analytical method, or the result of choosing an atypical sample.

At the larger of the Princess Royal Islands beds of Orksut-type lithology are exposed in an interfingering relationship with the Blue Fiord Formation. They consist of approximately 9 metres (30 ft) of grey, crinoidal limestone interbedded with dark grey to black shale and calcareous shale (Plate VIIIA, IXB). The calcareous shales contain many trilobites and other fossils (Thorsteinsson and Tozer, 1962, p. 52, GSC no. 40794). The shales thicken to the west, as the crinoidal limestones thin out. As was discussed in an earlier section, the limestones represent part of the Blue Fiord Formation, and at this locality they comprise part of a laterally impersistent reef talus slope.

Age and Correlation. Tentaculitids from the 1293-1268 metre (4,160-4,240 ft) level of the Nanuk well were examined by A. W. Norris who identifies them as *Nowakia* sp. cf. *N. barrandei* (GSC no. C-24620). Norris states: "Although the material is very poorly preserved the overall shape, fine, very closely spaced longitudinal markings, and sharply angular annular rings suggest that the species represented is closely related to *Nowakia barrandei*. In Bohemia this species occurs in the upper part of the Zlichovian (upper Emsian) of late Lower Devonian age." Samples from the same interval in the well were analysed for conodonts by T. T. Uyeno but without success. Samples were also taken from the core at the 1355-1361 metre (4,445-4,463 ft) level and analysed for palynomorphs by A. R. Sweet, again without success. According to Sweet the sample was barren, possibly as a result of excessive thermal carbonization. An Emsian age is assigned to the Orksut Formation at Nanuk.

No information is available from the Storkerson Bay Orksut section. A latest Emsian date is suggested for the thin development of the Orksut Formation at this locality, on the basis of stratigraphic reconstruction (Figure 4).

Core #4 in the Orksut I-44 well spans the Mesozoic-Paleozoic contact; samples from the lower part of the core were analysed for palynomorphs by A. R. Sweet and D. C. McGregor. The following megaspore assemblage was identified by A. R. Sweet (GSC nos. C-28074, C-28075):

Brochotriletes sp.
Raestrichia sp.
Convolutispora sp.
Calyptosporites sp.
Rhabdosporites sp.
?*Corystisporites multispinosus* Richardson 1965
Unidentified, Pl. XXIII, Figs. 22, 23, McGregor and Owens 1966
Deltoidospora sp.
?*Hystricosporites* sp.
Leiospheridia sp. (common)

Sweet tentatively assigns a Givetian or Frasnian age to this collection.

McGregor reports the following assemblages of microspores:

1829 metres (6,002 ft) (GSC no. C-28074):

Ancyrospora sp.
Chelinospora concinna Allen
Cymbosporites ?cyathus Allen
Dictyotriletes sp.
cf. *Grandispora mammillata* Owens
Laevigatosporites n. sp.
Lophotriletes sp.
cf. *Perotriletes bifurcatus* Richardson

1834 metres (6,017 ft) (GSC no. C-28075):

?Ancyrospora sp.
Cymbosporites ?catillus Allen
Dictyotriletes sp.
Laevigatosporites n. sp.
cf. *Perotriletes bifurcatus* Richardson.

McGregor states: "the spores are somewhat carbonized and in general rather poorly preserved. Those that could be identified indicate a Givetian, possibly late Givetian age."

Two channel samples from the unwashed Orksut drill cuttings were analysed for conodonts by T. T. Uyeno without success. The intervals were 1845-1875 metres (6,050-6,150 ft) and 2149-2180 metres (7,050-7,150 ft).

In summary the formation is assigned an early(?) to late Givetian age range at the Orksut well. This is considerably younger than the age range of the formation in the Nanuk and Storkerson Bay wells.

An outcrop eighteen miles southwest of Armstrong Point (northwest Victoria Island, see Fig. 1) was described by Thorsteinsson and Tozer (1962, p. 50) as consisting of black shale, calcareous shale and argillaceous limestone and was tentatively assigned to the Eids Formation. It is assigned to Orksut Formation in the present report. Fossils collected from this locality by Thorsteinsson and Tozer (GSC no. 40796) were identified by D. J. McLaren as follows: *Styliolina* sp., *Chonetes* sp., *Plectospirifer* sp., rhynchonellid indet. No age assignment was made. Samples collected by the author from the same locality have been examined for conodonts by T. T. Uyeno, who reports the following assemblage (GSC nos. C-30546, C-30547, C-30548):

?*Pandorinellina expansa* Uyeno and Mason
(juvenile P element)
?*Polygnathus* cf. *P. costatus costatus* Klapper
(very fragmentary)
Polygnathus perbonus perbonus (Philip) (late form)
"*Ozarkodina*" *denckmanni* Ziegler (single O_1 element)
"*Belodella*" spp.
unassigned N, A_1 and A_3 elements

An Emsian age is assigned to this collection by Uyeno.

The outcrops of Orksut Formation on Princess Royal Island contain an abundant benthonic fauna. Trilobites from this fauna have been studied by Ormiston (1967) who identified (p. 18) the following species:

Platyscutellum brevicephalus
Cornuproetus tozeri
Leonaspis eremia
Harpes cf. *macrocephalus*
Otarion balanops
Astycoryphe aff. *cimelia*
Dechenella sp. indet.

According to Ormiston this assemblage indicates an age close to the Emsian-Eifelian boundary. The age assignment also provides local control for the Orksut-Blue Fiord contact which, it is interpreted earlier, is exposed in the island.

The age range of the Orksut Formation overlaps in part the age ranges of several other units of similar lithology in the Canadian Arctic, for example the Eids Formation of Bathurst Island, to which Kerr (1974, p. 41) assigns an Emsian and Eifelian age range. The reasons for not using the formation name Eids for the Banks Island rocks are discussed in the introduction to this chapter.

The Orksut also overlaps in part the age range of the Hare Indian Formation (Givetian) of Mackenzie Platform (Tassonyi, 1969;Lenz, 1972) which is also a unit composed mainly of calcareous shale. The Orksut, Hare Indian and Eids represent similar depositional environments, and the development of these environments depended on the configuration of shelf and basin areas which shifted with time through the Early and Middle Devonian. Some of the regional implications of this diachroneity will be discussed in a later section of this report dealing with paleogeography (Chapter IV).

Depositional Environment. The predominance of shale in the Orksut Formation and the presence of the pelagic fauna of *Tentaculites* and

Styliolina suggest a deep marine origin for these rocks. Although detailed lithologic relationships cannot be deduced from well chip samples, in general the rocks appear to be similar to the "basin slope" facies of Tyrrell (1969, p. 94) and the basin margin rocks of Wilson (1969). Depths of water up to 600 metres (2,000 ft) have been proposed for this facies by various workers, as summarised by Wilson (1969, p. 13). The carbonate material was probably derived from the nearby shelf and would have been carried into the basin area by bottom currents. Limestone turbidites are a common feature of this facies;they have not been recorded from the Orksut Formation but have been described in rocks of similar age and environmental setting in the Lower Mackenzie Basin (MacKenzie, 1970).

Nanuk Formation (original description)

Definition, distribution and thickness. A distinctive unit of siliceous shale with interbedded chert overlies the Orksut Formation in two wells in western Banks Island, Storkerson Bay A-15 and Nanuk D-76. This unit is herein named Nanuk Formation. The type section is designated as the 1126-1262 metre (3,695-4,140 ft) interval in the Nanuk D-76 well;a detailed log is provided in Appendix II of this report.

Stratigraphic reconstruction (Fig. 4) shows that the Nanuk Formation is a lateral facies equivalent of part of Orksut and Blue Fiord Formations, and may be also a lateral equivalent of the lowermost Weatherall Formation.

It represents a particular type of sedimentary environment which was restricted to the western and northwestern parts of the Banks Island area. The formation is 136 metres (446 ft) thick at Nanuk and 197 metres (645 ft) thick at Storkerson Bay. The section in the Nanuk well is incomplete because the formation is cut by the top Paleozoic erosion surface. However, the missing interval is probably in the order of only a few metres. (This section was chosen as the type section in preference to that at Storkerson Bay, in part, because core is available in the Nanuk well, and this permits a better description of the lithologies.)

Lithology. At the Nanuk well the Nanuk Formation consists primarily of siliceous shale and argillaceous chert. The shale is very dark grey, non-calcareous and highly indurated. Core no. 1 in this well recovered ten feet of section from the 1140-1144 metre (3,738-3,752 ft) interval, and showed the shale to be finely but very faintly laminated, and to contain occasional stylolitic surfaces, pyrite along minor fractures and larger fractures lined with microcrystalline white quartz.

Chert is abundant in the lower part of the section. It is predominantly light grey with darker streaks, generally massive but with occasional bedding traces and occasional pinpoint vugs. X-ray diffraction analyses of two samples of the siliceous shale indicate that hand-specimen identifications can be misleading, and that chert is, in fact, abundant throughout the succession in an argillaceous form. The analyses are as follows: 1131-1137 metre

(3,710-3,730 ft) interval, 5% clay minerals, 89% silica, 4% pyrite;1177-1183 metre (3,860-3,880 ft) interval, 4% clay minerals, 91% silica, 3% pyrite.

Minor interbeds of medium grey, slightly micaceous siltstone are present in the lower part of the succession in the Nanuk well.

At Storkerson Bay the contact between the Nanuk Formation and the overlying Weatherall Formation is gradational. The upper 76 metres (250 ft) of the Nanuk succession contains interbeds of pale grey, very fine grained, silty, quartzose sandstone similar to the sandstone of the overlying Weatherall Formation. However, the predominant lithology in this interval is black, micaceous, slightly siliceous, non-calcareous, laminated, fissile shale. Lower in the section the shale is in part silty or dolomitic in addition to being micaceous and slightly siliceous. Pyrite is a persistent but minor accessory throughout.

No fossils were recorded in either the Nanuk or Storkerson Bay sections but in the lower part of the Storkerson Bay section the shale contains occasional spherical siliceous structures averaging 0.12 mm in diameter, which may be of radiolarian origin.

Age and Correlation. Samples from core no. 1 at Nanuk D-76 were analysed for conodonts and for palynomorphs without success. The absence of palynomorphs may be due to a high degree of thermal carbonization in the rocks at this level (A. R. Sweet, unpublished report, 1973). Cuttings from the 1738-1768 metre (5,700-5,800 ft) interval of the Storkerson Bay well were analysed for palynomorphs by D. C. McGregor, who states that all the material is highly carbonized and very poorly preserved. *Cymbosporites* spp. and/or *Verruciretusispora* cf. *magnifica* are tentatively identified, and these suggest a Givetian age for the upper part of the formation at this locality. At Nanuk the formation overlies the Orksut Formation, which contains a late Emsian tentaculitid. At Storkerson Bay the base of the formation is 35 metres (116 ft) above the upper limestone beds of Blue Fiord Formation, which yielded a late Emsian conodont fauna at this locality.

The above evidence when reconstructed as shown in Figure 4, suggests an early Eifelian to early Givetian age range for the Nanuk Formation.

Lithologically the Nanuk Formation is very similar to the Ibbett Bay Formation. The latter was named by Tozer (1956, p. 13) for a succession of dark grey to black shale, calcareous shale, argillite, dolomite, chert and minor limestone beds in eastern Melville Island. Tozer and Thorsteinsson (1964, p. 52) gave the age range of this formation as Early Ordovician to latest Silurian. However, at Giddy River on Melville Island, Tozer and Thorsteinsson (1964, p. 56) recorded the occurrence of *Monograptus* n. sp. A 210 metres (700 ft) below the top of the Ibbett Bay. Later (Thorsteinsson, *in* Berdan *et al.*, 1969, p. 2172), this species was equated with *M. yukonensis* which is of late Siegenian or early Emsian age. The 210 metres (700 ft) of unfossiliferous beds above this graptolite horizon are probably at least as young as Emsian, and therefore the age range of the Ibbett Bay Formation extends into the Early Devonian and possibly even into the Middle Devonian. The Nanuk Formation may thus be similar in age to or only slightly younger than the uppermost part of the Ibbett Bay, and may represent a tongue of the Ibbett Bay facies which projects to the edge of the craton. Until this correlation can be conclusively demonstrated it would not be correct to assign the siliceous shales of Banks Island to the Ibbett Bay Formation.

As discussed in the introduction to this chapter the Nanuk Formation may be compared and correlated with "Canol-like" shales of northern Yukon. According to Lenz (1972, p. 325-326) these shales vary in age locally from upper Emsian to Famennian.

Depositional Environment. The Nanuk Formation of Banks Island is interpreted as deep water in origin. The abundant chert may have been derived from radiolarian remains, which are typical of deep water deposits. For example, Garrison and Fischer (1969) showed that depths of 3 to 4 kilometres or possibly even greater prevailed during the accumulation of the Ruhpolding Beds, a Jurassic radiolarian chert in the Alps. Alternatively, the chert may have been produced in part by deep-water, penecontemporaneous diagenesis of clay minerals, a mechanism proposed by Keene and Kastner (1974) to explain the origin of certain modern oceanic cherts. The absence of carbonate in the Nanuk Formation suggests that the sediments were deposited below the carbonate compensation depth. This is a depth below which the rate of carbonate dissolution is greater than the rate of carbonate deposition

(Milliman, 1974, p. 223). In modern oceans this depth varies between 3 and 7 kilometres depending on such factors as temperature and pressure. A complicating factor is that many of the planktonic calcareous organisms which nowadays provide an abundant carbonate supply in the deep oceans did not evolve until the Mesozoic (op. cit., p. 81). The absence of carbonate in the Nanuk Formation is therefore of uncertain significance.

The Storkerson Bay section contains the stratigraphically earliest beds of siltstone and sandstone in the Devonian of the Banks Island area. There appears to be an upward gradation from the Nanuk into the Weatherall Formation, and the sand-bearing upper 76 metres (250 ft) of Nanuk beds may be regarded as a transitional unit during the formation of which environmental conditions began to undergo a fundamental change. The thick, predominantly clastic Melville Island Group of which the Weatherall Formation is part, was developed as a result of major tectonic uplift to the north and northeast (or northwest) of Banks Island, and the uppermost Nanuk beds of Banks Island probably represent the period of time during which this clastic influx first commenced. The clastic detritus is unlikely to have been derived from the shelf areas to the south or southeast as contemporaneous strata in these areas contain virtually no clastic material other than scattered quartz silt grains which can probably be attributed to wind transportation. That the Nanuk sands are genetically part of the Melville Island Group clastic wedge therefore seems certain.

A possible analogy may be made with the Blackley Member of the Weatherall Formation in western Melville Island. Thorsteinsson and Tozer (1964, p. 76) define this unit as a succession of grey micaceous shale with siltstone interbeds 700 metres (2,300 ft) thick. The siltstone beds are between 2 and 30 centimetres (1-12 in) in thickness. Embry and Klovan (1974), who propose to raise this unit to formation status, state that the siltstone beds are characterised by sharp basal contacts with numerous sole structures, including flute and groove casts. They also appear to show graded bedding. Embry and Klovan interpret these siltstones as basinal turbidites formed on a submarine fan. Owing to a lack of core in the Storkerson Bay well it is impossible to be certain if the analogy with the upper Nanuk Formation at this locality is appropriate. However, the stratigraphic setting of the Banks Island beds is very similar to that of the Blackley Member of the type area and, in addition, as will be discussed in a later section, this interpretation raises no paleogeographic problems.

Middle and Upper Devonian

Melville Island Group

Definition, distribution and thickness. This unit was first defined as the Melville Island Formation by Tozer (1956, p. 14) for a thick sequence of Devonian clastic sediments that outcrop on the west coast of Melville Island. Later work by Tozer and Thorsteinsson (1964) resulted in the elevation of the unit to group status and the recognition of three formations within the group. These were named the Weatherall, Hecla Bay and Griper Bay Formations. The Weatherall of the type area in eastern Melville Island consists of 1400 metres (4,600 ft) of thin bedded, marine sandstone, siltstone and shale, and was dated by McGregor and Uyeno (1972) as Givetian. The Hecla Bay Formation comprises 550 to 790 metres (1,800-2,600 ft) of nonmarine sandstone of upper Givetian to lower Frasnian age. The Griper Bay Formation consists of at least 910 metres (3,000 ft) of marine sandstone, shale, siltstone and thin coal seams, dated as lower Frasnian to lower Famennian in age.

The Melville Island Group is the only Paleozoic rock unit exposed at the surface on Banks Island. The outcrops were described by Thorsteinsson and Tozer (1962) before the Melville Island was formally subdivided into three formations. However, Thorsteinsson and Tozer made tentative lithologic comparisons between the Banks and Melville Island areas, most notably that between a prominent sandstone unit 43 metres (140 ft) in thickness exposed in the sea cliffs facing M'Clure Strait, and map unit 7 of Thorsteinsson and Tozer (1959). The latter was the unit subsequently renamed the Hecla Bay Formation. This correlation was followed by Klovan and Embry (1971) who studied the stratigraphy and sedimentology of the Banks Island outcrops in greater detail. They recognised the three formations, Weatherall, Hecla Bay and Griper Bay, in a composite section 1116 metres (3,660 ft) thick, measured along the coastline of northeastern Banks Island. Klovan and Embry also defined a new unit, Mercy Bay Member, for a succession of biostromal limestones which occur near the top of Weatherall Formation.

However, work by Hills *et al.* (1971) showed that the rocks exposed on the northeast coast of Banks Island (section 1 in Fig. 3 and section 2 in Fig. 4) range in age from lower Frasnian to middle Famennian, which falls almost entirely within the age range of the Griper Bay Formation of the type area, on eastern Melville Island (McGregor and Uyeno, 1972). The use of the three formation names on Banks Island is therefore appropriate only in the sense that they imply certain facies characteristics, as will be discussed below. Recent work by Embry and Klovan (1974) has shown that the ages of the various facies vary markedly across the Parry Islands, and that a major stratigraphic revision is necessary. However, the terms Weatherall, Hecla Bay and Griper Bay are used here in order to facilitate comparisons with previously published data.

No complete section through the Melville Island Group is yet available from the Banks Island area. The composite section of Klovan and Embry (1971) is the thickest, at 1116 metres (3,660 ft). An unknown thickness has been removed by erosion from the outcrops in northeastern Banks Island, and the base is not exposed. Beds of Givetian age which have been assigned to the Weatherall Formation crop out along the west coast of Prince of Wales Strait, but these were not included in Klovan and Embry's (1971) composite section, and their thickness is not known. The thicknesses of the various units in Klovan and Embry's section are as follows: Weatherall Formation 795+ metres

(2,610+ ft), including the Mercy Bay Member, which averages 61 metres (200 ft), Hecla Bay Formation 43 metres (140 ft), Griper Bay Formation 277+ metres (910+ ft). Thicknesses at Uminmak are slightly less: Weatherall Formation 589+ metres (1,933+ ft), Hecla Bay Formation 43 metres (140 ft), Griper Bay Formation 196+ metres (642+ ft). The base of the Weatherall Formation was not reached in the Uminmak well. The section at Cape Crozier, which correlates with the Weatherall of Klovan and Embry (1971) is 365 metres (1,198 ft) in thickness. The lower 167 metres (549 ft) of the Weatherall were penetrated in the Storkerson Bay well.

The stratigraphic reconstruction shown in Figure 4 indicates a possible thickness of 1800 metres (6,000 ft) in the vicinity of central Banks Island. Owing to lateral facies changes the thickness is expected to increase towards the north, and to decrease towards the south.

Lithology. The section in the Storkerson Bay well is the only one at present available in the report area in which the lower contact of the Melville Island Group is present. Rocks of the Weatherall Formation overlie the shales, siltstones and minor sandstones of the Nanuk Formation with a gradational contact.

The Weatherall at Storkerson Bay consists primarily of sandstone and shale, with minor siltstone. The sandstone is white or pale to dark grey, very fine grained with occasional fine grained or silty streaks, silica cemented and well indurated. In thin section (Table IV and Plate IIIA) the sandstones are observed to be predominantly quartzose, containing rare chert and rare plagioclase feldspar grains. Occasional grains of greenish biotite mica, clastic dolomite and clastic limonite are also present, the latter probably representing decomposed grains of ferromagnesian minerals from igneous or metamorphic sources. Quartz grains are commonly in contact, with straight or interpenetrating boundaries. The grains are dominantly angular, but in a few cases rounded ghost outlines are visible, indicating the existence of diagenetic overgrowths. A minor amount of dolomite matrix is present in the sandstones, some of which is recrystallised to small euhedral rhombs. Limonite and clay minerals are, however, the dominant matrix elements.

The interbedded shales at Storkerson Bay are dark grey, carbonaceous, silty, micaceous, laminated, and fissile. Pyrite is a minor constituent throughout the Weatherall section.

A more complete section through the Melville Island Group is present at Uminmak. Samples recovered from the Melville Island beds in this well consist of sandstone, siltstone, shale and minor coal. Geophysical log interpretation indicates that these lithologies are interbedded with one another on a fine scale, bed thicknesses averaging a few decimetres. The logs also indicate that the gross character of the succession remains virtually the same throughout, with the exception of an interval near the middle of the section which is indicated from the gamma ray log to contain two relatively clay free, porous sandstones. This interval is assigned to the Hecla Bay Formation; it has the same thickness as the unit referred to as Hecla Bay Formation by Klovan and Embry (1971). A detailed interpretation of the nature of the succession, based on samples and geophysical logs, is given in Figure 3.

The individual lithologies present in the Uminmak well are as follows: sandstones are pale grey, fine to very fine grained, quartzose, containing disseminated carbonaceous grains, and are calcareous, well cemented and (with the exception of the sandstones of the Hecla Bay, as noted above) show low intergranular porosity. Siltstones are similar in character. Shales are medium grey, silty and micaceous, or dark grey and carbonaceous. Rare reddish brown shales are also present. Fragmented plant remains are common. Two thin dolomite stringers are present in the lower part of the section. The dolomite is reddish brown in colour and fine grained.

A small portion of the Uminmak section 6 metres (19 ft) thick was cored just below the Paleozoic-Mesozoic contact, and this reveals additional lithologic information (Plate XB, C, D). Interbedding of the sandstone, siltstone and shale varies from interlaminated to thinly interbedded. Sedimentary structures include small asymmetric ripples, wavy and lenticular bedding (as defined by Reineck and Wünderlich, 1968), bioturbation, soft-sediment slumps and rolled-up sandstone intraclasts. A few of the sandstone laminae

TABLE IV. SANDSTONE PETROGRAPHY, WEATHERALL FORMATION

		Per Cent of Total Clastic Grains (approximately 200 grains counted per section)									
Location	Sample Position	Quartz	Chert	Plagio-clase	Clay Frag-ments	Musco-vite	Sericite Aggre-gates	Dolomite	% Clay Matrix	% Limonite Matrix	Notes
Storkerson Bay	1591 m (5220 ft) below KB	87	2	tr	4	2	-	6	15	13	tr detrital limonite, biotite
Cape Crozier	150 m above base	90	7	-	2	1	-	-	?	-	
Cape Crozier	316 m above base	95	4	1	tr	tr	1	-	16	-	
Cape Crozier	334 m above base	92	1	1	4	tr	-	-	15	2	tr glauconite

Note: These thin sections not stained for K-feld. identification. Small percentage probably present.

show graded bedding. Nodules and lenses of clay-ironstone approximately 2.5 centimetres (1 in) in thickness are present at several levels in the core.

Similar lithologies were observed in the Devonian section at Cape Crozier (Plate XI). Shale is the dominant lithology, but there are abundant interbeds of sandstone and minor interbeds of siltstone. No coal was observed at this locality. The shales are predominantly dark grey, silty, micaceous, well laminated, and contain occasional nodules of clay ironstone. Ripples and feeding trails are rarely present. The sandstones are pale in colour, medium to very fine grained, variably argillaceous, silty, carbonaceous, non-calcareous, slabby or blocky weathering. Fossils include fragmentary brachiopods, wood and trace fossils. Sedimentary structures are all small in scale. Ripples are the commonest structure;sole structures, including various tool markings, are also fairly common. Some of the sandstones are bioturbated.

Thin sections of three sandstone specimens from the Cape Crozier locality were analysed for mineral content by point counting (Table IV). The results indicate a predominance of quartz grains, plus minor amounts of chert, detrital clay fragments, muscovite and plagioclase, in decreasing order of importance. The high proportion of clay matrix places these sandstones just within the wacke category of Okada (1971), although whether the matrix is entirely clastic and primary in origin or whether part of it is the result of diagenetic alteration of rock fragment clastic grains (a process first described by Cummins, 1962) is uncertain at the present time. The relative abundance of the various clastic grains places most of the Melville Island sandstones within the quartzose wacke class of Okada (1971, Fig. 5).

The exposures of the Melville Island Group in northeastern Banks Island have been described in detail by Klovan and Embry (1971). The Weatherall Formation consists of interbedded sandstones, siltstones and shales very similar to those described above. Larger scale sedimentary structures are present than at Cape Crozier, including planar crossbed sets up to 1 metre (3 feet) in thickness. Brachiopods and trace fossils are common. One coal seam is recorded by Klovan and Embry (1971). A prominent reefoid limestone unit 200 feet thick (61 m), named the Mercy Bay Member by Embry and Klovan (1971), occurs near the top of the Weatherall Formation. The main constituent of this unit is a series of coral and stromatoporoid bioherms.

The Hecla Bay Formation on northeastern Banks Island (as defined by Klovan and Embry, 1971) consists of pale, fine to medium grained, porous sandstone. Large planar and trough crossbed sets are abundant. No stratigraphically distinctive fossils are present.

The Griper Bay Formation consists of an alternating sequence of sandstones, siltstones, shales and minor coals. Sandstones are crossbedded; marine fossils are absent.

<u>Age and Correlation</u>. As noted earlier, the outcrops of the Melville Island Group on northeastern Banks Island, along M'Clure Strait, have been dated as ranging in age from lower Frasnian to Famennian, on the basis of

megaspores (Hills *et al.*, 1971), brachiopods (Harrington, 1971) and corals (A. E. H. Pedder, as reported in Klovan and Embry, 1971). The Weatherall Formation, as defined by Klovan and Embry (1971), is lower to upper Frasnian, the Mercy Bay Member is middle Frasnian, the Hecla Bay Formation, upper Frasnian and the Griper Bay Formation, upper Frasnian to middle Famennian. Fossils collected by geologists of Elf Oil Canada Ltd. along the coast of Prince of Wales Strait (localities are shown in Fig. 1) show that the Weatherall Formation includes beds at least as old as Givetian, and a similar age is assigned to the basal Weatherall Formation in the Storkerson Bay well, on the basis of palynomorphs obtained from the immediately underlying Nanuk Formation.

The collections from Prince of Wales Strait are as follows (identifications by A. W. Norris):

GSC location no. C-12538, Lat. 73°04'N; Long. 117°20'W

undet. pelecypod
Spinatrypa sp.
Emanuella sp.
Nucleospira? sp. - mold
large echinoderm ossicle with single axial canal
Dechenella (Dechenella) aff. *D. (D.) struvei* R. & E. Richter, 1950 - head fragment
undet. trilobite tail fragment

GSC location no. C-12539, Lat. 73°13'N;Long. 116°58'W

Rhyssochonetes sp. cf. *R. aurora* (Hall) - faint concentric rugae
Emanuella sp.
large and small echinoderm ossicles with single axial canals

Norris states: "The trilobite *Dechenella (Dechenella)* aff. *struvei* present in sample C-12538, has been recorded by Ormiston (1967, pp. 98-99) from the Melville Island Group, south of Ibbett Bay, Melville Island, where the containing beds are dated as Givetian by Ormiston. Accordingly, sample C-12538 is dated as late Middle Devonian (Givetian) in age. The most diagnostic element in sample C-12539 is *Rhyssochonetes* sp. cf. *R. aurora*. *R. aurora* occurs typically in the Hare Indian and Ramparts Formation of the lower Mackenzie River area, in the Pine Point Formation of the Great Slave Lake area, and in the Dawson Bay Formation of southeastern Manitoba. From the known distribution of *R. aurora* in the above mentioned formations, a late Middle Devonian (Givetian) age is strongly suggested for sample C-12539."

The section in the Uminmak well compares closely in age span with the composite section of Klovan and Embry (1971). Four samples were analysed by A. R. Sweet for palynomorphs, principally megaspores, with the following results:

Sample 1: 878-884 metres (2,881-2,900 ft) interval, core no. 1 (GSC no. C-23953)

Megaspores:

?Ancyrospora magnifica Owens, 1971 (abundant)
Lagenicula sp. A. Hills, Smith and Sweet, 1971, Figs. 1-3 (common to rare)
Ancyrospora sp. (rare)
Hystricosporites sp. (rare)
Auroraspora macromanifestus (Hacquebard), Richardson, 1960 (rare)

Selected Microspores:

Lophozonotriletes cristifer (Luber) Kedo, 1957
Lophozonotriletes spp.
Stenozonotriletes simplex Naumova, 1953
Cyclogranisporites spp. McGregor and Owens
1966, Plate XXVI, figs. 3-4
Diaphanospora perplexa Balme and Hassel, 1962
?Hymenozonotriletes semilucensis (Naumova) Kedo,
1957
unidentified McGregor and Owens, 1966, Plate XXVII
fig. 19 (common)

Sweet comments that the megaspore and microspore assemblage in this sample matches that found above the 869 metre (2,850 ft) interval of Hills *et al.* (1971) in the composite outcrop section, and assigns a lower to middle Famennian age to the collection.

Sample 2: 1082 metre (3,550 ft) level, chip cuttings (GSC no. C-24083): Sweet states that the general megaspore population resembles that found in the 878-884 metre (2,881-2,900 ft) interval except for the appearance of small numbers of:

?Triangulatisporites rootsii Chaloner (1959)
Lagenicula devonica Chaloner (1959)
Ocksisporites sp. B. Hills, Smith and Sweet (1971),
Pl. 1, fig. 1
Ocksisporites maclarenii Chaloner (1959)

Hence, although the population is still dominated by *Lagenicula* sp. A Hills *et al.* (1971) and *Ancyrospora magnifica* Owens (1971), the appearance of the species listed above indicates the age of this interval to be Frasnian and correlative with the Hecla Bay or Weatherall Formation (as defined by Klovan and Embry, 1971).

Sample 3: 1235 metre (4,050 ft) level, chip cuttings (GSC no. C-24084): Sweet states that although all forms of megaspores reported for the 1082 metre (3,550 ft) interval were observed in this sample the darker specimens (i.e. those most apt to be representative of the actual population at this horizon) are mainly *Hystricosporites* spp. in association with some *Biharisporites* and *Ancyrospora*. This association is more indicative of the horizon below the Mercy Bay Member of the Weatherall Formation in the Banks Island section, and is assigned a Frasnian age.

Sample 4: 1677 metre (4,500 ft) level, chip cuttings (GSC no. 24085): Sweet comments that although translucent microspores were recovered from this sample any megaspores remained opaque even with repeated oxidation. Hence, the microspores are considered to be from cavings. The most plausible identification of the megaspores would be to *Biharisporites*, which would be suggestive of a Frasnian, possibly early Frasnian type population. The degree of carbonization is similar to that of the 1738-1768 metre (5,700-5,800 ft) interval of the Elf *et al.* Storkerson Bay A-15 well.

These age determinations indicate that the two dolomite units in the Uminmak section do not correlate with the Mercy Bay Member (they are somewhat older); the latter is thus not represented in the subsurface at Uminmak.

Seven samples from the Cape Crozier composite section were also analysed by A. R. Sweet for megaspores (GSC nos. C-26370 to C-26376).

Similar assemblages were found in each, although the samples spanned the full 363 metres (1,198 ft) of the section. The complete megaspore list for the combined seven samples is as follows:

Biharisporites spp. including *B. submamillarius* McGregor, 1960
Ancyrosporites ampulla Owens, 1971
Hystricosporites sp.
Archaeoperisaccus sp.
Ocksisporites spp.
Lagenicula devonica Chaloner, 1959.

Sweet comments that although recovery was sparse in all these samples due, at least in part, to extensive carbonization, by considering the total assemblage a fairly definite Frasnian age assignment can be made. A single brachiopod collected from this section (GSC no. C-33281) was identified by A. W. Norris as *Nervostrophia* sp. and was assigned a Frasnian age. Correlation with the lower part of Klovan and Embry's (1971) composite surface section is therefore reasonable.

Depositional Environment. The Weatherall Formation is predominantly marine, as indicated by the presence of brachiopods in the surface outcrops of the formation in northeast Banks Island (Klovan and Embry, 1971, p. 716; Harrington, 1971) and at Cape Crozier (as noted earlier in the present report). The Hecla Bay and Griper Bay Formations lack marine fossils and are probably predominantly nonmarine (brackish to fresh water). The Hecla Bay was interpreted as a nearshore marine facies by Klovan and Embry (1971) but subsequent work by Embry and Kovan (1974) has shown that the Hecla Bay facies is fluvial-deltaic in origin.

The present author interprets the bulk of the Melville Island succession as deltaic in origin, using that term in its broadest sense to cover a variety of subfacies ranging from marine, distal, delta-fringe shales and siltstones to proximal, nonmarine deposits such as channel sands formed within delta distributaries. The complete succession appears to represent a gradual regression, as shown by the distribution of marine fossils within the group.

In detail there is abundant evidence of rapid but comparatively low energy, shallow water sedimentation. This includes the immaturity of the sandstones, in particular the angularity of the quartz grains and the abundance of fine-grained matrix (Table IV, Plate XA), the preponderance of small-scale sedimentary structures such as ripples (Plate XC) and tool markings, the limited amount of bioturbation visible in the rocks, the frequency of roll-up structures (Plate XD) and the abundance of plant material. A variety of environments are probably represented in the succession. Lithologies and sedimentary structures are similar to those of many modern deltas, as illustrated by Kanes (1970), Donaldson *et al.* (1970), Oomkens (1970). Occasional thicker, cleaner sands as, for example, those comprising much of the Hecla Bay Formation probably represent a period of deltaic progradation, when channel sands built outwards over finer grained, more distal deposits. The sandstone unit at the base of the Hecla Bay at Uminmak (1099-1110 metre interval) appears from gamma ray logs to be part of a coarsening-upward cycle, such as are typical of prograding units (Pirson, 1970, Chapter 2).

The upward transition from marine to nonmarine within the Melville Island Group is a change that might be expected to accompany the advance of a prograding deltaic wedge. However, other lines of evidence for progradation are lacking. There is, in particular, little apparent change in sand/shale ratio between the Weatherall and the Griper Bay, and other than the upward disappearance of marine fossils the only other evidence that the Griper Bay was deposited under more proximal conditions than the Weatherall is an upward increase in coal and plant material (Fig. 3, section 1).

The change from marine to nonmarine probably was the result of marine circulation having been cut off by deltaic progradation somewhere else in the western Arctic, whereas the lack of major change in the sand/shale ratio suggests that at least in the Banks Island area subsidence kept pace with sedimentation. Thus once deltaic conditions had been established, in Givetian time, progradation, as such, probably did not play a significant part in the buildup of the Melville Island Group clastic succession.

Post-Devonian

A major stratigraphic gap is present throughout Banks Island between the Devonian rocks and those of Jurassic and Cretaceous age. Rocks of Mississippian to Triassic age have nowhere been recorded in the project area. However, several suggestive lines of evidence indicate that late Paleozoic and early Mesozoic rocks may have been deposited over parts of the Banks

Island area and may still be present in the subsurface. This evidence is noted below.

1. Seismic evidence (Lerand, 1973, Fig. 16) indicates that near the edge of the continental shelf off southwestern Banks Island the Devonian carbonate rocks appear to dip steeply to the west. Between these rocks and what are interpreted as the Cretaceous section is a wedge of strata of intermediate age, and this may include some sediments of Late Paleozoic age. The regional structural pattern is such that these sediments may be present along much of the continental shelf west of Banks Island.

2. Sands of the upper sand member of the Kanguk Formation (Miall, 1975b), which are Campanian or Maastrichtian in age, outcrop at Antler Cove 14 kilometres (9 miles) southeast Cape Crozier. They contain pebbles consisting of coral fragments. E. W. Bamber identifies the fauna as follows (GSC no. C-26204):

horn corals indet.
lophophyllid coral
?*Bothrophyllum* sp.
Protowentzelella sp.
bryozoans indet.

Bamber states that *Protowentzelella* is common in the Belcher Channel Formation and its equivalents in the Sverdrup Basin, but has not been reported from northern Yukon or Alaska. An Early Permian, probably Artinskian, age is assigned to the fauna. The Kanguk sands may be of local derivation or they may include material from Melville Island. They are interpreted as barrier island or shoreface sands and paleocurrent evidence is such that longshore drift from the north-northeast could not be ruled out (Miall, 1975b). The distance of transport implied by this proposed origin should not be regarded as excessive. Allen (1972) postulates distances of transport up to at least 800 km for sandy and pebbly material in the deltaic Early Cretaceous rocks of southern England. This is more than double the distance from northern Banks Island to Sverdrup Basin.

3. The sands of the Isachsen Formation (Lower Cretaceous) in Banks Island are in general considerably coarser than those of the more obvious potential source rocks such as the Melville Island Group, or the Glenelg Formation; yet all are of second cycle or polycyclic origin, as shown by the abundance of quartz grains with rounded detrital cores and secondary quartz overgrowths. Derivation from local outcrops of Late Paleozoic clastics such as the Canyon Fiord Formation, and consequent destruction of these outcrops, is a possibility.

4. Palynomorphs in the Melville Island Group, particularly in the Orksut, Nanuk and Storkerson Bay sections, are moderately to highly carbonized (A. R. Sweet, pers. com., 1974) to a degree greater than that which would be indicated by present depths of burial. Hydrocarbon maturation in the Paleozoic sections in all these wells is in the dry gas phase, except for the 1830-2160 metre (6,000-7,100 ft) interval in the Orksut well (L. R. Snowdon, pers. com., 1974) and there is an abrupt upward transition into the wet gas

phase at the Paleozoic-Mesozoic unconformity (Devonian-Jurassic at Orksut, Devonian-Cretaceous elsewhere). These facts suggest either that at some stage prior to the Jurassic, Devonian strata were at depths several thousand metres greater than they are at the present day, or that prior to the Cretaceous there was an unusually steep geothermal gradient. A thick cover of Late Paleozoic rocks is a possible explanation.

None of the wells drilled to date on land have penetrated any strata of Late Paleozoic age. However, if small erosional pockets of such sediments are present they may be hard to discover. Small remnants of once-extensive spreads of sediment can survive for considerable periods of time as small erosional outliers or as downfaulted slices, as shown by the distribution of Cretaceous sediments on the Arctic Platform east of Banks Basin. For example, outliers of Isachsen are present near Rodd Head in northeast Banks Island (Klovan and Embry, 1971) and on southeast Melville Island (Tozer and Thorsteinsson, 1964), and Kanguk shales are preserved on Somerset Island in a downfaulted slice 480 kilometres (300 mi) from the main area of outcrop of that formation in Sverdrup Basin (Dixon *et al.*, 1973). The most likely locality for Late Paleozoic sediments in Banks Island is Northern Banks Basin, which gravity data (Stephens *et al.*, 1972) suggest to be the deepest sedimentary basin in the project area, i.e. the one with probably the most continuous history of sedimentary infill.

CHAPTER III

STRUCTURAL GEOLOGY

The Paleozoic rocks of northeast Banks Island form part of Prince Albert Homocline (Thorsteinsson and Tozer, 1960). Beneath the Mesozoic and Tertiary cover the Paleozoic strata decrease in thickness southwards, so that Cretaceous sediments rest directly on the Precambrian at Rufus River, Nelson Head and De Salis Bay. The nature of this thinning is unknown at present, but is probably the result of pre-Cretaceous erosion followed by overlap by the basal Cretaceous sediments. The Precambrian-Paleozoic unconformity is not exposed in Banks Island and has not been penetrated by exploratory drilling. On Victoria Island the unconformity exhibits considerable topographic relief and, as a result, the basal Paleozoic unit (clastics and minor dolomite of Cambrian age) has a very erratic distribution (Thorsteinsson and Tozer, 1962, p. 40; Christie, 1972, p. 54).

The structural geology of the outcrop area of the Melville Island Group in northeastern Banks Island has been described by Klovan and Embry (1971, p. 720-722). The dominant feature is a broad syncline, the axis of which trends approximately 10° east of north and crosses the coastline near Pim Ravine. The east limb of the syncline shows very gentle dips, typically in the order of 2°. Near Parker Point the beds are virtually flat lying. This limb is coincident with the northwest portion of Prince Albert Homocline. The west limb of the syncline passes westwards into a region of closely spaced anticlines and synclines and normal faults, all trending approximately north-south. Deformation in general increases towards the west, although dips nowhere exceed 10° and the throws in the faults do not exceed 90 metres (300 ft). The contact with the Cretaceous near Cape Vesey Hamilton is mainly fault bounded.

The outcrops of the Melville Island Group at Cape Crozier (Plate XIA) and Cape M'Clure (Plate XII) are fault bounded at least in part, as shown by Thorsteinsson and Tozer (1962). Dips are again gentle, varying from 10° to the southwest, near the eastern edge of the Cape Crozier inlier, to 4° to the east-southeast at the tip of Cape Crozier. The fault which forms the east side of the Cape Crozier inlier juxtaposes Weatherall Formation against Christopher Formation (Lower Cretaceous), a throw in the order of 300 metres (1,000 ft). This fault, along with others in Northern Banks Basin, may have been active at several stages during the history of the region, as discussed in Chapter IV.

Proterozoic rocks are brought to the surface in southern Banks Island at Cape Lambton Uplift (Miall, 1975a). The lower, carbonate-chert member of the Glenelg Formation is exposed in the core of this uplift, at Cape Lambton. There is little or no angular discordance between the Proterozoic and the Cretaceous, indicating that pre-Mesozoic tectonic activity in this area can have consisted only of broad warping movements. Dips measured in the Glenelg by the author nowhere exceed 3°. Gravity data (Stephens *et al.*, 1972) suggest that the Cape Lambton Uplift follows a northerly trend, but the outline of the uplift is far from being clearly defined, except at its eastern edge. East of Nelson Head, a north-south trending normal fault juxtaposes the Glenelg Formation against shales of the Christopher Formation (Plate XIIB). The downthrow increases to a maximum of at least 600 metres (2,000 ft) a few kilometres to the north, such that Eureka Sound Formation is present against the fault on the downthrow side. Beyond this point the throw decreases, and the fault dies out near Nelson River, 16 kilometres (10 miles) inland. Other faults oriented in a north to northeasterly direction are present within the outcrop belt of the Glenelg Formation. All of these appear to cut the Cretaceous rocks and are thus probably of post-Cretaceous origin.

Subsurface control is as yet inadequate to provide reliable information on structural geology in the area of Mesozoic and Cenozoic cover (except for those in possession of confidential seismic data). Most of the island is characterized by block faulting, but how much of this is an extension of pre-Mesozoic tectonic activity is very hard to assess (see next chapter). Dipmeter logs indicate low dips (less than 5°) at the Uminmak location and steeper dips (up to at least 20°) at Nanuk. Stylolites in Emsian limestone (Blue Fiord Formation) comprising core no. 1 at Storkerson Bay are oriented both horizontally and vertically, indicating that lateral compressive forces as well as overburden stresses have acted on the rocks. Tensional or shear stresses have given rise to numerous small fractures, now infilled with secondary minerals. These are visible in most of the cores from the Paleozoic rocks. Several fractures in the Storkerson Bay core are infilled with fluorite (Plate VIB). The problem of lost circulation was encountered in the Devonian limestone at total depth in the Storkerson Bay well, as a result of fractures. Numerous fractures were also encountered while drilling through the siliceous shales (Nanuk Formation). These gave rise to severe loss of circulation in the Nanuk well between 4,065 feet (1239 m) and total depth. A large fracture, at least 5 metres (16 ft) in width, is exposed in the Devonian rocks (Melville Island Group) east of Mercy Bay at Lat. 75°05' N; Long. 118°39' W. The fracture is filled with sparry calcite, which may have originated as tufa. The deposit predates the Cretaceous, as shown by the truncation of the fracture at the Melville Island-Isachsen unconformity.

Gravity data (Stephens *et al.*, 1972) indicate that a series of highs and lows underlies Banks Island. Banks Basin (Fig. 2) is the largest of these, with a known axial length of 250 kilometres (150 mi) and a maximum relief of at least 1800 metres (6,000 ft). One of the uplifts brings Hadrynian rocks to the surface near De Salis Bay (Fig. 5). Jurassic, Cretaceous and Tertiary sediments contain evidence that these structural features were in existence during their deposition (Miall, 1974b, 1975b), but to what extent, if at all, the highs and lows reflect earlier Paleozoic trends, is unknown.

Coppermine Arch, as defined by Lerand (1973, Fig. 7) was an active uplift during Devonian times (see Chapter IV) and probably also controlled sedimentation during the Early Cretaceous (Miall, 1975b). It is thought to exist at the present day as a broad, subdued feature largely covered by the waters of Amundsen Gulf.

There is no convincing evidence that the Paleozoic rocks in the subsurface of western Banks Island are structurally deformed to an extent comparable with, say, Parry Islands Fold Belt. The extensive faulting in the area affects rocks as young as the Eureka Sound Formation (Maastrichtian to Eocene) and is therefore of Mid- or Late Tertiary age. Extensive deformation of earlier (for example Ellesmerian) age cannot be demonstrated. The fact that several different Devonian formations are present at the Cretaceous-Devonian unconformity in different areas indicates that some structural deformation in pre-Cretaceous times did take place, but this may have been limited to gentle warping or limited faulting movements.

A sketch map of the paleogeology of the area immediately prior to the commencement of Mesozoic sedimentation is given in Figure 6. The regional dips shown are calculated from subsurface control, using the assumption that the Paleozoic-Mesozoic unconformity surface was a horizontal plane at the time. The dip shown to the south of the Orksut location is based on the assumption that 600± metres (2,000± ft) of Paleozoic rocks lie beneath the Silurian(?) strata in which the Orksut well was terminated. That between Uminmak and Nanuk follows from the stratigraphic reconstruction (Fig. 4) showing approximately 1800 metres (6,000 ft) of Paleozoic strata between the top of the Nanuk Paleozoic succession and the top of the Uminmak Paleozoic succession. Figure 6 shows that the outcrop pattern which can be reconstructed from the available evidence is consistent with a regional structure similar to that of Prince Albert Homocline of Victoria Island, i.e. very gentle regional dips and no evidence of strong lateral compression.

Figure 7 is a structural cross-section through central and southern Banks Island. The line delineating mature and immature portions of the section will be discussed in Chapter V (Economic Geology).

CHAPTER IV

GEOLOGICAL HISTORY

Proterozoic

The Glenelg rocks of southern Banks Island form part of the Late Precambrian succession of Amundsen Basin (Christie, 1972, p. 45) or Embayment (Young, 1974, p. 38). They are part of a belt of sediments extending along the entire west side of North America, which Stewart (1972) regards as a continental terrace-wedge deposit of a proto-Pacific ocean. The lower member of the Glenelg, consisting of stromatolitic, cherty dolomite, was deposited in a shallow shelf sea. Stromatolite orientations in parts of Victoria Island indicate currents oriented northeast-southwest and are interpreted by Young (1974, p. 37) as corresponding to the direction of longshore currents.

Uplift in the craton during the latter part of Glenelg time is indicated by the flood of sandy detritus which now comprises the upper member of the Glenelg. Paleocurrent evidence from southern Banks Island indicates derivation by a fluvial system flowing from the southeast. Part of the upper Glenelg at Nelson Head consists of interbedded fine grained sandstone, siltstone and mudstone and is interpreted as intertidal or shallow subtidal in origin. A fluctuation between fluvial-deltaic and shallow marine conditions is therefore indicated. Environments of this type have been referred to as fan-deltas by McGowan and Scott (1974). A marine transgression is indicated by the upper 100 metres of section at Nelson Head, in which fluvial sands pass up into texturally more mature sands of possible littoral marine origin, and these in turn pass up into a shale unit of probably open marine origin. Similar depositional environments are interpreted for the Glenelg Formation of Victoria Island by Young (1974). Young has obtained more direct evidence of a tidal influence on parts of the succession, in the form of bimodally distributed paleocurrent directions. As shown by Klein (1970) this type of current pattern is the result of tidal ebb and flow. Young also obtained evidence for strong local uplift in the form of pebble conglomerates in the basal Proterozoic succession (probably Glenelg) on the flanks of Wellington High at Starvation Cove, on the south central coast of Victoria Island.

Following deposition of the remainder of Shaler Group, diabase-gabbro sills were emplaced. K-Ar dates on these rocks indicate a very late Precambrian age for the intrusions (Christie, 1964, p. 10). Uplift and gentle folding along a northeast-southwest trend in latest Precambrian or earliest Cambrian times resulted in the development of Minto Arch (Fig. 2) (Fortier *et al.*, 1954), within which were formed several major subsidiary structures, including Holman Island Syncline and Walker Bay Anticline (Thorsteinsson and Tozer, 1962). The exposure of Glenelg Formation at Nelson Head and Cape Lambton is on strike with Walker Bay Anticline and is considered to be part of the same broad structure. Elsewhere, as in Thorsteinsson and Tozer (1960, 1962, p. 73) and Christie (1972, p. 81) the Hadrynian rocks of southern Banks

Island have been interpreted as part of Prince Patrick Uplift, a north-south trending structure. However, recent work in Banks Island (Miall, 1975b) has demonstrated that there is no convincing case for a structural link between these two areas of uplift.

During latest Precambrian and earliest Cambrian times at least the southern part of the report area was probably undergoing erosion, as shown by the unconformable contact between Proterozoic and Cambrian strata in adjacent areas of Victoria Island.

Paleozoic

Owing to the fact that none of the wells drilled to date in Banks Island have penetrated strata older than Lower Devonian or latest Silurian, little can yet be said concerning the early Paleozoic history of the report area. The regional history and paleogeography during the Devonian is now fairly well understood, however, and a discussion thereof forms most of the remainder of this chapter. The regional correlation chart, Table V, should be referred to throughout this discussion, as should Figure 8, which is a series of three regional stratigraphic cross-sections, placed side by side for comparative purposes. The Jurassic to recent geological history of the area will be discussed in later reports to be prepared by the author (including Miall, 1975b).

The Cambrian to Devonian time interval appears to have been dominated by a gradual but persistent sedimentary encroachment southwards and eastwards onto the Arctic Platform. Most of the Cambrian to Silurian craton sediments are shallow water marine carbonates, as described by Thorsteinsson and Tozer (1962). There are erosional breaks in the sedimentary record, but no indications of major environmental changes which would indicate tectonic events altering the extent and configuration of the craton itself. The evidence for this assertion is limited to that which is known from Victoria Island, owing to the lack of deep well penetrations on Banks Island. Evidence will be discussed below which demonstrates that geosynclinal conditions spread to western Banks Island in Early or Middle Devonian times. Deeper well penetrations may show that, in fact, the geosyncline was present in this area much earlier.

Subsurface evidence described in this report shows that early in the Devonian much of the Banks Island area formed part of the Arctic Platform, but that in the mid-Early Devonian deep water sedimentation spread southwards and southeastwards from the Franklinian Geosyncline, indicating a subsidence of the craton edge. In the Middle Devonian the Franklinian Geosyncline began to fill with clastic sediments derived from new tectonic lands to the north or northeast or northwest. This clastic influx rapidly spread to Banks Island, and during the latter part of the Middle Devonian the shelf edge receded farther to the south and east as the Franklinian Geosyncline and its Banks Island extension continued to subside and to receive great quantities of detrital sediments. Clastic sedimentation persisted through most of Late Devonian time, although how far it continued to encroach on the craton of

Banks and Victoria Islands is unknown, as strata of this age are not present in southern Banks Island or on Victoria Island.

The earliest period for which sufficient information is available to allow the construction of a paleogeographic map is the late Emsian, i.e. the end of the Early Devonian (Fig. 9). At this time, at the Nanuk location, subsidence had allowed the commencement of deep water sedimentation of Ibbett Bay type (Nanuk Formation). The underlying strata, of Emsian and possibly older age, are calcareous shales of the basin slope facies (Orksut Formation). The lithologic transition is thus an indicator of the final subsidence of the shelf in the Nanuk area. Late Emsian strata of Storkerson Bay comprise shelf carbonates, but these pass up within a few feet into a thin basin slope facies and then into the deep water siliceous shale facies, indicating that subsidence took place rapidly at this locality. Princess Royal Island and parts of northwestern Victoria Island were similarly located at the very edge of the shelf at this time. The shelf-basin slope transition is in fact exposed on Princess Royal Island, where talus slopes of crinoidal limestone from a shelf-edge bioherm or biostrome interfinger with deeper water shales. The Orksut location is situated well within the stable shelf. Late Emsian strata are dolomites, and carbonate sedimentation persisted here until the middle of Mid-Devonian times.

To the southwest of Coppermine Arch in Mackenzie Basin and northern Yukon a similar shelf and basin slope assemblage is present. It is composed of the carbonates of Gossage, Bear Rock and Ogilvie Formations and the argillaceous Prongs Creek Formation (Lenz, 1972).

Several regional implications are apparent from the paleogeographic map. Thus, the influence of Coppermine Arch, as outlined by Lerand (1973, Fig. 7), appears to be indicated by the bend in facies belts in central Banks Island. The Arch at this time took the form of a platform submerged under a shallow shelf sea. At some time prior to the Cretaceous the Arch was emergent, for at Nelson Head on southern Banks Island, and at Darnley Bay, on the mainland, Cretaceous rocks have overstepped all Paleozoic units to rest directly on the Proterozoic. (A regional cross-section through the southwest flank of the arch which shows this relationship is given by Yorath, 1973, Fig. 2). According to Cook and Aitken (1969) structural relationships near Brock Inlier suggest a period of post-Early Silurian, pre-Middle Devonian tectonism. Therefore part of Coppermine Arch may have been a land area during the Early Devonian, as shown in Figure 9. By Middle Devonian time the sea had probably returned, for Cook and Aitken record a single outcrop of Hume Formation on the east flank of Brock Inlier. The outcrop exposes coral and stromatoporoid limestone, which suggests a typical platform facies with no nearby terrigenous sediment sources.

Some of the other structural elements which were important during the Mesozoic and Tertiary such as Big River Basin, Banks Basin and Storkerson Uplift (Miall, 1974b, 1975b), are not apparent in Early Devonian times, as shown by Figure 9. Thus the Nanuk well is located on the flanks of Storkerson Uplift but in Early Devonian times this location was part of a deep trough. Conversely, Coppermine Arch appears to have had little effect on Mesozoic and Tertiary sedimentation in Banks Island, except perhaps during the Early Cretaceous, as discussed by Miall (1975b).

The area of deep water sedimentation in northwestern Banks Island is considered to be part of Hazen Trough. The latter was originally named by Trettin (1971a) for an area of deep water sedimentation in northeastern Ellesmere Island. Subsequent field work (Trettin, 1971b, 1974) and regional compilations (Trettin *et al.*, 1972) have indicated that this belt extends to the southwest as far as Melville Island, and that rocks which are sedimentologically part of the trough succession are exposed in several different parts of Ellesmere Island outside the original type area. Different parts of Hazen Trough had different histories;thus in the Lake Hazen area sedimentation commenced with a deep water cherty shale facies in the Early Ordovician and continued with a flysch facies through the Mid-Ordovician, Silurian and Early Devonian (Trettin *et al.*, 1972). In western Melville Island (the type area of Ibbett Bay Formation) the chert and shale facies persisted from Early Ordovician to Early, and possibly Middle Devonian times (as discussed in Chapter II). The stratigraphy of the Nanuk well shows that deep water sedimentation did not commence at that locality until late Early Devonian times, but the narrowness of the basin slope facies belt in that area suggests that lateral facies changes there may occur over very short distances, and it is possible that in the vicinity of, say, the Uminmak location, the deep water facies may have commenced considerably earlier. This is consistent with the history of general southward and eastward facies migrations in the Banks Island area that was outlined earlier in this chapter.

It is possible that the Hazen Trough linked with Richardson Trough during much of its history. Lenz (1972) shows that the latter was undergoing deep water sedimentation throughout most of Cambrian to Middle Devonian time. The eastern margin of the trough appears to trend in a northeasterly direction in the Fish River-White Mountains area of northern Yukon. This trend would carry the shelf-trough margin along the Tuktoyaktuk fault-flexure zone which, according to Lerand (1973, p. 327), was active during the Paleozoic. It is possible that the present tremendous northward downthrow along this fault zone is a reflection of a much older flexure corresponding to the craton edge, although deep well control is sparse in this area and thus Paleozoic facies changes are not mapped at the present time. This interpretation is consistent with the paleogeography of Banks Island, the shelf edge "wrapping around" the northwestern end of Coppermine Arch as shown in Figure 9.

Whether or not the Arctic Ocean Basin existed at this time is a subject that has been speculated upon at length (Churkin, 1970; Tailleur and Brosgé, 1970; Miall, 1973). The evidence available from the Early Devonian of the project area could be interpreted in several ways; either the southwest part of Hazen Trough was in fact only a nearshore segment of a larger ocean basin corresponding approximately to the present Arctic Ocean, or Hazen Trough and perhaps an extension to Richardson Trough, formed an axial seaway along or adjacent to an embryonic rift which later opened, causing Alaskan and Arctic Islands continental plates to separate. The northwestern shoreline of Hazen Trough is at present known only in Ellesmere Island where it is referred to as Pearya Geanticline (Trettin *et al.*, 1972). Trettin *et al.* (1972, Fig. 29) suggest that Hazen Trough and Pearya Geanticline were located within the continental crust, and that an ancestral Canada Basin, floored by oceanic crust, lay farther to the northwest. These hypotheses are examined later in this chapter.

Between earliest Eifelian and earliest Givetian times the facies belts shown in Figure 9 shifted gradually southwards. To the north, on Melville Island, the turbidites of the Blackley Member represent the first distal fringe of the Melville Island Group clastic wedge. These sediments may have spread gradually southwards across Banks Island, but there is at present no conclusive evidence of the existence of this facies within the report area. At Storkerson Bay the earliest sandstone units are of upper Eifelian or lower Givetian age. None of the other wells penetrate this part of the section. Carbonate sedimentation persisted at Orksut, and the same carbonate facies probably developed all along the craton edge southwards into the Mackenzie Platform region, where it constitutes the Hume Formation.

During middle Givetian to middle Famennian time the Hazen Trough was filled with the fluvial and deltaic sands, shales and silts of the Melville Island Group. The succession marks a gradual southward marine regression, for the lower, Givetian and Frasnian part of the Melville Island Group contains a marine fauna, whereas the upper part of the group (Famennian) lacks such a fauna and is probably largely nonmarine in origin. As discussed earlier, the disappearance of the marine influence may be the result of regional paleogeographic changes, rather than a local evolution in the depositional environment, for the sediments of the Griper Bay Formation on Banks Island (definition of Klovan and Embry, 1971) are not significantly more proximal in nature than those of the Weatherall Formation. Marine circulation in the Banks Island area may have been cut off by deltaic progradation so that the sea locally became brackish or fresh (evaporite formation would have been prevented by the continual influx of river-borne fresh water).

The Hazen Trough was an area of deep water during Early Devonian times, perhaps as much as 3 to 4 kilometres deep, if the analogy (discussed elsewhere in this report) between the Nanuk and Ibbett Bay Formations and the Ruhpolding Beds (Garrison and Fischer, 1969) is accurate. Yet the evidence available indicates that the thickness of Melville Island Group strata is less than 2 kilometres. Insofar as the Melville Island Group is to be regarded as the final sedimentary infill of Hazen Trough, the thickness of the infill does not appear to be sufficient. Much of the succession is interpreted as shallow marine or nonmarine in origin, so that by at least early Frasnian times water depths cannot have been greater than a few tens of metres. Four points may be made here:

1. Post-Devonian, pre-Pennsylvanian erosion may have removed considerable thicknesses from the upper part of the Griper Bay Formation.

2. Continued drilling, especially in northwestern Banks Island, may reveal much greater thicknesses of Melville Island strata than have yet been recorded. The figure of 1800 metres (6,000 ft) that is shown in Figure 4 is believed to be accurate only for the central part of Banks Island.

3. Lowermost beds of the Melville Island Group may be deep water in origin. This is, for example, a strong possibility for the turbidite beds of Blackley Member, which is 700 metres (2,300 ft) thick on western Melville Island. Trettin *et al.* (1972, p. 95) state that the flysch infill of Hazen Trough in Ellesmere Island exceeds 2700 metres (9,000 ft). Beds of similar facies and comparable thickness may be present in northern Banks Island.

4. Bearing the preceding in mind, it is nevertheless possible that the disappearance of Hazen Trough resulted as much from epeirogenic uplift as from static sedimentary infill. Such uplift would be consistent with the regional uplift which took place to the north and northeast and which culminated in the Ellesmerian Orogeny.

A paleogeographic map has been drawn for the Middle and Late Givetian time interval (Fig. 10). Shelf carbonate sedimentation had ceased within the report area by this time, although it persisted to the southwest, in the form of biohermal limestones of Ramparts Formation, at Norman Wells and may have persisted also in the vicinity of Brock Inlier, where Cook and Aitken (1969) record a single outcrop of Middle Devonian platform limestone. At Orksut shallow water carbonate sedimentation was replaced by a (probably) deeper water environment in which fine, micaceous, silty clays accumulated. Little is known about northern Banks Island during the Givetian. For at least part of this stage the area may have been undergoing flysch-type deposition under relatively deep water conditions.

Insufficient new information is available for the author to improve on the paleogeographic interpretations made by Klovan and Embry (1971) and Embry and Klovan (1971) for the Frasnian and Famennian. Only one new control point has become available within the report area - the section at the Uminmak well, and this shows a very similar Upper Devonian succession to that described in the first of the two quoted papers. The only major difference is that the Mercy Bay Member appears to be completely absent at Uminmak.

In general the Upper Devonian rocks of northern Banks Island (as almost everywhere else in the North American Arctic) record a gradual southward deltaic progradation. By latest Frasnian times this resulted in the deposition of a fluvial unit in northeast Banks Island, the Hecla Bay Formation (Klovan and Embry, 1971). However, deposition of this unit was preceded by a short-lived marine transgression, which slowed the clastic influx into the area and allowed the development of the stromatoporoid reef limestones of Mercy Bay Member (Embry and Klovan, 1971). Evidence from the Mercy Bay bioherms indicates that water depths were in the order of 27 metres (90 ft) and that predominant wind and current directions were from south to north and from east to west. A warm climate is indicated which, as noted by Embry and Klovan (1971, p. 774), is consistent with a paleolatitude determination of 25° south by Creer (1967). The Mercy Bay reefs are confined to an outcrop area approximately 80 kilometres (50 mi) in diameter, although the northerly and westerly limits are unknown owing to cover by the sea and by the younger rocks of Northern Banks Basin. Lateral persistence to the west may be limited, as indicated by the absence of the member at the Uminmak well.

The Melville Island Group is part of a wedge of Middle and Upper Devonian clastic sediments that extends from Ellesmere Island in the east to northern Alaska and Wrangel Island in the west. Thickness variations and facies relationships indicate that most of the detritus comprising this wedge was derived from sources to the north of present land areas, located in what is now the Arctic Ocean Basin (although Klovan and Embry, 1974, disagreed with this interpretation, as noted below). Various tectonic models have been proposed to explain the origin and subsequent disappearance of these sediment sources. Churkin (1970) referred to a circum-Arctic tectonic belt, and interprets the clastic wedge as having been derived from tectonic lands within the belt. Tailleur and Brosgé (1970), Freeland and Dietz (1973) and Miall (1973) suggested that Alaska and the Arctic Islands may have collided during the Late Devonian, and that a rotational movement of the Alaskan plate subsequently gave rise to the present geographic dispositions. Trettin *et al.* (1972) derived the Late Devonian clastics of the Canadian Arctic from Pearya Geanticline, an ancient orogenic belt located along the north coast of Ellesmere Island (Fig. 11); they suggested (op. cit., p. 167) that activation of the geanticline may have taken place during a collision between the Arctic Islands and a Siberian plate. This model was further developed by Herron *et al.* (1974), who suggested that the Arctic Islands collided with a plate corresponding to the Kolymski area of Siberia. Subsequently, according to this latter interpretation, rifts developed during the Jurassic about a triple point junction located in the vicinity of the Mackenzie Delta. Two rifts, one along the northern continental edge of Alaska and one along the northwestern margin of the Canadian Arctic Islands, opened fully, so that the Siberian plate drifted completely away from the North American continent. The third rift became, according to this model, a "failed arm" in the terminology of Burke and Dewey (1973). Herron *et al.* (1974) suggested that Mackenzie Delta represents this failed arm.

A further complication was raised by the work of Klovan and Embry (1974), who proposed that the bulk of the Middle to Upper Devonian clastic wedge in the Canadian Arctic was derived from Greenland and not from

Pearya Geanticline. Their main lines of evidence include paleocurrent determinations and sand petrography. Thus current directions in Melville and Bathurst Islands indicate derivation from easterly rather than northerly sources.

None of these regional models are fully satisfactory, in that all leave certain facts unexplained. The various proposals regarding continental drift all neglect to consider the plate tectonic history of Siberia itself, or the evidence accumulated by Churkin (1972) which suggests that Alaska and eastern Siberia were never separated by drift movements during the Paleozoic. Similarly, the paleogeographic model offered by Embry and Klovan (1974) may have much to commend it for the Canadian Arctic Islands, but it cannot explain the origin of the Upper Devonian clastic sediments of Yukon Territory or Alaska, all of which appear to have been derived from the north. Even their paleocurrent evidence is not conclusive, for current directions in the centre of a depositional trough may not be the same as those at the edge. Many modern rivers show marked changes in direction along their present day courses, as a result of local tectonic influences.

As discussed in an earlier section, evidence regarding the Mississippian to Triassic time interval is scanty in the Banks Island area. Several arguments were advanced which suggested that thick Late Paleozoic sediments may once have covered the area, but none of these are conclusive. Two problems arise in this connection: when would these sediments have been deposited? and when would they have been removed? The history of the region was presumably similar to that of Sverdrup Basin or to the Arctic mainland, and so a comparison with either region may be appropriate. Sediment thicknesses in Sverdrup Basin are of the order of magnitude necessary to explain such features as the high degree of thermal carbonization of the Devonian rocks (given a normal geothermal gradient). The Canyon Fiord Formation (Pennsylvanian) alone, is estimated to be 1200 metres (4,000 ft) thick in Raglan Range, Melville Island (Tozer and Thorsteinsson, 1964, p. 98), and the BP *et al.*, Satellite F-68 well, on Prince Patrick Island, penetrated a 3000-metre (10,000 ft) thick Pennsylvanian to Triassic section. However, the main tectonic episode in the Paleozoic of this area is thought to have taken place during the latest Devonian or earliest Mississippian, before the Late Paleozoic sediments were accumulated. Thus if equivalent thicknesses were deposited in Banks Island the problem arises as to when their uplift and erosion took place. Late Paleozoic (Early Permian) movements, the Melvillian Disturbance, are known to have occurred in two areas in the Arctic Islands (Tozer and Thorsteinsson, 1964, p. 209; Thorsteinsson and Tozer, 1970, p. 572) but as stated by Trettin *et al.* (1972, p. 132) any uplifts associated with the disturbance in these two areas must have been relatively minor because there is no evidence of deep erosion or of a major clastic wedge. Virtually contemporaneous movements have been demonstrated by Bamber and Waterhouse (1971, p. 93) to have taken place in northern Yukon. The uplift appears to have been greatest along Aklavik Arch, a northeast-southwest trending tectonic lineation extending through northern Richardson Mountains. In this region Lower Permian rocks rest on the Upper Devonian Imperial Formation. Some authors, e.g. Norris (1973, p. 39) and Lerand (1973, p. 334) suggested that Aklavik Arch may extend northeastwards into the Banks-Victoria Islands area. However, speculations regarding the Late Paleozoic history of the area must remain tentative until more evidence becomes available.

A paleogeological sketch map of the report area as it existed in pre-Jurassic times has been given earlier (Fig. 6). The outcrop pattern indicates that post-Devonian, pre-Jurassic earth movements were gentle in this area, for there is no evidence of any strong folding or faulting in the Paleozoic rocks that can be demonstrated to be of pre-Mesozoic age. Evidence from the basal Mesozoic rocks indicates that considerable local relief existed on the Paleozoic erosion surface at the time of their deposition. This was accentuated by faulting activity in the Early Cretaceous. The subsequent geological history of the report area is discussed elsewhere (see Miall, 1975b). A structural cross-section through Banks Island has been provided earlier (Fig. 7).

CHAPTER V

ECONOMIC GEOLOGY

Oil and Gas

No shows or seepages are known in the Paleozoic rocks of Banks Island. Traces of bitumen are present in the Blue Fiord Formation at the Orksut well. Only one drill stem test was carried out in the Paleozoic sections at the four wells described in this report. The test was carried out over the 1116-1139 metre (3,660-3,738 ft) interval of the Nanuk D-76 well, which includes the basal 11 metres (35 ft) of the Christopher Formation and the uppermost 13 metres (43 ft) of the Nanuk Formation. Recoveries consisted of 177 metres (580 ft) of watery gas cut mud and 835 metres (2,740 ft) of gas cut, slightly sulphurous water. No gas flowed to the surface. Water salinity was measured at 44,093 parts per million.

Various indicators suggest that much of the Paleozoic section in Banks Island is over-mature with respect to hydrocarbon generation. Spore colour is a measure of the degree of thermal alteration of the enclosing sediments (Staplin, 1969). Preliminary applications of this technique to the palynological recoveries made from the subsurface Paleozoic rocks indicate a rather high degree of alteration. Qualitative descriptions, only, are available at the present time. These are listed below (estimates by A. R. Sweet and D. C. McGregor).

Storkerson Bay A-15	1737-1768 metres	(5,700-5,800 ft)	high carbonization
Nanuk D-76	1139-1144 metres	(3,738-3,752 ft)	high carbonization
Uminmak H-07	878- 884 metres	(2,881-2,900 ft)	low carbonization
Uminmak H-07	1676 metres	(5,500 ft)	high carbonization
Orksut I-44	1829-1834 metres	(6,002-6,017 ft)	moderate carbonization

High carbonization levels suggest an over-mature sedimentary section, which would be expected to yield dry gas, only. Moderate carbonization levels indicate a mature section, in which oil generation may be expected if sufficient kerogenous organic matter is present.

These results are confirmed by unpublished geochemical analyses carried out by L. R. Snowdon (pers. com. 1974) using the techniques described in Snowdon and McCrossan (1973) and Snowdon and Roy (in press). The Paleozoic sections in the Nanuk and Storkerson Bay wells are described as over-mature, as is the section in the Orksut well below a depth of 2160 metres (7,100 ft). Above 2160 metres the Paleozoic section at Orksut is mature. The Paleozoic section at Uminmak includes abundant coal and plant remains and would be expected to yield dry gas, only. In terms of thermal alteration it is rated as immature to mature.

It is of interest to note that, as shown in Figure 7, whereas at the Nanuk and Storkerson Bay locations the over-mature stage is reached at depths of 1200 metres (4,000 ft) or less, at the Orksut well the same maturity level is not reached until a depth of 2160 metres (7,100 ft). In an earlier section (post-Devonian stratigraphy) it was argued that maturity levels in the Devonian rocks may have resulted from deep burial in pre-Jurassic time. The varying depth of the mature-over mature boundary may reflect differences in pre-Jurassic burial depth across Banks Island or, alternatively, it may reflect regional variations in geothermal gradient in pre-Jurassic time. In either case the data would tend to suggest that prospects for oil, as opposed to gas, may be greater in central than in western Banks Island.

Analysis has shown that organic carbon content is very low throughout the subsurface Devonian rocks except for that derived from plant material (L. R. Snowdon, pers. com., 1974). There are thus no obvious source beds in the strata that are described in this report.

Carbonate sediments of the Blue Fiord Formation are regarded as the best potential reservoir rocks in the Devonian of the Banks Island area. Beds of similar age and lithology have yielded the only live oil recovery yet obtained from the Paleozoic rocks of the Arctic Islands, at the Panarctic Tenneco *et al.* Bent Horn N-72 well, located on Cameron Island 430 kilometres (270 miles) northeast of Banks Island (Oilweek, April 8, 1974, p. 41. Cameron Island is the northernmost of the small islands northwest of Bathurst Island). The Blue Fiord in the Storkerson Bay and Orksut wells exhibits very low to zero porosity, except for fractures, but the formation is in part dolomitized and facies studies suggest that biohermal or biostromal developments may be present. Therefore a potential for significant porosity does exist.

The biostromal and biohermal limestones comprising Mercy Bay Member are also potential reservoir rocks, but the organic banks are relatively small; the largest is described by Embry and Klovan (1971, p. 760) as 60 metres (200 ft) thick, 180 metres (600 ft) wide and at least 300 metres (1,000 ft) in length. Although the limestones are probably present in the subsurface beneath and to the west of Mercy Bay their areal distribution may not be very great. The Mercy Bay Member is absent in the Uminmak well.

Some of the sandstone units in the Melville Island Group, particularly those of Hecla Bay Formation, may be good potential reservoir beds, although most of the samples studied to date contain in excess of 15% of clay or limonitic matrix and are of very low porosity.

Trap possibilities are of two main types, structural traps associated with block faulting, and stratigraphic traps associated with facies changes, particularly the Blue Fiord - Orksut transition. Little can be said about the first type of trap possibility. Normal faults are known to be relatively common at least in northern Banks Island where the surficial cover is thin and structural mapping has been possible. Throws vary from a few metres to at least 600 metres (2,000 ft). The details of how such faults affect the Paleozoic strata at depth can only be obtained from further detailed exploratory work.

Possible stratigraphic traps associated with the Blue Fiord-Orksut facies transition are regarded as having the greatest potential for hydrocarbon accumulations in the Paleozoic rocks of the report area. As shown in Figures 8 and 9 the facies change is interpreted as occurring in the southern and eastern part of Banks Island. At the Princess Royal Islands the transition is exposed at the surface, but it is present at a depth of 1945 metres (6,380 ft) in the Storkerson Bay well, and 2221 metres (7,285 ft) at the Orksut well. The carbonate sediments of the Blue Fiord Formation are the potential reservoir beds, and the shales of the Orksut Formation the seal. If the facies transition is truncated by the sub-Mesozoic unconformity its potential at that point must be considered to be much reduced, for throughout much of Banks Island the basal Mesozoic unit comprises highly porous, unconsolidated sands of the Isachsen Formation, and in such a case there would be no effective seal. In addition, available evidence suggests that the Devonian rocks reached their present maturity levels prior to the Jurassic. If correct, this would mean that any trap breached by pre-Jurassic erosion would have lost any contained hydrocarbons at that time.

Coal

Rare coal seams are present in the Weatherall Formation. They are slightly more abundant in the Griper Bay Formation. Klovan and Embry (1971, p. 712) record a 1.2-metre (4 ft) thick seam 1030 metres (3,380 ft) above the base of their measured section in northeastern Banks Island. Coal fragments are present in cuttings from all levels in the section through the Melville Island Group at the Uminmak well. However, it is possible that coal recorded as having been derived from the Weatherall Formation in fact was caved from the Griper Bay Formation higher in the well. No analyses of these coals are available at the time of writing.

Mineral Deposits

Traces of pyrite mineralisation are present in the lower, cherty dolomite member of the Glenelg Formation at Cape Lambton, and are also present in the Blue Fiord and older carbonate rocks at the Orksut well. Fluorite is present in fractures in the Blue Fiord limestones at the Storkerson Bay well.

Lead-zinc accumulations are commonly associated with carbonate-shale facies transitions, as in the case of the Pine Point deposit (Callahan, 1964, Macqueen *et al.*, 1975) and the Arvik Mines Ltd. deposit on Little Cornwallis Island (Sangster, 1974; J. Wm. Kerr, pers. com., 1974). The importance of unconformities and paleotopography in the genesis of these ore bodies is commonly stressed; such features are thought to account for the localisation of mineralizing fluids in much the same way that structural culminations provide a trapping mechanism for hydrocarbons (Callahan, 1964). Carbonate-shale transitions generally develop in areas of marked paleotopographic relief, such as at a shelf edge, and this is commonly thought to account for the localisation of mineral deposits, especially where the relief is emphasised by reef development. The shale itself may also be of major importance, however, as a metal source. The ores may be formed by concentration of mineralised fluids which are expelled from the shale during differential compaction (Jackson and Beales, 1967; Macqueen *et al.*, 1975). It has been demonstrated that a carbonate-shale facies change of major stratigraphic importance is present on Banks Island. No geochemical prospecting has been carried out in these rocks, to the author's knowledge, but it is clearly an avenue of research that should be pursued.

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APPENDIX I: Summary of Subsurface Paleozoic Stratigraphy.

Figures are given in metres and, in brackets, feet

Thicknesses	Storkerson Bay A-15	Nanuk D-76	Uminmak H-07	Orksut I-44
Melville Island Group	167+(549+)	-	828+(2715+)	-
Griper Bay Formation	-	-	196+(642+)	-
Hecla Bay Formation	-	-	43 (140)	-
Weatherall Formation	167+(549+)	-	589+(1933+)	-
Nanuk Formation	197 (645)	137+(445+)	-	-
Orksut Formation	15 (50)	115+(378+)	-	392+(1285+)
Blue Fiord Formation	103+(339+)	-	-	692 (2269)
Unnamed dolomite-shale formation	-	-	-	50 (164)
Unnamed dolomite formation	-	-	-	98+(322+)
Log Depths				
Melville Island Group	1566(5136)	-	871(2858)	-
Griper Bay Formation	-	-	871(2858)	-
Hecla Bay Formation	-	-	1067(3500)	-
Weatherall Formation	1566(5136)	-	1109(3640)	-
Nanuk Formation	1733(5685)	1126(3695)	-	-
Orksut Formation	1930(6330)	1262(4140)	-	1829(6000)
Blue Fiord Formation	1945(6380)	-	-	2221(7285)
Unnamed dolomite-shale formation	-	-	-	2913(9554)
Unnamed dolomite formation	-	-	-	2963(9718)
Total Depth	2048(6719)	1377(4518)	1699(5573)	3061(10040)

Subsurface Elevations (relative to sea level)	Storkerson Bay A-15	Nanuk D-76	Uminmak H-07	Orksut I-44
Melville Island Group	-1546(-5072)	-	-759(-2490)	-
Griper Bay Formation	-	-	-759(-2490)	-
Hecla Bay Formation	-	-	-955(-3132)	-
Weatherall Formation	-1546(-5072)	-	-997(-3272)	-
Nanuk Formation	-1714(-5621)	-1027(-3368)	-	-
Orksut Formation	-1910(-6266)	-1162(-3813)	-	-1693(-5552)
Blue Fiord Formation	-1926(-6316)	-	-	-2084(-6837)
Unnamed dolomite-shale formation	-	-	-	-2776(-9106)
Unnamed dolomite formation	-	-	-	-2826(-9270)
Total depth	-2029(-6655)	-1278(-4191)	-1587(-5205)	-2924(-9592)

APPENDIX II: Detailed Lithologic Logs

LOWER GLENELG FORMATION: CAPE LAMBTON SURFACE SECTION

Location: 71°05'N; 123°08'W; photo index (Norris, 1972) A17374-77; X=5.8; Y=3.4
Measured and described by A. D. Miall, June 26, 1974.

Cumulative thickness from base of section	Thickness of unit	Description
metres	metres	
		Section terminates at covered interval below fault(?)
87.0	27.0	Dolomite, fine grained, medium grey, well laminated, with lenses and laminae of chert; stromatolitic lamination, commonly replaced by chert. Poor vuggy porosity in chert.
60.0	7.3	Dolomite, similar to underlying unit, with patches of chertified breccia; fair vuggy porosity in chert.
52.7	2.2	Dolomite, dark grey, laminated, wavy (stromatolitic?) lamination, abundant lenticles dark grey chert.
50.5	2.5	Dolomite, light grey, fine grained, massive.
48.0	3.0	Dolomite, dark grey, laminated, ripple bedded.
45.0	2.0	Dolomite, as in 37.8-39.5 m interval.
43.0	3.5	Dolomite, as in 37.8-39.5 m interval but brecciated, in part, chert replacement lenticular in distribution.
39.5	1.7	Dolomite, medium grey, well laminated, wavy (ripple) bedded; at least 50% chert replacement in discrete laminae; fair vuggy porosity in chert.
37.8	0.6	Dolomite, medium grey, very fine grained, massive, recessive.

Cumulative thickness from base of section	Thickness of unit	Description
37.2	0.2	Conglomerate, flat-pebble, dolomitic.
37.0	23.7	Dolomite, medium grey, fine grained, laminated to thin bedded; brecciated zones filled with pyrite; rare lenticles pyrite replacement up to 30 cm in width, rare chert stringers.
13.3	0.3	Dolomite, medium grey, argillaceous, very thin bedded.
13.0	3.8	Dolomite, fine grained, well laminated.
9.2	0.2	Chert breccia, angular chert fragments up to 20 cm in length, in fine grained dolomite matrix.
9.0	0.5	Chert, well laminated, low amplitude ripple bedding, fair vuggy porosity.
8.5	1.3	Dolomite, medium grey, well laminated, very resistant.
7.2	6.2	Dolomite, fine grained, thin bedded, patches of pyrite mineralization, occasional (?)stromatolitic lamination. Persistent chert lenticle up to 10 cm thick at top of unit.
1.0	0.5	Dolomite and chert interbedded, thinly bedded, low amplitude domal stromatolitic(?) lamination, traces pyrite mineralization.
0.5	0.5	Dolomite, fine grained, very resistant.

Base of section is at sea level.

UPPER GLENELG FORMATION: NELSON HEAD SURFACE SECTION

Location: 71°05'N; 122°53'W; photo index (Norris, 1972) A17374-77; X=5.9; Y=2.9
Measured and described by A. D. Miall, June 25, 1974.

Cumulative thickness from base of section	Thickness of unit	Description
metres	metres	
		Section terminates at covered interval, a few metres below a thick diabase sill which caps the cliffs at this locality.
393	12	Shale, medium greenish grey, with lenses of sandstones, white, fine-grained, quartzose; sandstone lenses vary in lateral persistence from less than 1 m to in excess of 30 m. Shale rests on underlying unit with sharp, flat contact.
381	58	Sandstone, white, quartzose, generally massive but with occasional planar cross-stratification (some contorted) and parting lineation, yellowish weathering. Two units of grey shale 2 m in thickness in top 20 m of unit.
323	47	Sandstone, as in 14.0-73.5 m interval, mainly slabby weathering, abundant parting lineation, rare dark red silt-stone laminae becoming more abundant near top of unit.
276	32	Silty sandstone, dark red-brown, with abundant kappa cross-stratigication (Allen, 1963); lenses up to 20 cm thick of sandstone, fine grained, quartzose, becoming thicker and more abundant near top. Unit has gradational contact with overlying beds.

Cumulative thickness from base of section	Thickness of unit	Description
244	89	Sandstone, as in 14.0-73.5 m interval, grain size rarely coarse sand grade, laminated, blocky weathering, rare silt-flake conglomerates, abundant alpha cross-stratification (Allen, 1963) and parting lineation.
155	1	Silty sandstone, dark red-brown, with ripple cross-stratification. Unit rests on underlying beds with erosional relief of up to 7 cm.
154	46	Sandstone, as in 14.0-73.5 m interval, occasional ripple cross-stratification; abundant alpha cross-stratification (Allen, 1963) some contorted; occasional thin-bedded intervals with parting lineation; occasional thinly laminated intervals with heavy mineral concentrations in discrete laminae.
108	5	Sandstone, dark red-brown, silty, micaceous, very fine grained, with abundant kappa cross-stratification (ripple amplitude less than 1 cm).
103	10	Sandstone, medium red-brown, fine grained, very finely laminated abundant parting lineation; gradational contact with overlying unit.
93	6.5	Interbedded sandstone, siltstone and mudstone; sandstone is pink, fine grained, quartzose, in lenticular bodies less than 10 cm in thickness and showing megaripple structure, wavelength approximately 1 m; siltstone and mudstone are dark red, micaceous, with abundant ripples of many types: straight, sinuous, bifurcating: wavelength varies from 1 to 12 cm.

Cumulative thickness from base of section	Thickness of unit	Description
86.5	1.5	Sandstone, as in 14-73.5 m interval, interbedded with siltstone, dark red, sandy, alpha cross-stratification (Allen, 1963), gradational upper and lower contacts.
85	4.5	Sandstone, as in 14-73.5 m interval, mainly planar laminated with abundant parting lineation.
75.5	2.0	Siltstone, dark red-brown, micaceous, well laminated, with interbeds of fine sand in thin laminae, load casts, symmetrical and interfering ripples, desiccation cracks.
73.5	59.5	Sandstone, pink to medium red-brown, fine to medium grained, quartzose, well cemented, well laminated to thin bedded, abundant alpha cross-stratification (Allen, 1963), commonly contorted; fairly abundant parting lineation.
14	14	Sandstone, mainly covered by talus but probably similar to that in 14-73.5 m interval.

Base of section is at sea level.

PALEOZOIC SECTION: DEMINEX CGDC FOC AMOCO ORKSUT I-44

Location: Lat. 72°23'44.66"N; Long. 122°42'08.81"W.
Elevation: 447.7 feet (136.4 m) KB
Total depth: 10,040 feet (3060 m)
Completed (rig release): 28 March, 1973
Status: Dry and abandoned

Log by A. D. Miall from samples and cores stored at Geological Survey of Canada, Calgary, Alberta, 9 November, 1973 - 15 March, 1974.

Depths, elevations and thicknesses are given in feet and, in brackets, metres.

Depth from KB	Elevation subsea	Thickness	Description
			Paleozoic strata are overlain by sandstones and shales of Early to Middle Jurassic age (Wilkie Point Formation)
			<u>Orksut Formation: 6000 feet (1828.7 m)</u>
6000.0 (1828.7)	-5552.0 (-1692.1)	5.0 (1.5)	Core #4 Shale, silty, dark grey, slightly micaceous, non-calcareous, finely laminated.
6005.0 (1830.2)	-5557.0 (-1693.7)	12.0 (3.7)	Shale, dark grey, fissile, non-calcareous, slightly micaceous, streak of coal at 6011 ft. *Styliolina* at 6013 ft, 2 mm diam. orthocone nautiloids at 6015 ft.
6017.0 (1833.9)	-5569.0 (-1697.3)	3.0 (0.9)	Shale, dark grey, fissile, calcareous, grading to very argillaceous limestone, dark grey, compact. Abundant *Styliolina*, rare *Tentaculites*. Beds finely laminated and streaked with carbonaceous debris. End of core #4.

Depth from KB	Elevation subsea	Thickness	Description
6020 (1835)	-5572 (-1698)	60 (18)	Shale, dark grey, fissile, variably calcareous, micaceous, with minor interbeds of dark grey, argillaceous limestone.
6080 (1853)	-5632 (-1717)	810 (247)	Shale, medium to dark greenish grey, slightly calcareous, slightly micaceous, slightly silty, trace of fracture filling calcite, trace of pyrite, minor argillaceous siltstone. Dark grey shale as in 6020-6080 ft interval is common in samples above 6250 ft, may be cavings. Recycled or caved pelecypod fragments and foraminifera also common, small brachiopod at 6380 ft, pyritized *Tentaculites* and *Styliolina* at 6050-6150 ft.
6890 (2100)	-6442 (-1963)	60 (18)	Shale, dark grey, carbonaceous, non-calcareous, finer grained, less micaceous, less silty than succeeding unit, finely laminated, crinoid ossicles at 6930 ft.
6950 (2118)	-6502 (-1982)	310 (94)	As in 6890-6950 ft interval, plus minor siltstone interbeds. Siltstone is pale grey, quartzose, with specks of ?carbonaceous material. Calcite vein material, minor pyrite as small nodules and disseminated grains. Thin interbeds of medium brownish grey, fine grained, argillaceous limestone at 7090, 7170 and 7200 feet, containing calcispheres 0.1-0.2 mm diameter.

Depth from KB	Elevation subsea	Thickness	Description
7260 (2213)	-6812 (-2076)	25 (8)	Shale, very dark grey, slightly calcareous, slightly micaceous, interbedded with dark brown-grey, microcrystalline limestone. Vein calcite common.
			Blue Fiord Formation: 7285 feet (2220 m)
7285 (2220)	-6837 (-2084)	80 (24)	Limestone, medium brownish grey, microcrystalline, with shell (?brachiopod) and *Tentaculites* fragments, rare brachiopod spines. *Tentaculites* increases in abundance towards base of unit. Gradation into next lower unit.
7365 (2245)	-6917 (-2108)	15 (5)	Limestone, very dark grey, argillaceous, very fine grained, grading into next lower unit.
7380 (2249)	-6932 (-2113)	16 (5)	Shale, black, calcareous.
7396 (2254)	-6948 (-2117)	184 (56)	Limestone, pale to medium brownish grey, microcrystalline, trace of ?brachiopod shell fragments, *Styliolina* and *Tentaculites*, rare pyrite, occasional thin interbeds of shale, black, bituminous, slightly calcareous, white calcite spar common.
7580 (2310)	-7132 (-2174)	30 (9)	Limestone, white, microcrystalline.
7610 (2319)	-7162 (-2183)	10 (3)	Limestone, as in 7396-7580 ft interval, no fossils noted. Rare, scattered, silt sized dolomite rhombs.

Depth from KB	Elevation subsea	Thickness	Description
7620 (2322)	-7172 (-2186)	10 (3)	Limestone, as in 7396-7580 ft interval with occasional small dolomitized patches and scattered dolomite rhombs.
7630 (2325)	-7182 (-2189)	30 (9)	Limestone, pale to medium brownish grey, occasionally dark grey and argillaceous, partially dolomitized; locally up to 60% dolomite, but averaging 10%, dolomite occurs as rhombs averaging 0.04 mm diameter, trace of pyrite.
7660 (2335)	-7212 (-2198)	40 (12)	Limestone, pale to medium brownish grey, approximately 50% dolomitized, white, undolomitized calcite spar common, microscopic veinlets of calcite also common.
7700 (2347)	-7252 (-2210)	100 (30)	Dolomite, pale to medium brownish grey, approximately 10 to 60% calcite in a matrix of silt-sized dolomite rhombs; undolomitized or slightly dolomitized calcite spar, fairly common, probably fairly tight, occasional shale interbeds.
7800 (2377)	-7352 (-2241)	280 (85)	Dolomite, pale to medium brownish grey, less than 10% calcite, commonly less than 5% calcite as residual grains in a dolomite rhomb matrix. Less than 5% calcite spar, occasional shale interbeds, containing trace of pyrite, *Tentaculites* at 7880 ft. Darker coloured grains slightly coarser in grain size (0.02 mm) than pale grains (0.01 mm).

Depth from KB	Elevation subsea	Thickness	Description
8080 (2467)	-7632 (-2326)	220 (67)	Dolomite, white, microcrystalline, mean grain size approx. 0.04 mm, 1-5% calcite, occasional thin shale interbeds, trace disseminated pyrite grains, low pinpoint and intercrystalline porosity. Gradation into next lower unit.
8300 (2530)	-7852 (-2393)	520 (158)	As in 8080-8300 foot interval but including finer grained material with mean grain size approx. 0.02 mm, trace sparry calcite, less than 1% calcite grains in dolomite matrix, trace gypsum, trace pyrite, virtually no visible porosity.
8820 (2688)	-8372 (-2552)	68 (21)	No samples. Lost circulation 8817-8888 ft. Interpreted as dolomite with vuggy porosity.
8888 (2710)	-8440 (-2572)	112 (34)	No samples. Log character indicates lithology similar to that in 8300-8820 ft interval.
9000 (2743)	-8552 (-2606)	250 (76)	Dolomite pale to medium grey and grey-brown, mean grain size ranges from 0.02 to 0.08 mm, virtually no visible porosity.
9250 (2819)	-8802 (-2683)	304 (93)	Dolomite, pale to medium grey, mean grain size 0.03 mm, trace sparry calcite, trace pyrite, occasional grains show pelletal and coated grain texture, plus scattered mud intraclasts up to 0.8 mm, trace pinpoint porosity.

Depth from KB	Elevation subsea	Thickness	Description
			<u>Unnamed dolomite-shale formation: 9554 ft (2912 m)</u>
9554 (2912)	-9106 (-2775)	71 (22)	Dolomite, medium brown-grey, very fine grained, with occasional rhombs up to 0.3 mm, trace bitumen, trace pyrite, poor to fair pinpoint porosity, occasional argillaceous and shaly beds.
9625 (2934)	-9177 (-2797)	93 (28)	Dolomite, medium grey, occasionally dark grey, very fine grained, argillaceous, poor pinpoint porosity, interbedded with shale. Virtually no shale in samples but its presence is indicated by mechanical logs.
			<u>Unnamed dolomite formation: 9718 ft (2962 m)</u>
9718 (2962)	-9270 (-2825)	322 (98)	Dolomite, medium to dark brownish grey, very fine grained, argillaceous, trace of rhombic dolomite, sparry calcite and pyrite as cavity infilling, no visible porosity.
10040 (3060)	-9592 (-2923)		Total depth.

Drill Stem Tests

No tests were run on the Paleozoic section

PALEOZOIC SECTION: ELF *et al.* STORKERSON BAY A-15

Location: Lat. 72°54'00"N; Long. 124°33'29"W.
Elevation: 64 feet (19.5 m) KB
Total depth: 6719 feet (2048 m)
Completed: December 10, 1971
Status: Dry and abandoned

Log by A. D. Miall from samples and cores stored at Geological Survey of Canada, Calgary, Alberta, 22 January, 1973 - 30 May, 1973.

Depths, elevations and thicknesses are given in feet and, in brackets, metres.

Depth from KB	Elevation subsea	Thickness	Description
			Paleozoic strata are overlain by argillaceous siltstone and minor sandstone interbeds of Albian age (Christopher Formation)
			Weatherall Formation: 5136 feet (1565 m)
5136 (1565)	-5072 (-1546)	29 (9)	Sandstone, white to pale grey, mainly very fine grained with occasional fine grained or silty streaks, quartzose, quartz cement, indurated, very low porosity. Samples contain up to 50% siltstone cavings (plus rare Cretaceous forams).
5165 (1574)	-5101 (-1555)	69 (21)	Sandstone, similar to 5136-5165 foot interval but medium to dark grey in colour. Rare micaceous, fissile silty shale streaks, minor pyrite at 5210.
5234 (1595)	-5170 (-1576)	16 (5)	Carbonaceous shale, dark grey, with silty and sandy streaks.
5250 (1600)	-5186 (-1581)	23 (7)	Sandstone as in 5165-5234 foot interval, minor pyrite as small nodules and disseminated grains.

Depth from KB	Elevation subsea	Thickness	Description
5273 (1607)	-5209 (-1588)	22 (7)	Shale, carbonaceous, dark grey, laminated, fissile.
5295 (1614)	-5231 (-1594)	129 (39)	Sandstone as in 5165-5234 foot interval with silty and shaly streaks, minor pyrite.
5424 (1653)	-5360 (-1634)	26 (8)	Shale, dark grey, silty, carbonaceous, slightly micaceous, laminated, fissile.
5450 (1661)	-5386 (-1642)	70 (21)	Sandstone with minor shale and siltstone as in 5165-5234 foot interval.
5520 (1682)	-5456 (-1662)	165 (50)	Sandstone and shale interbedded. Lithologies as in preceding two intervals, minor calcareous matrix in sandstone.
			Nanuk Formation: 5685 feet (1733 m)
5685 (1733)	-5621 (-1713)	126 (38)	Shale, black, micaceous, slightly siliceous, laminated, fissile, noncalcareous, minor disseminated pyrite grains. Thin beds of very fine grained sand in upper portion of unit. Occasional thin calcite-filled fractures.
5811 (1771)	-5747 (-1752)	24 (7)	Sandstone, very fine grained, quartzose, light grey.
5835 (1778)	-5771 (-1759)	25 (8)	Shale, as in 5685-5811 foot interval.
5860 (1786)	-5796 (-1767)	80 (24)	Interbedded sandstone and shale. Sandstone is very fine grained, quartzose, pale grey, occasionally silty, laminated. Shale is black, slightly micaceous, laminated, slightly siliceous, occasionally silty. Minor disseminated pyrite grains present in shale. Sandstone decreases in abundance in lower part of interval.

Depth from KB	Elevation subsea	Thickness	Description
			Note: Mechanical logs not available for depth correction and lithology separation below 5910 foot level.
5940 (1810)	-5876 (-1791)	50 (15)	Shale, black, well indurated, slightly siliceous, and minor silty shale, medium to dark grey, slightly micaceous, fissile; minor pyrite disseminated throughout, commonly as small euhedral cubic crystals, plus occasional small calcite-filled fractures.
5990 (1826)	-5926 (-1806)	80 (24)	Silty shale, medium to dark grey, micaceous, slightly siliceous, fissile, plus minor very fine grained, silty, noncalcareous, nonporous, quartzose sandstone; occasional small, calcite-filled veins, minor disseminated pyrite.
6070 (1850)	-6006 (-1831)	15 (5)	Shale, dark grey to black, well indurated, micaceous, slightly silty, slightly siliceous, minor pyrite.
6085 (1855)	-6021 (-1835)	40 (12)	Dolomitic siltstone, light to medium grey, quartzose, micaceous, fissile, minor very fine sand.
6125 (1867)	-6061 (-1847)	205 (62)	Shale, as in 6070-6025 foot interval, occasional very fine quartzose, sandy streaks, showing very fine, even lamination; shale occasionally dolomitic and containing minute dolomite veinlets. Occasional fragments of siliceous shale present containing minute ?siliceous spherical structures, average 0.12 mm in diam. Shale becomes more siliceous and less micaceous near base of interval.

Depth from KB	Elevation subsea	Thickness	Description
			Orksut Formation: 6330 feet (1929 m)
6330 (1929)	-6266 (-1910)	50 (15)	Shale, dark grey to black, dolomitic and calcareous, siliceous, micaceous with comminuted fossil debris, probably crinoids and ostracodes. Occasional minute veins of calcite and dolomite. Staining with alizarin red-S suggests finer grained shell and vein material is calcite, and that it is partially recrystallized and altered to coarser grained dolomite.
			Blue Fiord Formation: 6380 feet (1945 m)
6380 (1945)	-6316 (-1925)	10 (3)	Argillaceous limestone, medium grained, fossiliferous, pale grey.
6390 (1948)	-6326 (-1928)	20 (6)	Limestone (lime mudstone), pale grey, variable minor amounts of argillaceous impurities but generally pure, chalky texture with occasional crystals up to 0.6 mm, occasionally bioclastic, nonporous.
6410 (1954)	-6346 (-1934)	36 (11)	Limestone (lime mudstone), cryptocrystalline, medium buff-grey, very dense, nonporous, very low argillaceous content, occasional pelletal texture, occasional calcite-filled fractures, no fossils noted.
6446.0 (1964.6)	-6382.0 (-1945.1)	1.25 (0.4)	Core #2 Limestone (lime mudstone), medium and dark grey, cryptocrystalline, strong mottled texture. Pale-coloured patches have rod-shaped outline, oriented perpendicular to stylolitic surfaces and at angle of approximately 10° to vertical core axis. (perpendicular to bedding?) Dark coloured patches probably argillaceous. This lithology interpreted as recrystallized algal or colonial coral structure. Minor fractures common.

Depth from KB	Elevation subsea	Thickness	Description
6447.25 (1965.0)	-6383.25 (-1945.5)	0.5 (0.2)	Limestone (lime mudstone), medium buff-grey, cryptocrystalline, dense, faint mottled texture, numerous minor fractures and stylolites. Fractures occasionally filled with sparry calcite.
6447.75 (1965.2)	-6383.75 (-1945.7)	4.75 (1.4)	Limestone (lime mudstone) medium buff-grey, cryptocrystalline to lithographic, dense, faint mottled texture, numerous minor fractures and stylolitic surfaces plus several larger fractures up to 0.5 ins in width, filled with bitumen? and with sparry calcite. Bedding faint to absent. *Syringopora, ?Amphipora* and a tabulate coral present at 6452.5 foot level.
6452.5 (1966.6)	-6388.50 (-1947.1)	0.5 (0.2)	Limestone (lime wackestone), dark grey, argillaceous, bioclastic, containing small corals plus gastropod and ?brachiopod shell fragments, fairly abundant pellets, frequent lenses rich in argillaceous material. Stylolitic surfaces and sparry calcite-filled fractures common. Matrix is lime mud, porosity low to zero.
6453.0 (1966.8)	-6389.0 (-1947.3)	5.0 (1.5)	Limestone (lime mudstone) similar to 6447.75-6452.5 foot interval. Includes calcite- and fluorite-filled fractures up to 0.25 ins wide at 6455.0-6456.0 foot level, ?favositid coral, ?brachiopod and stromatoporoid fragments, several stylolitic surfaces. Fenestrate texture near base of unit.
6458.0 (1968.3)	-6394.0 (-1948.8)	1.0 (0.3)	Limestone (lime wackestone to lime packstone) abundant. *Stachyodes*-type stromatoporoid remains plus large (up to one inch) domal shaped

Depth from KB	Elevation subsea	Thickness	Description
			stromatoporoid fragments showing concentric structure (?*Atelodictyon* sp.) occasional crinoid ossicles. Matrix of lime mudstone, containing variable argillaceous content. Occasional stylolites and minor fractures. Occasional vertical stylolites intersecting or stopping at the horizontal stylolites.
6459.0 (1968.6)	-6395.0 (-1949.1)	0.25 (0.1)	Limestone (lime mudstone) very faint mottling texture, occasional ?crinoid ossicles, numerous minor fractures.
6459.25 (1968.7)	-6395.25 (-1949.2)	0.75 (0.2)	Limestone (lime mudstone) similar to 6462.25-6463.0 foot interval but mottling fainter, fenestral texture.
6460.0 (1968.9)	-6396.0 (-1949.4)	0.75 (0.2)	Limestone (lime mudstone), light and dark grey, strongly mottled, cryptocrystalline, containing stromatoporoid fragments. Textures on etched slab suggest mottling due to partial recrystallization, resulting in pure microcrystalline calcite and argillaceous content concentrated in dark patches. Numerous stylolites. Grades down into next lower unit.
6460.75 (1969.1)	-6396.75 (-1949.6)	3.0 (0.9)	Limestone (lime mudstone), very similar to 6458.0-6459.0 foot interval, and containing several lenses up to 2 inches thick of stromatoporoid-rich bioclastic lime wackestone and packstone. Dip of beds varies from near horizontal to approx. 10°.
6463.75 (1970.0)	-6399.75 (-1950.5)	0.5 (0.2)	Limestone (lime mudstone), very similar to unit above but stromatoporoid remains scarce. Strong lamination present.

Depth from KB	Elevation subsea	Thickness	Description
6464.25 (1970.2)	-6400.25 (-1950.8)	1.5 (0.5)	Limestone (lime packstone) similar to 6463.0-6467.0 foot interval. Numerous large stromatoporoid fragments present, including domal forms up to 1.5 inches in diameter.
6465.75 (1970.7)	-6401.75 (-1951.2)	6.0 (2.0)	Limestone (lime mudstone) similar to 6447.75-6452.5 foot interval, fenestrate texture, numerous minor fractures.
6471.75 (1972.5)	-6407.75 (-1953.0)	1.75 (0.5)	Lime mudstone, mottled near top of unit with argillaceous and non-argillaceous streaks imparting light and dark grey coloration, most of unit dark grey, argillaceous, fenestrate texture, numerous small stromatoporoid and algal fragments. Sharp, wavy, ?stylolitic contact with next lowest unit.
6473.50 (1973.0)	-6409.5 (-1953.5)	0.5 (0.2)	Lime mudstone, well laminated, fenestral texture (6474.0 feet is end of core #2).
6474 (1973)	-6410 (-1954)	56 (17)	Limestone (lime mudstone), pale to medium grey, cryptocrystalline, occasional fragments of dark grey, argillaceous, cryptocrystalline limestone, plus abundant fragments of dark grey to black, micaceous, non-calcareous, fissile shale. Shale probably cavings. Some suggestion of fenestrate texture present, fossils not observed. Minor greenish grey, silty, slightly calcareous shale in 6490-6500 foot interval, ?ostracodes at 6500-6510 foot interval. Samples grade imperceptibly into next lowest unit.

Depth from KB	Elevation subsea	Thickness	Description
6530 (1990)	-6466 (-1971)	150 (46)	Limestone (lime mudstone), pale grey to white, cryptocrystalline to very fine grained, very pure micrite. Favositid coral fragments noted at 6580, 6620, pelecypod fragment at 6540, stylolites common, brachiopod fragment at 6570, 6670. Occasional minute euhedral quartz crystals up to 0.5 mm in length, below 6630. Occasional pelletal texture. Very low to zero intergranular porosity.
6680 (2036)	-6616 (-2016)	39 (12)	Limestone, similar to 6530-6680 foot interval but containing coarse-grained sparry vein calcite (rhombic habit). Floating quartz crystals fairly common.
6719 (2048)	-6655 (-2028)		Total depth.

Drill Stem Tests

No tests were run.

PALEOZOIC SECTION: ELF NANUK D-76

Location: Lat. 73°05'13"N; Long. 123°23'45"W.
Elevation: 327 feet (99.7 m) KB
Total depth: 4518 feet (1377 m)
Completed: March 4, 1972
Status: Dry and abandoned

Log by A. D. Miall from samples and cores stored at Geological Survey of Canada, Calgary, Alberta, 20 November 1972 - 12 January 1973.

Depths, elevations and thicknesses are given in feet and, in brackets, metres.

Depth from KB	Elevation subsea	Thickness	Description
			Paleozoic strata are overlain by shale with minor siltstone interbeds of Aptian to Albian age (Christopher Formation)
			Nanuk Formation: 3695 feet (1126 m)
3695 (1126)	-3368 (-1027)	199 (61)	Shale, very dark grey, siliceous, non-calcareous, well indurated, occasional fractures lined with microcrystalline white quartz. Core No. 1, 3738-3752 feet. Recovered 10 feet. Faint, very fine lamination visible, occasional stylolitic surfaces, pyrite crystals along minor fracture planes.
3894 (1187)	-3567 (-1087)	96 (29)	Interbedded shale, dark grey, siliceous, and siltstone, medium grey, slightly micaceous.
3990 (1216)	-3663 (-1116)	86 (26)	Chert, light grey, with black streaks; especially near the base of the unit, generally massive but with occasional traces of bedding, occasional pinpoint vugs. Black chert has sub-conchoidal fracture, 4065 feet to TD open fractures caused loss of drilling mud.

Depth from KB	Elevation subsea	Thickness	Description
4076 (1242)	-3749 (-1143)	4 (1)	Shale, dark grey, siliceous.
4080 (1243)	-3753 (-1144)	30 (9)	Siltstone, medium grey, friable, grading down into next lower unit.
4110 (1252)	-3783 (-1153)	30 (9)	Shale, dark grey to black, very siliceous, well indurated.
			Orksut Formation: 4140 feet (1262 m)
4140 (1262)	-3813 (-1162)	100 (30)	Shale, dark grey, earthy texture, variably calcareous, bituminous, occasional fractures lined with sparry calcite. Rare *Tentaculites* at 4160 feet, becoming fairly common at 4230 feet. *Styliolina* also present at 4230 foot level.
4240 (1292)	-3913 (-1193)	181 (55)	Shale, dark grey, earthy texture, calcareous, virtually unfossiliferous, occasional disseminated grains of pyrite, slightly micaceous.
4241 (1347)	-4094 (-1248)	21 (6)	Dolomite, very argillaceous, dark grey, microcrystalline to fine grained, with abundant veins lined with coarse white dolomite crystals, rare pyrite.
4442 (1354)	-4115 (-1254)	76 (23)	Shale, as in 4240-4421 foot interval, pyrite in nodules and disseminated veins fairly common.
			Core No. 2, 4445-4463 feet. Recovered 18 feet. Pyrite in blebs and lenticles along ?bedding, showing displacement along minor fracture planes. Several major fracture zones, showing infill of crush breccia and sparry dolomite.
4518 (1377)	-4191 (-1277)		Total depth.

Drill Stem Tests

Interval	Recovery
3660-3738 (1116-1139) Nanuk Fm.	580 feet watery gas cut mud, 2740 feet gas cut water (slightly sulphurous), no gas to surface

PALEOZOIC SECTION: ELF UMINMAK H-07

Location: Lat. 72°36'29"N; Long. 123°00'30"W.
Elevation: 368 feet (112 m) KB
Total depth: 5573 feet (1699 m)
Completed: May 7, 1972
Status: Dry and abandoned

Log by A. D. Miall from samples and cores stored at Geological Survey of Canada, Calgary, Alberta, 19 February 1973 - 26 July 1973.

Depths, elevations and thicknesses are given in feet and, in brackets, metres.

Depth from KB	Elevation subsea	Thickness	Description
			Paleozoic strata are overlain by silty shale of Albian age (Christopher Formation)
			Griper Bay Formation: 2858 feet (871 m)
2858 (871)	-2490 (-759)	23 (7)	Sandstone, pale grey, very fine grained, quartzose, calcareous, much carbonaceous material as disseminated grains and thin streaks, low intergranular porosity. Occasional shale laminae.
2881 (878)	-2513 (-766)	6 (2)	Core #1 Sandstone, fine and very fine grained, silty, interbedded with siltstone and shale. Interbedding on mm to cm scale, giving rise to very fine laminations. Sandstone and siltstone medium grey, containing abundant disseminated grains of carbonaceous material. Siltstone and shale contain abundant large plant fragments. Shale commonly very carbonaceous and black in colour. Sedimentary structures include wavy and lenticular bedding (in the sense of Reineck and Wünderlich,

Depth from KB	Elevation subsea	Thickness	Description
			1968), occasional bioturbation, soft-sediment slumping and occasional rolled-up sandstone intraclasts. Graded bedding occasionally present. Minor fractures at 2883 ft level.
2887. 0 (879. 9)	-2519. 0 (-767. 8)	1 (0. 3)	Shale, black, carbonaceous, finely laminated, interlaminated with thin silty streaks showing abundant small bioturbation structures.
2888. 0 (880. 2)	-2520. 0 (-768. 1)	1 (0. 3)	Silty shale, medium grey, fine sandy laminae and minute carbonaceous streaks common.
2889. 0 (880. 5)	-2521. 0 (-768. 4)	0. 8 (0. 2)	Silty shale, medium grey, massive with faint lamination, slightly micaceous, contains scattered silty-sized carbonaceous grains. Brownish-coloured lens 1 inch thick near base of interval (clay ironstone).
2889. 8 (880. 7)	-2521. 8 (-768. 6)	1. 2 (0. 4)	Laminated sandstone-siltstone-shale, as in 2881-2887 ft interval.
2891. 0 (881. 1)	-2523. 0 (-769. 0)	6. 0 (1. 8)	Silty shale, medium grey, laminated, occasional sandy streaks present showing wavy and lenticular bedding, numerous small bioturbation structures. Several clay-ironstone concretion lenses present.
2897. 0 (883. 0)	-2529. 0 (-770. 8)	0. 2 (0. 1)	Silty shale as in 2891-2897 ft interval.
2897. 8 (883. 2)	-2529. 2 (-770. 9)	0. 8 (0. 2)	Sandstone, medium grey, laminated, fine and very fine grained, with darker silty streaks, showing major slump structures and rolled-up sand intraclasts.

Depth from KB	Elevation subsea	Thickness	Description
2898.0 (883.3)	-2530.0 (-771.1)	2 (0.6)	Section missing; end of core #1 at 2900 ft.
2900 (884)	-2532 (-772)	160 (49)	Interbedded sandstone, siltstone and shale with minor streaks of bituminous coal. Sandstone is pale grey, fine to very fine grained, quartzose, minor disseminated carbonaceous grains, well cemented, with low intergranular porosity. Siltstone similar in character. Shale is medium grey, slightly silty and micaceous, or dark grey and carbonaceous, or rarely reddish brown. Interrelationships of these lithologies not clear from samples, probably similar to that seen in core, immediately above. Much coal in samples at 2990 ft level.
3060 (933)	-2692 (-820)	26 (8)	Shale, dark to medium grey, micaceous, carbonaceous, occasionally silty.
3086 (941)	-2718 (-828)	414 (126)	Interbedded sandstone, siltstone and shale as in 2900-3060 ft interval. Thin coal seam at 3095 ft level. Much coal in samples at 3080, 3160-3180 ft; sandstone is calcareous and occasionally ferruginous, contains rare pyrite. Occasional calcite veins present. Vertical distribution of lithologies may be interpreted from mechanical logs and is shown on graphic strip log.
			<u>Hecla Bay Formation: 3500 feet (1067 m)</u>
3500 (1067)	-3132 (-955)	140 (43)	Samples as in 3086-3500 foot interval. Mechanical logs indicate porous sandstone units at 3500-3515 and 3603-3640 foot intervals.

Depth from KB	Elevation subsea	Thickness	Description
			<u>Weatherall Formation: 3640 feet (1109 m)</u>
3640 (1109)	-3272 (-997)	575 (175)	Samples as in 3086-3500 foot interval.
4215 (1285)	-3847 (-1173)	5 (2)	Dolomite, pale grey, fine grained.
4220 (1286)	-3852 (-1174)	190 (58)	Interbedded sandstone, siltstone and shale with minor coal as in 3086-4215 ft interval. Porous sand unit at 4360-4373 ft interval.
4410 (1344)	-4042 (-1232)	10 (3)	Dolomite, red-brown, fine grained.
4420 (1347)	-4052 (-1235)	1153 (351)	Interbedded sandstone, siltstone and shale with minor coal as in 3086-4215 ft interval. Much coal in samples at 5300, 5340, 5560 foot levels.
5573 (1699)	-5205 (-1586)		Total depth.

Drill Stem Tests

No tests were run on the Paleozoic section.

MELVILLE ISLAND GROUP: CAPE CROZIER SURFACE SECTION

Location: 74°30'N; 121°04'W; photo index (Norris, 1972) A-17130-36; X=2.6; Y=7.3.
Measured and described by A. D. Miall, June 30, and July 14, 1973.

Cumulative thickness from base of section	Thickness of unit	Description
metres	metres	
		Section terminates at covered interval 15 m below top of cliff. General notes: none of the rocks studied in this section were calcareous (as indicated by acid test); no sedimentary structures of medium or large scale were observed; all units appear to be very laterally persistent, in the order of at least hundreds of metres.
363.0	14.5	Shale, dark grey, micaceous, well laminated, recessive, with rare, impersistent lenticles of fine sandstone; ironstone nodules.
348.5	0.5	Sandstone, very fine grained, quartzose, well laminated, with small-scale ripples, resistant.
348.0	2.0	Shale, dark grey, micaceous, with sandy siltstone interbeds; moderately resistant.
346.0	11.0	Shale, dark grey, micaceous well laminated, very recessive.
335.0	3.0	Sandstone, white, quartzose, very fine grained, abundant small scale ripples and parting lineation, rare rain prints, very resistant.
332.0	2.0	Shale, dark grey, recessive.

Cumulative thickness from base of section	Thickness of unit	Description
330.0	2.0	Sandstone, white, fine grained, quartzose, with abundant small scale ripples, abundant fossil moulds.
328.0	11.5	Shale, dark grey, with rare sandstone interbeds up to 10 cm in thickness, very recessive.
316.5	2.5	Siltstone, with argillaceous interbeds, thinly bedded, abundant sole structures, most of which are feeding trails.
314.0	2.5	Sandstone, medium grey, fine grained, resistant with interbeds of shale, silty, dark grey; feeding trails.
311.5	5.5	Shale, dark grey, recessive.
306.0	2.5	Sandstone, pale cream in colour, fine grained, thin bedded, with abundant very thin argillaceous lenticles, abundant carbonized wood fragments, abundant feeding trails and vertical trace fossils.
303.5	4.0	Shale, dark grey, micaceous, laminated, recessive, with rare thin interbeds of siltstone.
299.5	0.5	Sandstone, quartzose, very fine grained, finely laminated.
299.0	2.5	Shale, dark grey, micaceous, recessive.

Cumulative thickness from base of section	Thickness of unit	Description
296.5	4.0	Sandstone, white, fine grained, quartzose, abundant small scale (less than 1 cm in height) overlapping and interfering symmetrical ripples; massive weathering.
292.5	8.0	Shale, dark grey, micaceous, finely laminated, recessive, with rare thin interbeds of siltstone.
284.5	2.5	Shale, dark grey, recessive.
282.0	3.5	Sandstone, cream in colour, fine grained, numerous fossil moulds, possibly of plant material, symmetrical ripples.
278.5	7.5	Shale, dark grey, micaceous, thinly laminated, recessive, with rare thin interbeds of siltstone; several beds show symmetrical ripples; rare feeding trails. Gradational contact with overlying unit.
271.0	3.0	Sandstone, medium grey, fine grained, resistant, with occasional silty and argillaceous interbeds, ripple lamination, rare brachiopod(?) impressions, wood fragments up to 20 cm in length.
268.0	3.0	Sandstone, pale grey, weathering orange-brown, fine to medium grained, quartzose, blocky weathering, slight intergranular porosity.
265.0	5.0	Sandstone, fine to medium grained, quartzose, with argillaceous partings, ripples.

Cumulative thickness from base of section	Thickness of unit	Description
260.0	4.0	Sandstone, pale grey, fine to medium grained, quartzose, blocky weathering, slight intergranular porosity.
256.0	8.0	Sandstone, fine to medium grained, quartzose, argillaceous partings, ripples; gradational contact with overlying unit.
248.0	29.0	Shale, silty, with rare impersistent interbeds of fine sandstone which contain abundant ripple laminations, rare ironstone nodules, as in 169-195 m interval.
219.0	2.0	Sandstone, fine to medium grained, with argillaceous partings, ripples, as in 200-201.5 m interval.
217.0	10.5	Shale, as in 169-195 m interval.
206.5	0.5	Sandstone, as in 200-201.5 m interval.
206.0	4.5	Shale, as in 169-195 m interval.
201.5	1.5	Sandstone, fine to medium grained, with argillaceous partings, ripples.
200.0	3.0	Shale, as in 169-195 m interval; gradational contact with overlying unit.
197.0	2.0	Sandstone, fine to medium grained, argillaceous partings, abundant ripples, mud clasts, feeding trails.

Cumulative thickness from base of section	Thickness of unit	Description
195.0	26.0	Shale, silty, rare impersistent interbeds of fine grained sandstone with abundant ripples, occasional ironstone nodules; gradational contact with overlying unit.
169.0	1.0	Sandstone, medium grey, silty, very fine grained, finely laminated.
168.0	11.6	Shale, silty, laminated.
156.4	0.4	Sandstone, fine grained, slightly argillaceous.
156.0	4.0	Shale, dark grey, slightly micaceous.
152.0	8.0	Sandstone, pale grey, fine to medium grained, quartzose, blocky weathering, orange-brown weathering, slight intergranular porosity. Sharp contact with overlying unit.
144.0	6.0	Sandstone, fine grained, silty, thin argillaceous partings, abundant ripple lamination, rare parting lineation, bioturbation.
138.0	7.8	Shale, dark grey, micaceous, silty, very finely laminated, with symmetrical ripples, feeding trails.
130.2	0.2	Sandstone, pale grey, fine grained, quartzose, siltflake intraformational conglomerate, symmetrical ripples, feeding trails, rare brachiopods.
130.0	24.0	Shale, dark grey, micaceous, silty, very finely laminated, rare siltstone interbeds, rare symmetrical ripples in the siltstones, feeding trails.

Cumulative thickness from base of section	Thickness of unit	Description
106.0	8.0	Siltstone, sandy, argillaceous and with shale interbeds, micaceous, platy weathering.
98.0	2.0	Sandstone, very fine grained, quartzose, slightly argillaceous.
96.0	7.0	Shale, dark grey, micaceous, silty, very finely laminated.
89.0	1.0	Siltstone, dark grey, argillaceous, micaceous.
88.0	3.0	Shale, dark grey, micaceous, silty, very finely laminated.
85.0	3.0	Sandstone, medium grey, fine grained, quartzose, argillaceous, small intra-formational shale pebbles, symmetrical ripples, slabby to blocky weathering.
82.0	6.0	Shale, dark grey, slightly silty.
76.0	21.0	Sandstone, medium grey, variably silty, fine to very fine grained, quartzose, asymmetrical ripples, feeding trails, brachiopod fragments, wood fragments.
55.0	1.0	Shale, dark grey, slightly micaceous, silty, finely laminated.
54.0	4.0	Sandstone, medium grey, very fine grained, silty, finely laminated with parting lineation.
50.0	8.0	Sandstone, medium grey, fine grained, silty, carbonaceous and plant debris; massive weathering.

Cumulative thickness from base of section	Thickness of unit	Description
42.0	5.0	Sandstone, medium grey, fine grained, very silty, rare shale interbeds, small asymmetrical ripples, slabby weathering.
37.0	1.0	Shale, dark grey, slightly micaceous, silty, finely laminated.
36.0	4.0	Sandstone, dark grey, very fine grained, silty, slabby weathering.
32.0	4.0	Sandstone, medium grey, fine grained, silty, comminuted carbonaceous debris and wood fragments; gradational contact with overlying unit.
28.0	2.0	Shale, dark grey, slightly micaceous, silty, finely laminated.
26.0	3.0	Sandstone, medium grey, fine grained, very silty, rare asymmetric ripples, finely laminated, slabby weathering.
23.0	4.0	Sandstone, medium grey, fine grained, silty, comminuted carbonaceous debris, wood fragments, rare brachiopods, massive weathering.
19.0	19.0	Shale, dark grey, slightly micaceous, silty, finely laminated, gradational contact with overlying unit.

Base of section is at sea level at northwest tip of Cape Crozier.

APPENDIX III: Paleocurrent data, Upper Glenelg Formation, Nelson Head Surface Section

Notes: 1. Greek letters refer to sedimentary structure classification of Allen (1963).

2. Parting lineation is caused by grain alignment and indicates two possible current directions at 180° to one another. The assumption is made herein that the correct direction is that which is closest to the direction given by other current indicators. If the data were other than strongly unimodal this deduction could not be made.

Interval (metres)	Sedimentary structure	Azimuth	Foreset dip	Thickness (cm)
14-73.5	alpha C.B.	275	20	12
		320	15	15
		210	15	6.5
		240	17	17
		300	18	28
		335	16	15
		000	12	19
		045	22	6.5
		345	11	8.5
		020	20	24
		070	14	22
		035	19	36
		035	19	9.5
		040	19	16
		010	24	20
75.5-85	part. lin.	250		
		250		
		260		
85-86.5	alpha C.B.	290	21	16
93-103	part. lin.	250		
		260		
		340		
		355		
		345		
		285		
		280		
		280		

Interval (metres)	Sedimentary structure	Azimuth	Foreset dip	Thickness (cm)
108-154	alpha C.B.	330	19	18
		345	20	11
		320	21	10
		320	13	21
		295	20	32
		345	21	15
		320	14	15
		340	23	37
		340	14	30
		295	15	17
	part. lin.	290		
		300		
		310		
		325		
		255		
155-244	alpha	355	7	15
		350	12	29
		335	25	50
		280	18	10
		135	22	54
		200	14	8
		000	16	29
		000	11	19
	theta	340	18	23
	part. lin.	345		
		335		