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DELTA EVOLUTION IN THE EUREKA SOUND GROUP, WESTERN AXEL HEIBERG ISLAND: THE TRANSITION FROM WAVE-DOMINATED TO FLUVIAL-DOMINATED DELTAS

B.D. Ricketts

1991

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PREFACE

The Eureka Sound Group in the Canadian Arctic Archipelago is significant because it provides the record of sedimentation and basin evolution during a major tectonic event, the Eurekan Orogeny.

This report deals with Eurekan rocks on the west side of Axel Heiberg Island, ranging in age from possibly middle Campanian to Middle Eocene. Emphasis is placed on the changes in patterns of sedimentation that took place during this period. The lithostratigraphy and sequence stratigraphy established here has already provided the framework for similar studies in the eastern Arctic Islands.

Significant resources of coal occur in Tertiary rocks throughout the Arctic. Estimates of resources are presented, and details of coal seams from specific sections are provided in an appendix.

Elkanah A. Babcock
Assistant Deputy Minister
Geological Survey of Canada

PRÉFACE

Le Groupe d'Eureka Sound, dans l'archipel arctique canadien, tire son importance du fait qu'il témoigne de la sédimentation et de l'évolution du bassin au cours d'un événement tectonique majeur: l'orogenèse eurékienne.

Le présent bulletin examine les roches eurékiennes qui se trouvent du côté ouest de l'île Axel Heiberg et dont l'âge s'échelonne du Campanien moyen (?) jusqu'à l'Éocène moyen. On y souligne les changements survenus dans la sédimentation au cours de cet intervalle. La lithostratigraphie et la stratigraphie séquentielle qui y sont établies ont déjà servi de base pour d'autres études semblables entreprises dans le secteur est de l'archipel arctique.

Les roches tertiaires de l'Arctique renferment des ressources charbonnières importantes. Le bulletin présente des estimations de ces ressources et, en annexe, des détails sur les filons houillers relevés dans des coupes particulières.

Elkanah A. Babcock
Sous-ministre adjoint
Commission géologique du Canada

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DELTA EVOLUTION IN THE EUREKA SOUND GROUP, WESTERN AXEL HEIBERG ISLAND: THE TRANSITION FROM WAVE-DOMINATED TO FLUVIAL-DOMINATED DELTAS

Abstract

The initial influx of coarse clastic sediment that formed the basal Eureka Sound Group at Strand Fiord followed the regression of the Kanguk Sea, and took place at least as early as middle Campanian. Sedimentation continued, largely in delta settings, until about the Middle Eocene. The locus of deposition at Strand Fiord corresponded approximately with the principal antecedent depocentre of eastern Sverdrup Basin. Eureka Sound Group strata on western Axel Heiberg Island were part of a much larger basin that extended to west-central Ellesmere Island.

Two principal delta types evolved. The Lower and Upper members of the Expedition Formation (Campanian to Lower Paleocene) represent successive stages of wave-dominated deltas, characterized by strandplain sandstones and subordinate barrier island deposits. Delta formation was terminated by a basin-wide (and perhaps Arctic-wide) transgressive event and subsequent accumulation of thick (regressive) shale making up the Strand Bay Formation (middle to Late Paleocene).

Resumption of delta growth during the subsequent regressive stage gave rise to the thick Iceberg Bay Formation (Upper Paleocene to Middle Eocene), containing a Lower member of stacked, distinctly cyclical, interdistributary bay/subdelta deposits, and a Coal member, consisting mostly of delta-plain facies. The Coal member is the highest stratigraphic unit in the area. This stage of delta growth was dominated by fluvial processes.

The transition from wave-dominated to fluvial-dominated deltas reflects decreasing slopes (as the basin filled) and a concomitant increase in wave attenuation. Significantly, however, the thickness of Iceberg Bay strata (almost 2000 m) and the style of cyclicity indicate that sedimentation was rapid enough to keep pace with equally rapid subsidence of the basin. Sediment was derived from older Sverdrup Basin, Franklinian and Precambrian Shield rocks, in an uplifted terrane bordering the basin to the north and east. Increased rates of subsidence and sediment supply toward the end of the Paleocene and Early Eocene probably reflect the approaching, climactic phase of Eurekan tectonism that began later in the Middle Eocene.

Résumé

L'apport initial de sédiments clastiques grossiers qui a contribuè à la formation du groupe basal d'Eureka Sound au fjord Strand a eu lieu après la régression de la mer de Kanguk à une époque au moins aussi lointaine que le Campanien moyen. La sédimentation s'est poursuivie, en grande partie dans des milieux deltaïques, jusque vers l'Éocène moyen. Le lieu de sédimentation au fjord Strand correspond approximativement au principal centre de sédimentation maximale antérieur, dans l'est du bassin de Sverdrup. Les couches du groupe d'Eureka Sound dans l'ouest de l'île Axel Heiberg faisaient partie d'un bassin beaucoup plus grand qui s'étendait jusqu'au centre-ouest de l'île d'Ellesmere.

Deux principaux types de deltas se sont formés. Les membres inférieur et supérieur de la formation d'Expedition (du Campanien au Paléocène inférieur) représentent les étapes successives de formation de deltas principalement érodés par les vagues, caractérisés par des grès de plaine littorale et des dépôts d'îles de cordons subordonnés. Une transgression à l'échelle du bassin (et peut-être de l'Arctique) la mise en place subséquente d'un schiste argileux (régressif) épais dont est formée la formation de Strand Bay (du Paléocène moyen au Paléocène supérieur) ont mis fin à la formation des deltas.

La reprise de la croissance des deltas durant au stade de régression subséquent a donné naissance à l'épaisse formation d'Iceberg Bay (du Paléocène supérieur à l'Éocène moyen), contenant un membre inférieur de dépôts empilés, nettement cycliques, mis en place en milieu de baie inter-effluent et de sous-delta, ainsi qu'un membre charbonneux, composé en grande partie d'un faciès de plaine deltaîque. Le member charbonneux est l'unité stratigraphique la plus élevée de la zone. À cette étape, la croissance du delta a surtout été modifée par des processus fluviatiles.

La transition de delta principalement érodé par les vagues à delta principalement érodé par les eaux fluviales s'est traduite par une diminution des pentes (à mesure que se remplissait le bassin) et par une atténuation concomitante accrue des vagues. Cependant, l'épaisseur des couches d'Iceberg Bay (presque 2000 m) et le style de leur cycle de sédimentation indiquent de façon significative que la sédimentation a été suffisamment rapide pour contrebalancer l'affaissement également rapide du bassin. Les sédiments provenaient de roches plus anciennes du bassin de Sverdrup, de l'orogène du Boucher franklinien et précambriennes, dans un terrane soulevé bordant le bassin au nord et à l'est. L'augmentation de la vitesse d'affaissement et l'apport de sédiments vers la fin du Paléocène et de l'Éocène inférieur reflètent probablement l'approche de la phase climatique du tectonisme eurékien qui a débuté ultérieurement au cours de l'Éocène moyen.

Summary

In the Strand Fiord area of west-central Axel Heiberg Island, siliciclastic sediment was introduced into the basin as early as middle Campanian. The restricted marine conditions that prevailed during Kanguk Formation deposition were terminated. The locus of early Eureka Sound Group deposition in this area corresponds closely to the principal depocentre of the eastern Sverdrup Basin. Eureka Sound Group strata at Strand Fiord are an erosional remnant of a much larger basin that extended to the west-central part of Ellesmere Island, and they record uplift during an early phase of the Eurekan Orogeny.

For the Cretaceous segment of the Eureka Sound Group, ages are based on palynology and a sparse, but well preserved Inoceramid fauna. Dating of the Paleogene part of the succession is based primarily on palynology (although in other areas this is augmented by foraminifera). The youngest strata are Middle Eocene.

The Eureka Sound Group found along western Axel Heilberg Island (at least 3000 m thick) represents two major episodes of delta accumulation. In the first stage, the Lower and Upper members of the Expedition Formation (middle Campanian to Lower Paleocene) consist of several coarsening-upward shale-to-sandstone units. These units record the transition from prodelta to shoreface and beach settings, on a segment of a (approximately) westward prograding, wave-dominated delta strandplain. Minor barrier island deposits occur, resulting from reworking of an abandoned segment of the delta. A lacuna may be present between the Lower and Upper members; a significant unconformity straddling the Cretaceous – Tertiary boundary has since been found in several other parts of the basin on Ellesmere Island (Ricketts, 1989). Wave-dominated delta accumulation was terminated during a middle Paleocene transgression. In an earlier account of Eureka Sound Group stratigraphy, Ricketts (1986) indicated the presence of a disconformity between the Expedition and Strand Bay formations. Re-examination of the sections and additional sampling of the critical stratigraphic interval (1988), has revealed a more or less continuous sequence between these two formations and no resolvable hiatus. The top of the Expedition Formation at Strand Fiord is now known to be Lower Paleocene.

Basin-wide, and perhaps Arctic-wide transgression was followed by deposition of a thick sequence of shale, the Strand Bay formation (middle to Upper Paleocene). A few thin sandstones occur within the shale sequence and may be analogous to thin, transgressive, barrier island deposits on abandoned delta lobes. The Strand Bay sequence constitutes the initial regressive stage of the next major period of delta construction.

Resumption of delta growth during the subsequent regressive stage gave rise to the thick (almost 2000 m) Iceberg Bay Formation (Upper Paleocene to Middle Eocene). Significant differences exist between the members of the Iceberg Bay Formation and those that make up the Expedition Formation. Renewed progradation and rapid sedimentation produced a thick succession of coarsening-upward shale-sandstone units—the Lower member of the Iceberg Bay Formation. The style of bedding, bedforms, and trace fossil assemblages indicate much lower-energy depositional regimes. Thin coal seams cap some coarsening-upward sequences high in the member. Each sequence represents a prograding, interdistributary bay/subdelta lobe, that was fed by semi-permanent crevasse channels.

Strata of the Coal member (Iceberg Bay Formation) are the youngest preserved in the area. In this unit, beds are arranged into fining-upward sequences that are commonly capped by coal; some seams are up to 6 m thick. These units are the products of deposition in high sinuosity fluvial channels on a delta plain. Regoliths occur locally, and minor marine incursions are recorded. Both the Lower and Coal members are indicative of a fluvial-dominated delta system.

The transition from wave-dominated to fluvial-dominated deltas in the Strand Fiord area reflects two important aspects of basin evolution. First, the transition indicates that wave attenuation

increased, probably as a result of decreasing slope of the submarine profile, concomitant with progressive basin infill. Second, the thickness of the fluvial-dominated component (Iceberg Bay Formation) and style of cyclicity, indicate that sedimentation was rapid enough to keep pace with equally rapid subsidence. Petrographic data indicate that, whereas the quartz-rich sands were ultimately derived from the Precambrian Shield, the sand may be multicyclic, having been reworked from older Sverdrup Basin and Franklinian rocks. The increase in sediment supply rate and basin subsidence rate toward the end of the Paleocene to Middle Eocene is a reflection of the approaching, climactic phase of Eurekan tectonism (folding and faulting).

Coal resources have been estimated (on a 'speculative' level of confidence) for seams contained mainly in the Coal member. A minimum thickness of 0.5 m is used; one seam is 6 m thick, and several exceed 2 m. A total of 115-118 million tonnes occurs.

Sommaire

À proximité du fjord Strand, dans le centre ouest de l'île Axel Heiberg, l'accumulation de sédiments silicoclastiques dans le bassin remonte jusqu'au Campanien moyen. Le milieu marin à circulation restreinte qui dominait durant la mise en place de la Formation de Kanguk a cessé d'exister. À cet endroit, le foyer du début de la sédimentation du Groupe d'Eureka Sound correspond étroitement au centre de sédimentation principal de la partie est du bassin de Sverdrup. Au fjord Strand, les strates du Groupe d'Eureka Sound représentent un résidu érodé d'un bassin beaucoup plus vaste qui se prolongeait jusqu'au centre ouest de l'île d'Ellesmere; elles témoignent d'un soulèvement survenu au cours d'une phase précoce de l'orogenèse eurékienne.

Les âges du segment crétacé du Groupe d'Eureka Sound se fondent sur la palynologie et sur une faune peu abondante mais bien conservée d'Inoceramidés. La datation de la partie paléogène de la succession se fonde principalement sur la palynologie (bien qu'à d'autres endroits, elle se base aussi sur les foraminifères). Les strates les plus récentes datent de l'Éocène moyen.

Le Groupe d'Eureka Sound qui se trouve dans l'ouest de l'île Axel Heiberg a au moins 3 000 m d'épaisseur et représente deux épisodes majeurs d'accroissement de delta. Les strates du premier épisode englobent les membres inférieur et supérieur de la Formation d'Expedition (Campanien moyen à Paléocène inférieur) et comprennent plusieurs unités à granoclassement inverse de shale passant à du grès. Ces unités attestent le passage d'un prodelta à une avant-plage et à une plage sur un segment de plaine littorale deltaïque dominée par des vagues, à progradation approximativement vers l'ouest. On y trouve une petite quantité de dépôts d'îles barrières qui sont le produit du remaniement d'un segment abandonné du delta. Une lacune pourrait séparer les membres inférieur et supérieur; une discordance importante à la limite du Crétacé et du Tertiaire a été reconnue depuis à plusieurs autres endroits dans le bassin dans l'île d'Ellesmere (Ricketts, 1989). Une transgression survenue au Paléocène moyen a mis fin à l'accumulation de sédiments dans un delta dominé par des vagues. Dans une description antérieure de la stratigraphie du Groupe d'Eureka Sound, Ricketts (1986) indique la présence d'une disconformité entre les formations d'Expedition et de Strand Bay. Une nouvelle étude (1988) des coupes et d'autres échantillons de l'intervalle stratigraphique en question révèle la présence d'une séquence relativement continue entre les deux formations, mais non pas d'un hiatus. Il a maintenant été établi qu'au fjord Strand, le sommet de la Formation d'Expedition remonte au Paléocène inférieur.

La transgression survenue dans l'ensemble du bassin, voire dans l'ensemble de l'Arctique, a été suivie par l'accumulation d'une séquence épaisse de shale, la formation de Strand Bay (Paléocène moyen à supérieur). La séquence de shale contient quelques grès minces qui pourraient être analogues à des dépôts transgressifs peu épais d'îles barrières sur des lobes deltaïques abandonnés. La séquence de Strand Bay représente l'épisode régressif initial de la prochaine grande période d'accroissement du delta.

Cette dernière a repris au cours de l'épisode régressif subséquent et a produit la Formation d'Iceberg Bay (Paléocène supérieur à Éocène moyen), qui a presque 2 000 m d'épaisseur. Il existe des différences importantes entre les membres de la Formation d'Iceberg Bay et ceux de la Formation d'Expedition. La reprise de la progradation et la sédimentation rapide a donné une succession épaisse d'unités de shale et grès à granoclassement inverse, le membre inférieur de la Formation d'Iceberg Bay. La stratification, la morphologie du fond et les associations d'ichnofossiles indiquent des régimes sédimentaires à énergie beaucoup plus faible. De minces filons houillers couronnent certaines séquences à granoclassement inverse qui se situent dans la partie supérieure du membre. Chaque séquence représente une baie entre les défluents ou un lobe de sous delta qui progradaient et étaient alimentés par des chenaux en crevasse semi-permanents.

Les strates du membre de Coal (Formation d'Iceberg Bay) sont les strates les plus récentes de la région. Les lits y sont disposés en séquences à granoclassement normal qui sont fréquemment couronnées de charbon; certains des filons ont jusqu'à 6 m d'épaisseur. Ces unités sont le produit de la sédimentation dans des chenaux fluviatiles très sinueux de plaine deltaque. Des régolites se manifestent par endroits, et il existe des indices d'avancées marines peu importantes. Les membres inférieur et de Coal témoignent de la présence d'un système deltaïque dominé par des cours d'eau.

Dans la région du fjord Strand, le passage d'un delta dominé par des vagues à un delta dominé par des cours d'eau reflète deux aspects importants de l'évolution d'un bassin. Premièrement, il indique que l'atténuation des vagues a augmenté, vraisemblablement en raison d'une réduction de la pente du profil sous-marin, et qu'il y a eu en même temps comblement progressif du bassin. Deuxièmement, l'épaisseur de la composante correspondant au milieu dominé par des cours d'eau (Formation d'Iceberg Bay) et le style de cyclicité montrent que la sédimentation était suffisamment rapide pour tenir tête à la subsidence, qui était tout aussi rapide. À en juger par la pétrographie, bien que les sables quartzeux dérivent en fin de compte du Bouclier précambrien, ils pourraient être polycycliques et avoir été remaniés de roches plus anciennes du bassin de Sverdrup et de Franklin. La vitesse accrue des apports de sédiments et de la subsidence du bassin vers la fin de la période s'étendant du Paléocène à l'Éocène moyen reflète l'imminence de la phase climacique de diastrophisme (plissement et formation de failles) eurékien.

On a estimé (avec un degré de confianceles «spéculatif» ressources en charbon des filons qui se trouvent principalement dans le membre de Coal. Une épaisseur minimale de 0,5 m est employée; un des filons a 6 m d'épaisseur et plusieurs autres ont plus de 2 m. Les réserves totales de charbon se situent entre 115 et 118 millions de tonnes.

INTRODUCTION

Sverdrup Basin was a long lived, intracratonic depression with a geological history spanning approximately 300 million years, from the Carboniferous to early Tertiary (Fig. 1). The Eureka Sound Group (Miall, 1986, 1988; Ricketts, 1986, 1988), despite being the youngest depositional unit in the Sverdrup Basin succession, is of prime importance because it provides a record of sedimentary and tectonic events during the Eurekan Orogeny, the last major period of diastrophism along the northern perimeter of the North American craton. In addition, Eureka Sound Group strata in the eastern Arctic contain large quantities of coal of potential economic value. Accordingly, detailed studies of stratigraphy, sedimentology and paleontology, the first objectives of this study on western Axel Heiberg Island, will provide important information on the nature and timing of basin filling and deformation. The second objective of this investigation is to prepare a more detailed analysis of the coal resource potential of Eureka Sound strata on western Axel Heiberg Island, to provide data for Canada's National Coal inventory.

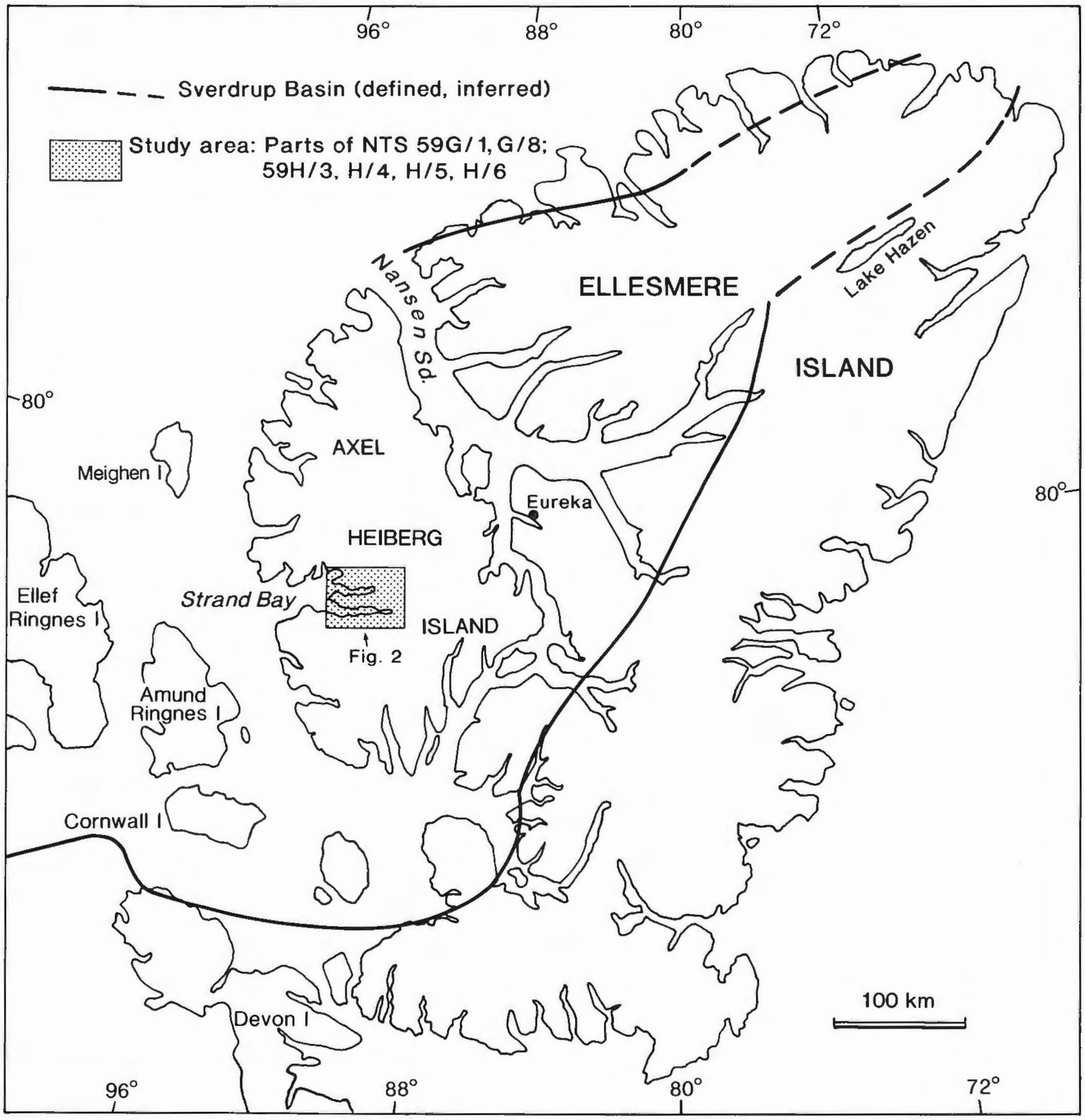

Figure 1. Index map, showing the geographic location of the study area in the eastern Queen Elizabeth Islands, Canadian Arctic Archipelago, in relation to the approximate depositional margin of Sverdrup Basin.

Fieldwork in 1983 was conducted in the vicinity of Strand Fiord and Expedition Fiord, part of the central mountain area of Axel Heiberg Island. The physiography of the area has been described by Roots (*in* Fortier et al., 1963, p. 418). Mapping of the Eureka Sound Group was completed at a scale of 1:50,000 (NTS map sheets 59 G and H).

Previous work

At the turn of the century, the second Polar Expedition (1898-1902) led by Otto Sverdrup, was in its second year of exploration in the Arctic Archipelago. In early 1900, two members of the expedition, Sverdrup and Fosheim, proceeded along the west coast of Axel Heiberg Island as far north as Rens Fiord. Many observations were made on this trek, although very few pertaining to what is now called the Eureka Sound Group.

More than half a century elapsed before geological investigations were resumed along the west coast of Axel Heiberg Island. During the Geological Survey of Canada's 'Operation Franklin' in 1955, geological mapping of the Strand Fiord area was undertaken by J.G. Souther, R. Thorsteinsson and E.T. Tozer, with the measuring of a number of stratigraphic sections along Kanguk Peninsula (*in* Fortier et al., 1963). Here for the first time, rocks of Late Cretaceous and Tertiary age were recognized and correlated with strata on Fosheim Peninsula that Troelsen (1950) had earlier named the Eureka Sound Group. Additional mapping in this vicinity was undertaken by the Jacobsen-McGill Arctic Research group (*in* Fricker, 1963). Geological maps were subsequently published by Thorsteinsson (1971a, b).

Since 1970, the Eureka Sound Group has been examined by various workers at several localities throughout the Arctic. The first detailed examination of these rocks along western Axel Heiberg was conducted by Bustin (1977) who measured a 645 m thick section along the north and south coasts of Strand Fiord, and interpreted the strata as delta front and lower delta plain in origin. Bustin (op. cit.) reported the age of this basal Eureka Sound section as Maastrichtian to possible middle Paleocene, based on palynology.

During the 1983 field season, the author identified five mappable units in the Eureka Sound Group at Strand and Expedition fiords. Subsequent studies on eastern Axel Heiberg Island and western Ellesmere Island provided data that permit the designation of formations (Ricketts, 1986). Minor changes to the biostratigraphic age determinations of two of the formations are presented here, based on more recent sampling (1988). This nomenclatural scheme is used here (an alternative scheme has been proposed by Miall, 1986). A discussion of the coal resource potential in the uppermost unit is included in a general summary of coal potential of the Arctic Archipelago by Ricketts and Embry (1984).

Stratigraphy and structural framework

A concise account of the stratigraphic evolution of Sverdrup Basin is provided by Balkwill (1978). The Eureka Sound Group of Late Cretaceous and Paleogene age has received the attention of several workers, providing information from localities scattered about the Arctic Islands. To date, the most detailed studies of the sedimentology and stratigraphy are those of Bustin (1977), Miall (1979a, 1982), and Miall et al. (1980) in the eastern Arctic (Ellesmere Island, Axel Heiberg Island and Bylot Island areas), and by Miall (1979b) in the west, on Banks Island. Miall (1981, 1984) has speculated on the existence of a number of subbasins during the deposition of Eureka Sound sediments, subbasins that formed by fragmentation of Sverdrup Basin during an initial compressive phase of the Eurekan Orogeny (Balkwill, 1978). Three important structural elements that developed during this phase of deformation were:

1. Late Cretaceous uplift on the Sverdrup rim where Eureka Sound strata of late Maastrichtian age rested unconformably on eroded Mesozoic rocks, along the southwestern and northern margin of Sverdrup Basin.
2. The north-plunging Cornwall Arch, where a major hiatus exists between the lower Maastrichtian or upper Campanian Eureka Sound Group and the Upper Paleocene – Eocene sandstone that lies with profound unconformity upon the Triassic Barrow Formation (bracketing the hiatus between late Maastrichtian and Middle Eocene; Balkwill, 1983, p. 47.
3. The south-plunging Princess Margaret Arch on Axel Heiberg Island, where Eureka Sound strata lie unconformably on rocks as old as the Triassic Blaa Mountain Formation. Balkwill (1983, p. 75) interpreted these large structures as regional uplifts formed during an early phase of Eurekan compression, with uplift and tectonic thickening taking place on reactivated listric faults that extended deep into the crust. The broader implications of these structures in terms of plate tectonic theory have been discussed by Balkwill (1978), Kerr (1982) and Miall (1984).

Of the seven subbasins recognized by Miall (1981, 1985) in the Arctic Archipelago, Strand Fiord Basin (formerly called Meighan Basin—Miall, 1981, 1986, and centered on western Axel Heiberg) and Remus Basin (centered on Fosheim Peninsula and named by Bustin, 1977) are pertinent to this study. Filling of the basins was affected by delta progradation, and Miall (1984) suggested that Remus Basin was characterized by a fluvial dominated system, whereas Strand Fiord Basin was dominated by marine delta conditions. According to these authors, the two basins were separated by the ancestral Princess Margaret Arch as early as Maastrichtian or late Campanian time. However, evidence presented here and in Ricketts (1987) demonstrates that the history of these subbasins is more complex; that the ancestral Princess Margaret Arch is probably no older than Middle Eocene, and therefore Strand Fiord and Remus basins were a contiguous entity prior to that time, rather than separate basins.

On western Axel Heiberg Island, the Eureka Sound Group conformably overlies upper Turonian to Campanian shales of the Kanguk Formation. The Kanguk shale commonly weathers recessively, except where it is underlain by ridge-forming volcanics of the Strand Fiord Formation.

Fold structures in the study area are characterized by open, north-northwest trending, doubly plunging synclines, separated by relatively tight, almost isoclinal anticlines that typically are breached by salt diapirs, or cut by steep extensional faults. Structural analysis of the diapir-cored folds has been undertaken by Berkel (1986) and Berkel et al. (1984). The diapirs consist of gypsum and anhydrite and contain exotic blocks of diabase, gabbro, sandstone and shale. At one locality near the northern end of Glacier Fiord Syncline, a salt intrusion truncates basal strata of the Eureka Sound Formation.

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STRATIGRAPHY

Introduction

Formal definitions of formations, type sections and reference sections are given in Ricketts (1986). The reader is also referred to an alternative nomenclatural scheme by Miall (1986). Discussion of the relative merits of these competing schemes can be found in Miall (1988) and Ricketts (1988). Stratigraphic sections that were measured or walked out are located on Figure 2, and summarized in Figure 3. Details for these sections are given in Figure 49. The best exposed and most complete section occurs approximately midway along the south coast of Kanguk Peninsula (RAK 25) where the basal contact with the Kanguk Formation is accessible, and where many of the fine grained lithotypes also are exposed. Strata at the basal contact also were examined in the following sections: along Kanguk River (RAK 31), at the western tip of Kanguk Peninsula (RAK 27), at the head of Strand Fiord (RAK 32A), and near Dragon Cliffs (RAK 29).

The Kanguk Formation is characterized by acidic, papery shale that weathers a distinctive pale grey colour. Contact with basaltic lava flows or volcaniclastic conglomerates of the subjacent Strand Fiord Formation is abrupt. A few bentonitic tuff beds occur in the lower part of the formation. The maximum thickness observed along Kanguk Peninsula is 243 m (RAK 25). Thinner sections recorded at the western end of Kanguk Peninsula are probably the result of faulting. Contact with the Eureka Sound Group is gradational. Thin siltstone, fine grained sandstone beds and resistant ironstone beds a few centimetres thick appear in the upper third of the Kanguk. Weathered surfaces of these sandstones are commonly jarositic.

Pelecypods, gastropods and rare ammonite fragments are best preserved in the thin, resistant ironstone beds and concretionary sandstone beds in the upper third of the Kanguk Formation. The macrofossils collected during the 1983 field season were identified by J.A. Jeletzky. Examples of *Inoceramus* up to 25 cm long include two species: *I.* (*Sphenoceramus*) *lundbreckensis* formerly of the *I. Lobatus* group, and *I. subquadratus*. Other mollusc species include *Pholadomy* sp., *Oxytoma* (*Hypoxytoma*) *nebraskana*, and *Crassatella* sp. One fragment of the ammonite *Clioscaphites* sp. was found.

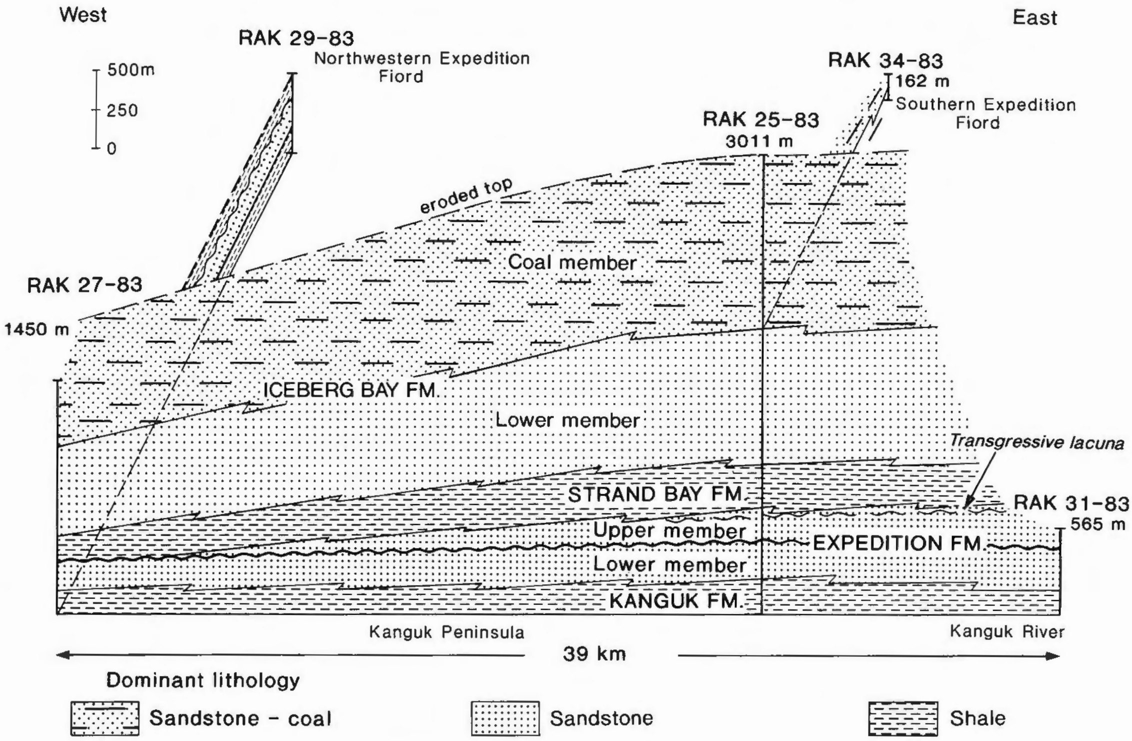


Figure 3. *A summary of Eureka Sound Group map units and measured sections (total thickness in metres) in the Strand Bay/Strand Fiord map area (see Figure 2). The Kanguk Formation/Strand Fiord Formation contact is used as a datum. Note that the unconformity between the two members of the Expedition Formation has been traced over much of the basin on eastern Axel Heiberg and western Ellesmere islands. The lacuna indicated near the top of the Expedition Formation (dashed line) is considered to represent a transgressive hiatus associated with the succeeding Strand Bay Formation/Iceberg Bay Formation regression; lithologically the sandstone beds above this hiatus are part of the Expedition Formation. The Strand Bay/Iceberg Bay contact is now regarded as being essentially conformable (cf. Ricketts, 1986). The geographic separation of Sections RAK 31–83 and RAK 27–83 is about 39 km.*

Redefinition of the Kanguk-Eureka Sound Group contact

Definition of the Kanguk-Eureka Sound Group contact is necessarily arbitrary because of its gradational nature. In their pioneering work on western Axel Heiberg both Thorsteinsson and Tozer (*in* Fortier et al., 1963) placed the boundary beneath the first major sandstone bed. However, the actual thickness of this major bed is left undefined—indeed the thickness of sandstone beds at the base of the Eureka Sound Formation is quite variable and is controlled by facies. Placing the contact at the first sandstone bed of any thickness also is unsatisfactory because the stratigraphic level at which this occurs can vary according to facies. An additional problem is encountered in a section originally examined by Souther (*in* Fortier et al., 1963 – his section no. 51), just east of Kanguk River (RAK 31), where the upper part of the Kanguk Formation contains several tens of metres of sandstone and thin interbedded shale, overlain by a 30 m thick unit of shale. The top of the Kanguk was placed immediately above this shale. However, the thick sandstones included in the Kanguk by Souther actually consist of coarsening-upward sequences that are very similar to sequences found in the lower Eureka Sound Group and therefore could logically be included in the latter unit.

The mollusc *Inoceramus lundbreckensis* is critical to this discussion because of its occurrence in the thin sandstones of the upper Kanguk Formation, and also in the thicker sandstone facies. For the upper Kanguk strata, this at least provides an age range of mid-late Santonian to early Campanian. If the thick, *Inoceramus*-bearing sandstones are determined to be basal Eureka Sound Group, then the lower limit of this unit is considerably older than previously thought. However, it should be noted that even if the sandstones are included in the Kanguk Formation as a local sandy facies, the base of the Eureka Sound Group as mapped by Souther would still fall into the range of middle to upper Campanian (see Section RAK 31).

I have included thick bedded sandstones, such as those exposed in the Kanguk River section (no. 31), in the Eureka Sound Group for two reasons:

1. The sandstones have many of the characteristics of the overlying Eureka Sound strata in terms of their bedding, internal organization and texture.

2. The Kanguk Formation remains a homogeneous lithostratigraphic entity. Any ambiguity in defining the Kanguk-Eureka Sound contact is removed, for example, where a contact might be placed at the base of the first "major" sandstone bed.

During the course of fieldwork, a useful criterion for defining the contact was found to be the stratigraphic level at which the sandstone/shale thickness ratio approached 40 to 60 per cent. Where the proportion of sandstone is less than 40 per cent, the outcrop is much less resistant to weathering. The Kanguk Formation – Eureka Sound Group contact defined on this basis is mappable, and has the affect of reducing the thickness of the Kanguk by a few tens of metres. The mapped contact in the Strand Fiord area has been adjusted accordingly in Figure 2.

General attributes of the Eureka Sound Group

The Eureka Sound Group consists of moderately well sorted, quartzose sandstone interbedded with siltstone, grey shale and subordinate coal seams. In the Strand Fiord area, the formation attains a maximum measured thickness of 2900 m in exposures along Kanguk Peninsula (RAK 25). An additional 100 to 150 m of poorly exposed, weakly indurated strata may occur above this measured limit, although stratigraphic continuity is difficult to demonstrate. The top of the formation is eroded. Section RAK 25 is the most complete section in the Strand Fiord area and is illustrated in Figures 4 and 49.

Throughout the succession there is considerable variation in lithology, bed thickness and vertical succession. Sandstone bed thicknesses range from a few centimetres to more than 40 m. However, such variations occur in regular patterns of coarsening- and fining-upward units. The latter are typically associated with coal seams in the upper part of the group. Five map units within the Eureka Sound Group are identified on the basis of these lithological attributes (Figs. 2, 3). The three formations relevant to the Strand Fiord area have been formally defined by Ricketts (1986). Further informal definition of members in the the Expedition and Iceberg Bay formations is given here. The two members of the Expedition Formation are similar in content and are

Figure 4. *A panorama (facing north) of the Eureka Sound Group reference section along the north shore of Strand Fiord (RAK 25 – 83), showing all the principal map units. GSC photos. 2045 – 205, 206. The resistant ridge on the left is underlain by Strand Fiord volanics.*

composed of thick, coarsening-upward shale-sandstone units, and thick, isolated sandstone beds. Large-scale crossbedding and bioturbation are common. The top of Expedition Formation is abruptly overlain by a thick shale succession making up the Strand Bay Formation, which in turn is succeeded by an additional sequence of sandstone and shale arranged in coarsening-upward cycles (Lower member, Iceberg Bay Formation). The cycles in this member are thinner and more numerous than those encountered in Expedition strata. Fining-upward sequences of sandstone and shale that commonly are capped by coal seams, characterize the Coal member of the Iceberg Bay Formation.

Macrofossils are rare in this area of the Eureka Sound Group, except in the lower part of the Expedition Formation where a few specimens of *Inoceramus* were found in concretionary sandstone. However, trace fossils are common in the other map units, although the number and diversity of traces decrease toward the top of the succession. None of the vertebrate fauna found in the Strathcona Fiord area by West et al., (1977) were encountered at Strand Fiord. Fortunately, the palynomorph and dinoflagellate assemblages are sufficiently diverse and well preserved to enable age assignments to all of the stratigraphic units recognized here.

The paleontology of the floral assemblages is discussed by D.J. McIntyre (Appendix 3). All age designations based on palynology are based on personal communications from D.J. McIntyre. Sparse microfossil assemblages are also reported in Appendix 2 by J.H. Wall.

The distribution of each map unit is illustrated in Figure 2. Coal-bearing Iceberg Bay Formation is preserved on Kanguk Peninsula in the cores of five synclines. South of the peninsula, uplift and erosion have removed the upper part of the Eureka Sound Group.

Expedition Formation – Lower member

Thickness

The Lower member is 170 to 300 m thick, with maximum exposed thickness at the reference section (RAK 25).

Contacts

Contact with the subjacent Kanguk Formation is gradational, and is placed at the level where sandstone beds make up 40 per cent of the section. At Section 25, the top of the member is placed immediately above a pair of massive, cliff forming sandstones, 16 m and 18 m thick, that are separated by an 8 m thick interval of shale (Fig. 4). The upper contact is abrupt and overlain by thick shale at the base of the Upper member. Toward the east, along Kanguk River (RAK 31), these two sandstone units increase in thickness to 20 m and 42 m respectively, with the intervening fine grained interval reduced to 3 m in thickness. On the west end of Kanguk Peninsula, the upper sandstone beds are much thinner because of lateral facies changes and are overlain abruptly by thick shales of the Strand Bay Formation.

Type Section

The type section of the Lower member is on the east side of Kanguk River, 2.5 km due north of Strand Fiord, latitude 79°16′N; longitude 90°35′W. This lies above the type section of the Kanguk Formation; measured section RAK 31, Figure 49.

Content

The Lower member is characterized by interbedded sandstone and shale wherein the proportion of sandstone increases from about 40 per cent at the base, to 60 to 70 per cent in the upper few tens of metres. Bed thickness also increases toward the top of the unit, from a few centimetres to 2 m. Beds occur as isolated units or, as is more commonly the case, in coarsening-upward sequences. The sandstones typically have a dirty appearance and usually are intensely bioturbated by *Chondrites*. Fragments and a few complete specimens of *Inoceramus* (*Sphenoceramus*) *lundbreckensis* occur in strata below the uppermost, massive, cliff forming sandstone.

Massive sandstones that define the top of the unit also are associated with coarsening-upward sequences. However, they tend to be cleaner and better sorted than their lower counterparts, and contain large-scale crossbeds. The corresponding trace fossil assemblage also is dominated by *Chondrites*. Trace fossils are described in more detail later in this bulletin.

Age

The Lower member of the Expedition Formation is probably as old as middle Campanian, based on the Inoceramid fauna identified by J.A. Jeletzky (pers. comm.) and discussed in the previous section. It may be as young as early Maastrichtian based on stratigraphic relationships with the Upper member.

Expedition Formation – Upper member

Thickness

The Upper member is 0 to 200 m thick, with a maximum thickness exposed at the reference section (RAK 25). An incomplete section, 150 m thick, occurs along the left bank of Kanguk River (type section, RAK 31). The unit pinches out between Section RAK 25 and the western end of Kanguk Peninsula and also the northwest end of Expedition Fiord (RAK 29), at which points, the Lower member is directly overlain by Strand Bay strata. This stratigraphic relationship is based on the common occurrence of *Inoceramus* in Lower member strata in Sections RAK 25 and 27, and the absence of any molluscan fauna in the Upper member. In addition there is no lithological break in the sequence in RAK 27 that corresponds to the Lower member/Upper member contact observed elsewhere.

Contacts

At Section RAK 25, the basal 60 m of the Upper member consist of shale and thinly interbedded sandstone, in abrupt contact with the cliff forming sandstones of the Lower member. Farther east, in Section RAK 31, the equivalent stratigraphic interval contains numerous shale and sandstone beds that are arranged in coarsening-upward sequences 2 to 10 m thick. Here, the lowermost shale unit in contact with the massive sandstones of the Lower member is only 5 to 10 m thick.

The upper boundary with dark grey, Strand Bay shale is abrupt and is placed at the top of the sandstone immediately below these shales.

Type Section

The type section of the Upper member is at the same location (given above) as the type section of the Lower member.

Content

The Upper member contains between 10 and 20 coarsening-upward units of sandstone and shale. At Section RAK 25, the thickness of individual units tends to increase toward the top of the unit, from 1 to 2 m, at the base, to 5 to 6 m at the top. A similar stratigraphic trend is found in more eastern exposures although the thickness of individual cycles increases to 5 to 10 m. In general the sandstones are cleaner and better sorted than those in the Lower member.

Grain size also increases toward the east; for example, in the Glacier Fiord and Wolf Fiord synclines, where medium to coarse grained and, locally, pebbly sandstones are present in crossbedded intervals. The only well bedded conglomerate observed is a thin pebble bed, located at the base of a fining-upward sandstone sequence at Section RAK 31. Other pebble lags occur locally, the most prominent at the base of the uppermost coarsening-upward unit, at the top of the member. Rare, shaly coal seams occur above a few sandstone beds. Comminuted plant material and wood fragments are common in some coarse grained and crossbedded sandstones. Bioturbation is common but, unlike the underlying member, the trace fossil assemblage throughout is dominated by *Skolithos*, and notably the first appearance of forms such as *Paleophycus*, *Gyrochorte* and *Terrebellina.*

Age

The age of the Upper member of the Expedition Formation is probably Early Paleocene, based on palynological analyses by D.J. McIntyre and presented in Appendix 3.

Strand Bay Formation

Thickness

The Strand Bay Formation attains a maximum thickness of 287 m at the type section (RAK 25), and is 141 m thick at Section 27.

Contacts

In the eastern and central parts of Kanguk Peninsula, and the Strand Fiord area, the Strand Bay shale lies abruptly on Expedition Formation strata (Fig. 4). However, at the west end of Kanguk Peninsula and Expedition Fiord, the shale directly overlies a thin coaly shale at the top of the Lower member of the Expedition Formation. There is no indication of any angular discordance between these units. Contact with the overlying Iceberg Bay Formation is gradational over a thickness of 10 to 20 m, as shale gives way to thin bedded, fine grained sandstone.

Type Section

The type section of the Strand Bay Formation is on a ridge situated along the north shore of Strand Fiord, 15.5 km due west of Kanguk River, and 3 km due east of Twin Diapirs; latitude 79°14′N, longitude 91°27′W; measured section RAK 25, Figure 49.

Content

Strand Bay shale in this area is characterized by dark, steel-blue and grey shale with a fine blocky fracture. Silty beds occur sporadically throughout. The shale unit thins toward the west. The best exposures are found in steeply dipping strata along the north and south coasts of Strand Fiord. At Section RAK 25, the thick shale sequence is interrupted by only a few thin sandstone beds about midway through the unit—here, four beds, ranging in thickness from 1.3 m to 10 m, are located within a stratigraphic interval of about 30 m. The sandstones form prominent ridges, have rectangular weathering profiles (compared to the fining- and coarsening-upward profiles in other map units), are fine to medium grained and contain abundant trough and planar crossbedding. Wood fragments up to 2 m long are common. A single, cross-bedded sandstone bed occurs at a similar stratigraphic level in sections farther west (RAK 27 and 29), providing a useful (but approximate) marker. The sandstone at Section RAK 27 also is overlain by a thin coal seam.

Age

The age of the Strand Bay Formation is middle to Late Paleocene, based on palynological determinations by D.J. McIntyre (Appendix 3). Supporting evidence is found in a sparse foraminiferal assemblage (J.H. Wall, Appendix 2).

Iceberg Bay Formation – Lower member

Thickness

The Lower member of the Iceberg Bay Formation is 890 m thick at the type section (RAK 25), and 554 m thick at the west end of Kanguk Peninsula (RAK 27); the lower value at Section RAK 27 may in part be due to faulting.

Contacts

At Section RAK 25, the top of the member is placed at the base of a thick, bluff-forming sandstone that contains abundant trough crossbedding. This contact also corresponds with the upper limit of coarsening-upward shale-sandstone sequences that characterize the member: a criterion that can be used elsewhere in the map area at localities that lack the bluff-forming sandstone (as at Section RAK 27). Contact with the subjacent Strand Bay Formation is gradational.

Type Section

The type section of the Lower member is located on the north shore of Strand Fiord, immediately above the type section of the Strand Bay Formation. Base of section, latitude 79°14′N, longitude 91°27′W; top of section, latitude 79°14.5′N, longitude 91°15′W; measured section RAK 25, Figure 49.

Content

The Lower member is characterized by stacking of more than 40 coarsening-upward, shale-sandstone units. Individual units range in thickness from 15 to 45 m in the lower half of the unit, becoming thinner toward the top where they range from 5 to 15 m. The sandstone component in each unit accounts for 30 to 50 per cent of this thickness. Despite the presence of coarsening-upward units in all three sandstone map units, any further resemblance between the Lower member of the Iceberg Bay Formation and the Expedition Formation is superficial: individual sandstone beds are thinner, the sandstones are slightly to moderately calcareous, and they rarely contain large-scale crossbedding. More commonly, bed forms include parallel laminae, low-angle planar crossbeds, rare hummocky cross-strata and a variety of ripple structures. In addition, the trace fossil assemblage is dominated by horizontal feeding and crawling burrows, whereas vertical burrow systems such as *Skolithos* are less common. All of these features serve to distinguish this unit from the Expedition Formation.

Shales in the lower part of each coarsening-upward sequence are medium to dark grey, have blocky fracture and locally are calcareous. Fine grained, laminated sandstones contain comminuted plant debris, and commonly are calcareous in the upper beds of each cycle. Less than 10 per cent of the coarsening-upward sequences are capped by thin coal seams or shaly coals.

Correlative strata in the Lower member at the west end of Kanguk Peninsula exhibit distinct thinning- and fining-upward trends. Because exposure is relatively poor, only about 15 coarsening-upward sequences were identified in Section 27. The thickness of individual cycles is more variable, ranging from 2 to 40 m, and the sandstone component accounts for as little as 10 per cent of each vertical sequence. Sedimentary structures are similar to those encountered in sections farther east. However, coal seams are rare.

Age

The age of the Lower member of the Iceberg Bay Formation is Late Paleocene, based on palynological determinations by D.J. McIntyre (Appendix 3).

Iceberg Bay Formation – Coal member

Thickness

The maximum preserved thickness of the Coal member of the Iceberg Bay Formation at the type section is 1060 m. The Coal Member was observed in three other areas on Kanguk Peninsula: at Section RAK 27, where the basal 461 m are exposed; along the southwest coast of Expedition Fiord where only a few tens of metres are preserved; and Section RAK 34 where the lower 30 m is found. Based on structural considerations, the unit is also inferred to be present in a broad syncline along north Expedition Fiord.

Contacts

The top of the Coal member, and therefore the top of the Eureka Sound Group, is eroded. At Section RAK 25, the lower contact is defined at the base of a thick, bluff-forming sandstone above which numerous fining-upward sandstone-coal sequences occur. Elsewhere, the contact is placed at the transition from coarsening-upward sequences of the upper sandstone member, to fining-upward sequences. The different contact relationships at these localities reflect facies variations at the base of the Coal member and, on the basis of field mapping, these occur at a similar stratigraphic level. Everywhere, the lower contact appears conformable.

Type Section

The type section of the Coal member is at the same location (given above) as the type section of the Lower member.

Content

The appearance of thick sandstone and fining-upward units at the base of the Coal member heralds important lithological changes in the upper part of the Eureka Sound Group in this area. Basal strata in the Coal member contain abundant trough crossbeds, some with basal pebble lags and wood fragments, and thus are quite distinct from sandstones lower in the formation. A large number of fining-upward units make up the remainder of the Coal member, and these range in thickness from 1 to 10 m and invariably are capped by coal seams, locally up to 6 m thick. In the upper half of the member, sandstone induration decreases, such that, locally, the most resistant strata are the coal seams. At least 45 seams of variable thickness occur at the type section. An additional lithotype, apparently unique to the Coal member, is represented by thin beds and lenses of nodular and highly calcareous ironstone that occur at the top of the fining-upward units and usually are associated with coal.

Bioturbation is drastically reduced in this member compared to subjacent units and, when present, consists mainly of simple *Planolites* trails. A distinct coarsening-upward sequence, 15 m thick, is present in the uppermost 100 m of exposed section at RAK 25; the sequence contains bed forms and bioturbation that are very similar to those encountered in the Lower member of the Iceberg Bay Formation.

Age

The age of the Coal member is Late Paleocene to Middle Eocene, based on palynological determinations by D.J. McIntyre (Appendix 3).

Time-rock stratigraphy

Correlation of map units in the Strand Fiord area is shown schematically in Figure 5. Strata of the Eureka Sound Group represent a major phase of delta construction in the Sverdrup Basin, and at Strand Fiord this has occurred in two distinct episodes.

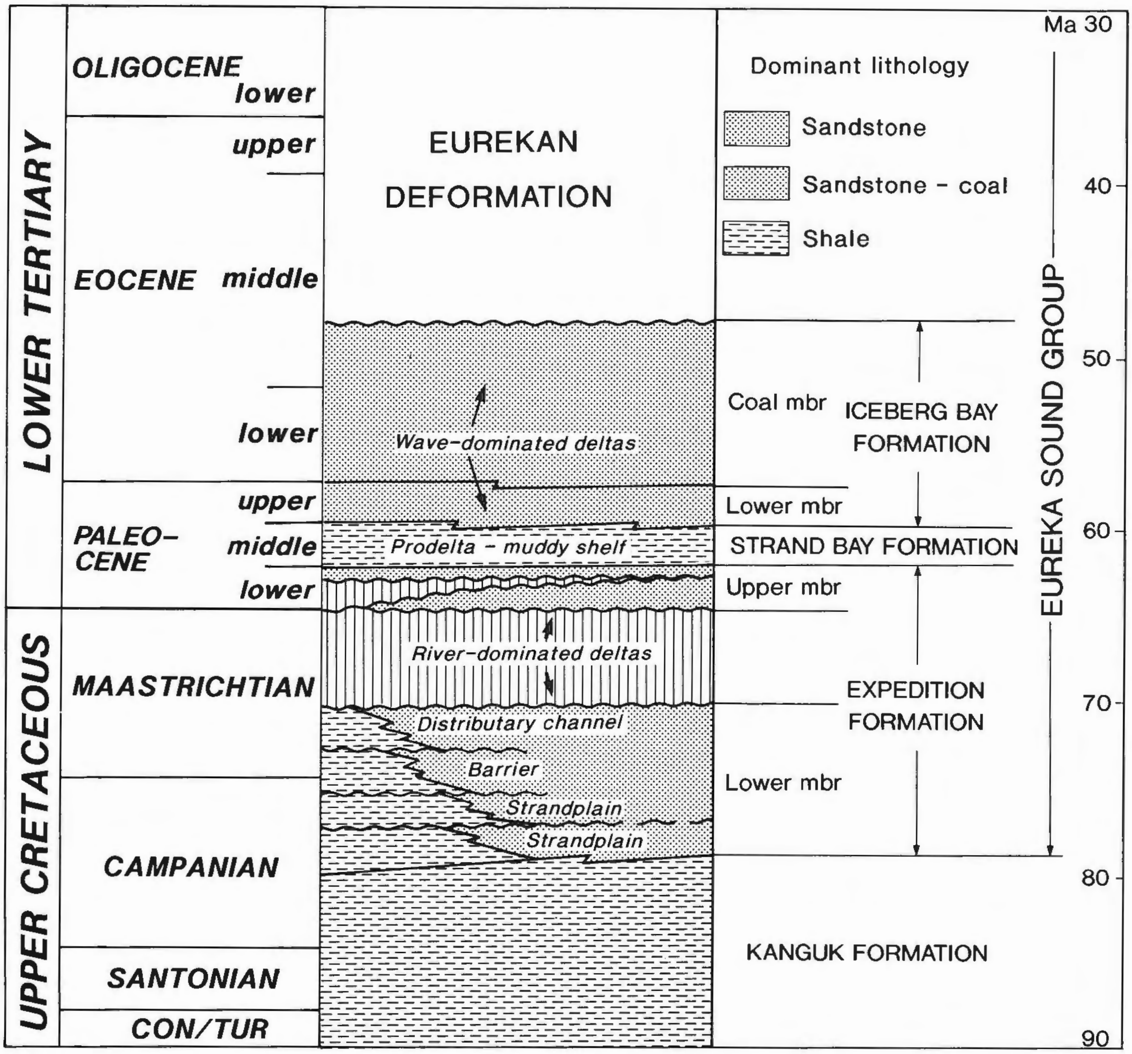


Figure 5. Time stratigraphic relationships within the Kanguk Formation/Eureka Sound Group sucession. The biostratigraphic constraints are summarized in sections dealing with lithostratigraphy, and in Appendices 2 and 3. The hiatus between the Upper and Lower members of the Expedition Formation corresponds to that observed in many other parts of the basin wherein part or all of the Maastrichtian stratigraphic record was removed by erosion. The time scale is that used for the Decade of North American Geology (Palmer, 1983).

A major unconformity, represented by the eroded top of the Eureka Sound Group, truncates strata folded during the Eurekan Orogeny. Sands and gravels of the upper Tertiary Beaufort Formation do not occur at Strand Fiord. Remnants of these deposits are preserved at a few localities on Ellesmere Island, where they overlie Eureka Sound strata with angular unconformity (e.g., south Strathcona Fiord; Ricketts, 1985).

An unconformity may be present near the top of the Expedition Formation, between levels 616.8 m and 707.1 m in Section RAK 25 (Fig. 49; Appendix 3); there is a gap in sampling here of about 90 m, because of poor exposure. This conclusion is based on the knowledge that a major unconformity spanning the upper Maastrichtian, and perhaps lowest Paleocene, exists over much of the basin (e.g., Ricketts, 1989). Further, as discussed below, the upper 30 m or so of Expedition strata probably represent the transgressive component of a major depositional sequence (that also includes the Strand Bay Formation); a disconformity likely occurs below these transgressive strata. An earlier report of a major unconformity at the Expedition/Strand Formation contact (Ricketts, 1986), is now discounted.

Three additional hiatuses of smaller magnitude can be inferred from sedimentological and stratigraphic aspects of these rocks. However, there is no direct paleontological evidence of extended lacunas. A disconformity between the volcanic Strand Fiord Formation and the Kanguk Formation is indicated at the west end of Strand Fiord, because relatively deep water shale overlies volcanic flows interpreted as subaerial in origin (Ricketts et al., 1985). This hiatus decreases eastward, where the Kanguk Formation overlies marine shale and siltstone of the Bastion Ridge Formation with apparent conformity.

Members of the Expedition Formation originated as prograding delta sand bodies that were separated by a brief transgression, probably represented by the basal shales of the Upper member. A nondepositional hiatus is inferred where a relative rise in sea level resulted in a rise in the base level of distributary channels, producing a subsequent decrease in the rate of sedimentation.

SEDIMENTOLOGY

Expedition Formation – Lower member

The Lower member of the Expedition Formation contains three principal sedimentary facies, the lower 60 per cent of the sequence exclusively comprising coarsening-upward facies, while the remainder (about 90 m thickness) consists of two very different facies types (Table 1).

Coarsening-upward shale-sandstone facies – Type 1

Two major coarsening-upward units (designated A and B) have been identified at Kanguk River (Section RAK 31), each consisting of several subsidiary coarsening-upward cycles (Figs. 6, 7). The lower part of Unit A (67 m thick) is characterized by brown weathering, texturally immature, fine grained sandstone that changes from Kanguk strata over an interval of 10 to 20 m. Bedding is obscured because of intense bioturbation by *Chondrites* and a few *Terebellina*. Two smaller-scale cycles occur in the upper part of A; these show a tendency toward cleaner, better sorted sandstones. Each of these cycles coarsens upward from a shale or siltstone base, and sandstone interbeds gradually become thicker. Sandstone beds, up to 50 cm thick and containing abundant *Chondrites* and subordinate trace fossils such as *Terebellina, Planolites* and *Teichichnus*, alternate with cleaner sandstones that contain parallel laminae, current ripples, and low-angle planar crossbeds. Fine carbonaceous debris is common. The upper 15 m of Unit A are relatively free of bioturbation and, in addition to the above bedforms, also contain some small-scale, planar tabular crossbeds. These sandstones are moderately indurated and, typically have a platy weathering habit, whereas bioturbated and/or rippled lithotypes tend to have rubbly weathered surfaces. Resistant, calcareous ironstone ribs, up to 40 cm thick, are common in this part of the Lower member, usually within the shales or at sandstone-shale contacts, and contain scattered *Inoceramus* fossils.

Unit B is 100 m thick and exhibits lithological trends similar to its subjacent counterpart (Fig. 6). The basal 30 m contain dark grey, blocky weathering shale that becomes more silty in its upper part, with a few thin sandstone beds (5 to 20 cm) and resistant *Inoceramus*-bearing ironstones. Shells up to 25 cm across occur. This is the highest stratigraphic level at which *Inoceramus* has been found (this also is the shale that was included in the uppermost Kanguk by Souther, 1963). The remainder of Unit B consists of at least eight subsidiary, coarsening-upward cycles, 5 to 15 m thick, each of which shows the following trends: thin bedded (a few centimetres), burrowed and rippled, fine grained sandstone at the

TABLE 1

A summary of the principal sedimentary facies in the Eureka Sound Group, western Axel Heiberg Island

Coal member, Iceberg Bay Fm.	Thick, trough crossbedded, sandstone facies Fining-upward sandstone-coal facies Coarsening- then fining-upward facies
Lower member, Iceberg Bay Fm.	Coarsening-upward shale-sandstone facies – Type 2
Strand Bay Fm.	Shale facies Sheet sandstone facies
Lower and Upper members, Expedition Fm.	Coarsening-upward shale-sandstone facies – Type 1 Coarsening- then fining-upward facies Thick bedded sandstone facies

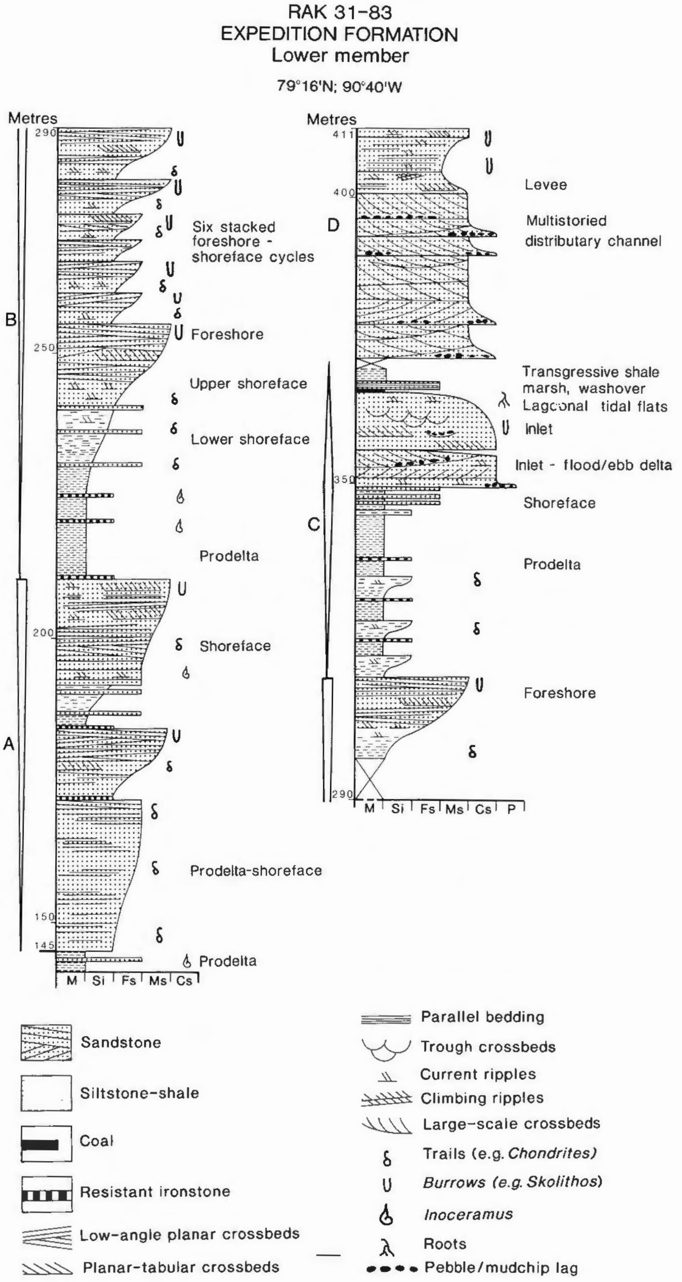


Figure 6. Schematic representation of Section RAK 31–83 along Kanguk River, showing four major depositional units (A to D) and their inferred paleoenvironments. Prograding strandplain/delta lobes (A and B), barrier/lagoon (C), and distributary channel (D) facies are represented. Coarsening- and fining-upward trends are indicated by arrows. Thickness is in metres relative to the base of the Kanguk Formation. The top of the Lower member occurs at 411 m. Grain sizes follow the Wentworth scale: M = mud; Si = silt; Fs, Ms, Cs = fine, medium and coarse sand respectively; P = pebble conglomerate.

base—the ichnogenus *Chondrites* predominates but *Planolites* and *Meunsteria* also occur; followed by a gradual coarsening-upward to medium grained sandstone that is better sorted, sparsely bioturbated, and contains bedforms such as low-angle planar crossbeds, small planar crossbeds and ripples. These structures are best developed in the upper part of each sequence. Even though accurate crossbed measurements were not possible, planar foresets dip both west and east. In general the sandstones, classified as quartz arenites and lithic quartz-arenites, are texturally more mature than those of Unit A.

Lateral changes in this facies are evident in sections 17 km (RAK 25) and 39 km (RAK 27) to the west. Although the lower part of the member is not well exposed at Section RAK 25, general coarsening-upward trends are apparent, with the proportion of sand increasing to about 60 per cent. However, the sandstones are finer grained and less mature, and in most outcrops exhibit so much bioturbation that primary sedimentary structures have been obliterated. A continuation of this trend to finer grained strata is seen at Section RAK 27 (Fig. 8). Here, pyritic shale, siltstone and fine grained sandstone occur as tabular beds a few centimetres thick, and in thin, coarsening-upward packages up to one metre thick. The sandstone content increases to 60 to 70 per cent in the upper part of this unit. Bioturbation, principally by *Chondrites*, imparts a dirty appearance to these beds and few ripples and parallel laminae are preserved. Several of the metre-thick coarsening-upward cycles are capped by indurated, light grey, argillaceous limestone beds, 20 to 40 cm thick. The limestones contain molluscs, in particular *Inoceramus* (*Sphenoceramus*) *lundbreckensis* which is also found in Units A and B at Section RAK 31.

Coarsening- then fining-upward facies

A major change in facies organization occurs above the coarsening-upward sandstones of Unit B in Sections 25 and 31. Informally designated Unit C, the facies contains mostly sandstone in beds that coarsen and thicken upward, and then follow a fining-upward trend. The coarsening-upward component is similar to Units A and B, and consists of interbedded, fine grained sandstone and shale. Ripples and low-angle planar crossbeds are common. Grain size and textural maturity increase rapidly upward. The middle part of the unit is coarse grained, and the interval between 347 and 355 m, shown on Figure 6, contains beds 50 to 200 cm thick. In contrast to subjacent strata, planar crossbed sets reach 80 cm in thickness and commonly are capped by ripples (Fig. 9). Individual sets frequently contain reactivation surfaces.

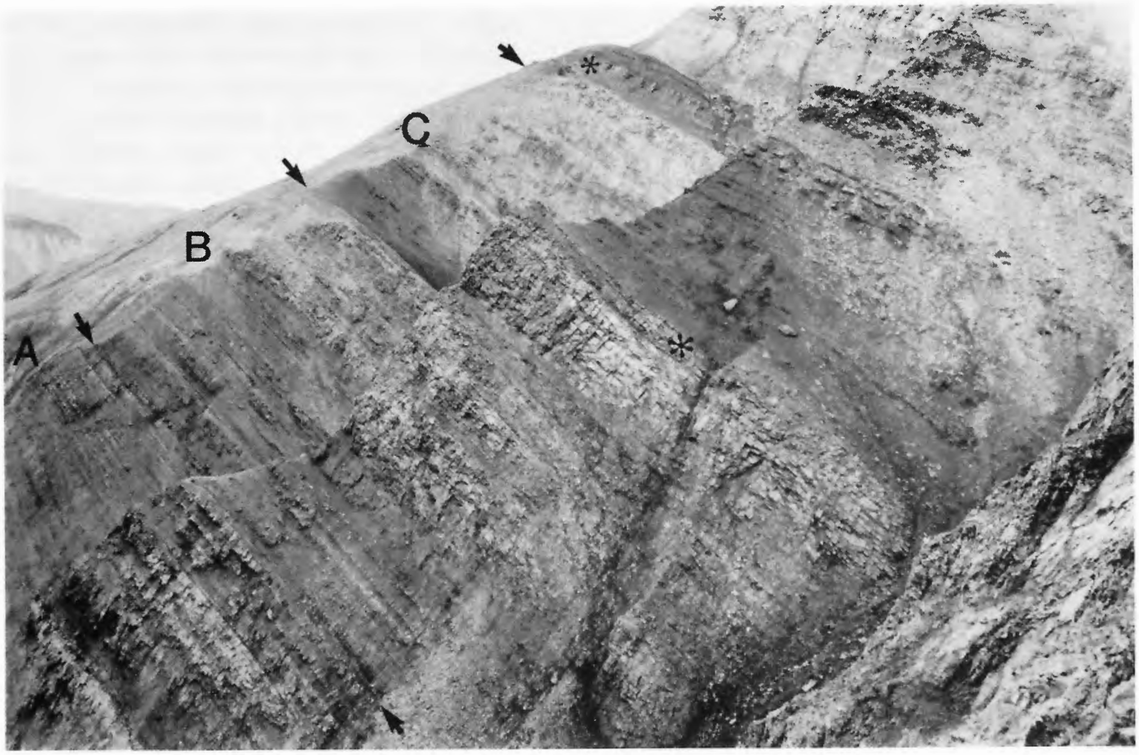


Figure 7. A view of coarsening-upward cycles in the lower part of the Lower member of the Expedition Formation at Section RAK 31 – 83, illustrating the upper part of Unit A and Units B and C (see Figure 6). Unit contacts are marked by arrows. Each unit consists of numerous small-scale cycles. Sandstones at the top of each unit are capped by a few centimetres of muddy sandstone (asterisks) that represent the transgressive component of the overlying (regressive) unit. Some of the transgressive sandstones have a greenish hue. Shale in the lower portion of Unit B (211 m, Fig. 6) contains ***Inoceramus*** *and was formerly included in the Kanguk Formation by Souther (1963). Unit B is 100 m thick. GSC photo. 2045 – 299.*

Foresets dip west at 10° to 15° and locally are veneered by ripples that appear to have migrated up foreset-dip. Trough crossbed sets, up to 100 cm thick, cut down into the planar sets. Some of the rippled and laminated sandstones contain abundant, fine, plant debris.

The fining-upward component of Unit C is 10 to 12 m thick. Crossbedded sandstones at the base contain numerous escape burrows where sands were deposited over a fine, bioturbated, carbonaceous substrate (Fig. 10). Beds thin upward from about 60 cm to 5-10 cm. Thin, shaly interbeds are highly carbonaceous. Trough and planar crossbeds also decrease in size and, in the upper few metres, ripples predominate. The fining-upward unit is capped by a shaly coal bed 5 to 20 cm thick, with abundant root structures that penetrate as much as 1.5 m into the underlying sandstone (Fig. 11). Overlying the coal is a 2 m thick bed of highly carbonaceous, medium to fine grained sandstone that contains parallel laminae and rare rippled crossbeds and shale veneers. This unit is in turn overlain by a dark grey shale that forms the top of Unit C.

The upper part of Unit C is well exposed at Section 25 (Fig. 8). However, the fining-upward aspect is less pronounced than at Section 31. Intervals of indurated, medium grained, lithic quartz arenite (2-5 m thick) alternate with finer grained sandstones. Individual beds contain trough and planar crossbeds with ripple and ripple-drift structures common at their upper contacts. Lags of mudchips and wood fragments are common and in some cases are thick enough (30 cm) to form discrete beds. *Skolithos* burrows are common at the top of the unit. A thin carbonaceous shale is preserved above the sandstones here, and probably is laterally equivalent to the shale that overlies the coal at Section RAK 31.

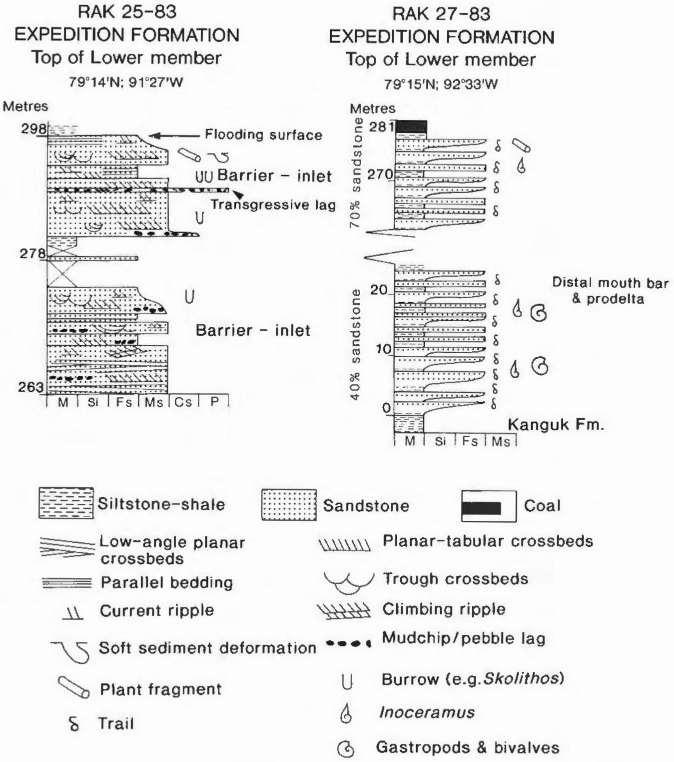


Figure 8. *Schematic representation of the Lower member of the Expedition Formation in Sections RAK 25–83 and RAK 27–83, illustrating stratigraphic relationships and facies interpretations. Only the upper part of RAK 25–83 is well exposed and the portion illustrated is approximately equivalent to Units C and D at RAK 31–83 (Fig. 6). Coarsening-upward cycles at Section RAK 27–83 are finer grained and much thinner than their counterparts at Sections RAK 25–83 and RAK 31–83.* ***Inoceramus*** *and other molluscs are locally common. Note that at Section RAK 25–83 the Lower member is overlain by the Upper member of the Expedition Formation, whereas at Section RAK 27–83 the Lower member is overlain by the Strand Bay Formation.*

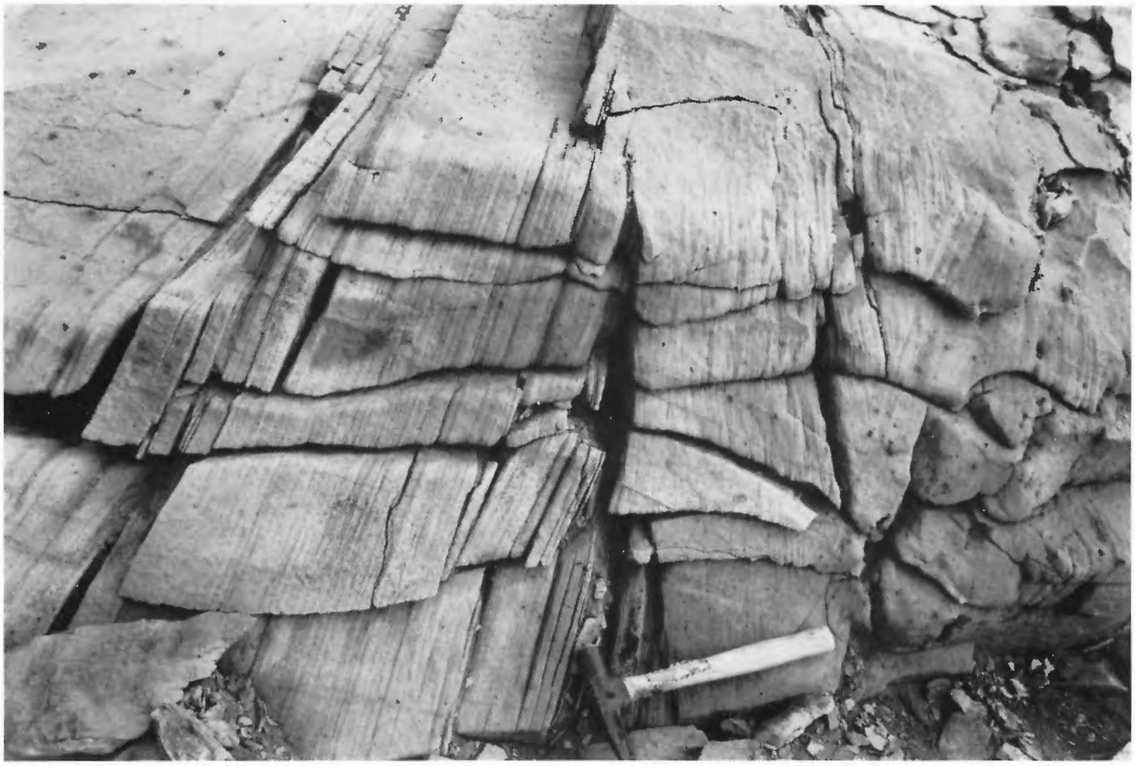


Figure 9. *Low-angle planar crossbeds are capped by current ripples (above hammer handle) in steeply dipping beds of Unit C, Lower member, Expedition Formation. Heavy minerals concentrated in some of the darker sandstone laminae are similar to concentrations developed in many modern upper shoreface and beach settings. Top is to the right. The hammer is 33 cm long. Section RAK 31–83. GSC photo. 2045–300.*

Figure 10. Escape burrows (a), originating from the bases of sandstone beds, and ***Skolithos*** *(b), originating from the tops of beds are common in the fining-upward component in Unit C, Lower member, Expedition Formation. The preponderance of these opportunistic trace fossils is consistent with the high-energy shoreface/strandplain setting wherein sands were continually shifting. Section RAK 31–83. The lens cap is 6 cm in diameter. GSC photo. 2045–154.*

Figure 11. Fining- and thinning-upward sandstone beds in the upper part of Unit C; Lower member of the Expedition Formation at Section RAK 31–83. The recessive interval at the top contains a thin shaly coal, underlain by root structures, and carbonaceous shale. The hammer is 33 cm long. GSC photo 2045–303.

Thick bedded sandstone facies

Massive, cliff forming sandstones (Unit D) constitute the highest stratigraphic interval of the Lower member (Fig. 6). As a distinct facies the unit is characterized by thick, clean, well sorted sandstone and only in the upper few metres is there an indication of fining-upward trends. At Kanguk River, the massive sandstone component is 30 m thick and contains very large crossbeds up to 3 m (Fig. 12). Individual sets can be traced laterally for at least 80 m. Groups of crossbeds occur in intervals up to 12 m thick, and successive intervals are separated by thin lags containing wood and scattered pebbles of quartz, chert and rare granite. Most of the crossbeds have flat, subhorizontal bounding surfaces and most likely have planar tabular geometry, although a few thinner sets show a distinct trough character and cut into the planar types. Crossbed foresets appear to dip toward the west and east at 8° to 10° (the nature of the exposure prevented accurate measurement of azimuths).

Capping this massive unit is a 4 m thick fining-upward sandstone with a different set of sedimentary structures. The lower, medium grained portion contains parallel laminae and low-angle planar crossbedding, whereas ripples and climbing ripples are more common at the top. These beds are gradational into fine grained, thin bedded strata at the top of Unit D. Beds increase in thickness from 20 cm to 50 cm, with a concomitant increase in crossbed size from ripple dominated to planar and low-angle planar bedforms in the upper metre. *Skolithos* burrows are common.

Correlative strata to the west (Section 25) are thinner but possess a similar succession of structures to strata at Kanguk River (Fig. 8). Sandstone at the base is in abrupt, locally erosional contact with shale of Unit C, and contains planar crossbed sets up to 65 cm thick. Mudchip lags are common, occasionally concentrated in pockets several centimetres thick. The tops of some crossbed sets are burrowed by *Skolithos*. Set thickness decreases upward, and in the upper few metres of fining-upward sandstone, ripples predominate. One bed shows abundant evidence of soft sediment deformation in the form of oversteepened crossbeds, ball-and-pillow, and dish structures.

Interpretation of facies

A number of statements can be made regarding general stratigraphic trends and lateral changes in the three facies:

1. There is an overall upward increase in the grain size of the sandstones from fine, to medium and coarse grained (Units A to D), together with an increase in textural maturity.
2. Over this stratigraphic interval there is a change in types of sedimentary structures, from those that formed under low-energy conditions at the base, to higher energy bedforms. A similar change occurs in the trace fossil assemblage, from *Chrondrites* dominated in Units A and B, to *Skolithos* dominated in the sandier lithotypes.
3. A marine macrofauna is preserved in the lower half of the Lower member. However, the intensity and style of bioturbation indicate that marine conditions probably prevailed throughout, with more brackish conditions developing locally.
4. Mapping of the Lower member along Kanguk Peninsula demonstrates general fining and thinning trends toward the west.

Figure 12. Massive weathering, thick sandstone facies of Unit D; Lower member of the Expedition Formation at Section RAK 31 – 83. Bedding dips to the right (east) at about 60°. The contact between Units C and D is indicated by a dashed line. Contacts between stacked, large-scale crossbed sets are indicated by arrows. Geologist for scale. GSC photo. 2045 – 305.

Coarsening- and thickening-upward facies in Units A and B indicate a transition from suspension dominated to bed load dominated deposition. Sharp-based sandstone interbeds in the lower shales, some containing rippled and graded bedding, represent sudden influxes of fine, silty sand into an otherwise tranquil environment, and have some of the characteristics of "distal" turbidites. These are commonly documented in muddy shelf-to-shoreface successions (e.g., Hamblin and Walker, 1979; Leckie and Walker, 1982). There is no evidence of reworking, and deposition likely occurred below storm wave-base.

Increasing sandstone content in each cycle indicates proximity to the shoreface. The lack of preserved hummocky crossbeds at this level may be a result of the intense bioturbation that pervades these strata. Increased bed load transport and movement of sand during deposition of the upper portion of each cycle resulted in a decrease in faunal activity. The coarsening-upward profiles observed here are similar to expected vertical successions that develop within a prograding shoreface/foreshore environment. Shale at the base of each unit was deposited in an offshore setting, below wave base. Shoreward, fine sands in the lower shoreface were intensely bioturbated whereas sands higher on the shoreface were subjected to stronger wave and/or current action. Vertical trends like these have been well documented in modern shoreface settings (Clifton et al., 1971; Kumar and Sanders, 1976). Parallel laminated and low-angle planar crossbedded sandstones are characteristic of the upper shoreface (Howard and Reineck, 1981), and have been observed to form in two different zones: near the outer part of the surf zone, and in the swash zone on the lower foreshore (Clifton et al., 1971). In both cases, upper flow regime plane bed conditions exist. Further evidence of the transition to a foreshore (beach) setting at the tops of some sandstone beds is reflected by planar crossbeds with foresets that dip up to 20°(?), apparently with bimodal azimuths; this type of bedding is known to form in landward-migrating ridge-runnel systems. The overall stratigraphic sequence and predominance of laminated sandstones in the *coarsening-upward facies* are, therefore, diagnostic of a prograding shoreface on a wave dominated coast.

In the *coarsening- then fining-upward facies* (Unit C), the lower coarsening-upward component is interpreted as being similar to the underlying facies. Interbedded sandstone and shale contain an increasing proportion of sedimentary structures that are indicative of shoreface deposition. However, a different style of bedload transport is preserved in the middle part of the sequence, where large planar crossbeds indicate megaripple migration, and local scouring is represented by trough crossbeds and pebble lags. The size and association of the bedforms suggest high energy, lower flow regime conditions and possibly confined (channelized) flow. Subsequent fining-upward trends and concomitant decrease in bedform size denote waning currents. Eventual emergence and growth of plants are indicated by the thin, coaly shale capping the fining-upward component. The complete facies is interpreted as a barrier bar/tidal inlet that, from lower shoreface to lagoon, is represented by a vertical thickness of about 25 m. The association of bedforms in the middle part of the facies resembles a modern tidal inlet succession described by Kumar and Sanders (1974), and Hennessey and Zarillo (1987). The megaripples could have formed on a flood or ebb ramp, or channel floor. Large-scale trough crossbeds, on the other hand, represent migrating bedforms in the deep part of the inlet channel. Reactivation surfaces provide some evidence of tidal current asymmetry. Parallel laminated and low-angle planar crossbeds higher in the unit correspond to spit beaches that prograded over the channel as the inlet migrated along the length of the barrier. Rippled and carbonaceous sandstone near the top of the unit indicates much lower depositional energies than those encountered in the inlet or seaward side of the barrier, and is more likely to have formed on back-barrier tidal flats. Here too, marsh peats were established. Laminated and rippled carbonaceous sandstone above the coal is interpreted as the product of storm washover events that encroached into the lagoon; highly carbonaceous shale veneers throughout the sandstone body provide some evidence of interfingering of lagoonal muds between storm events. Overall, the succession here of shoreface/channel ramp/back barrier/washover deposits is similar to facies successions predicted in some modern barrier-inlet settings (Kraft and John, 1979; Hennessey and Zarillo, 1987; Hayes, 1976). Measured sections through this facies at Kanguk River and farther west (RAK 25), contain about 50 per cent inlet channel deposits, with shoreface and back barrier strata accounting for about 25 per cent each.

Ninety per cent of the *thick bedded sandstone facies* consists of large-scale crossbeds that represent a complex amalgamation of migrating sand waves or megaripples. Given the overall thickness of the sandstone body (30 m) and continuity of bedforms within it, it is reasonable to infer that currents were consistently strong; whether they were unidirectional or bidirectional is not clear. Generation of these features probably occurred as a result of confined (channelized) flow, although channels were probably larger than the tidal inlets already described. The writer interprets the facies as a distributary channel or mouth bar deposit that accumulated at the position of transition between channel and marine processes. The facies is capped by a 4 m thick, fining-upward sequence containing sedimentary structures indicative of much lower energy flow conditions—the transition from high to low energy flow is actually quite abrupt. This fact, together with the vertical facies association, suggests that channel migration occurred and the succession subsequently was overlain by levee deposits. The abundance of climbing ripples attests to rapid sedimentation of fine sand from suspension, a feature often encountered in fluvial and delta distributary channel levees.

Summary of Lower member sedimentation

The three facies composing the Lower member are dominated by sandstone, are marine in character, and each records a period of coastal progradation. In the case of the *thick bedded sandstone facies* a period of channel aggradation is identified. Together, the facies are considered as representing a stage of delta growth over a period from approximately middle or late Campanian to possibly early Maastrichtian. Interpretations of individual facies indicate that wave dominated conditions prevailed. Although detailed measurements of paleocurrent azimuths are not available for the succession, lateral grain size and bed thickness trends suggest that the paleoslope dipped approximately to the west.

Lower member strata have been subdivided into units, labelled A to D, based on major coarsening-upward and thickness trends (Fig. 6). Contacts between units are at abrupt lithological changes from sandstone to thick shale and, in terms of sedimentation, represent major lateral facies shifts and concomitant changes in the loci of sand supply. Therefore, contacts can be viewed as hiatal surfaces—namely, surfaces of negligible or very slow rates of sedimentation: these qualify as surfaces of maximum flooding or transgression. This inference is reinforced by the presence of (resistant) calcareous ironstone beds at or near the contacts, which indicate a very low influx of clastic detritus (condensed section). Units A to D are shown schematically in Figure 13 (with the relevant measured sections located). Each unit is shown as a prograding clastic wedge that is similar in scale to a 'depositional event' of Frazier (1974). The hiatal surfaces tend to converge both landward and toward the basin. The corresponding paleoenvironments and paleogeography for each unit are illustrated in Figure 14, relative to the line of Section RAK 31 and its equivalent vertical succession. Thus, the transition from Units A to B records the lateral migration of a distributary channel, such that, in B, a greater thickness of strandplain deposits are preserved (i.e., upper shoreface and foreshore or beach ridge deposits). In Unit C, the main distributary channel migrated far enough for waves to rework the mouth bar and strandplain sands into barrier bars that encroached upon the older strandplain as subsidence continued. Possible modern analogues are seen in the Chandeleur Island barriers of the Mississippi Delta that are reworking an abandoned lobe, although here the most likely preserved remnant of these bars in the rock record would be a thin, transgressive sand sheet that lacked most of the original bar features (Coleman, 1981). A more fitting analogue is found along the Texas coast, where two rivers are presently building deltas with relatively broad strandplains, namely the Brazos River and Rio Grande (Shepard and Wanless, 1971). Both deltas supply sand to some of the world's longest barrier islands.

The sudden appearance of the thick channel sandstones of Unit D indicates an important switching or avulsion event of the delta distributary channel. The preserved section, as shown in Figures 6 and 13, contains mouth bar and channel sands that in places have eroded the underlying lagoonal mudrocks. That some lateral migration of the channel took place here is evident from the presence of stacked channel-fill units, the overlying levee deposits, and the generally tabular nature of the sequence.

Expedition Formation – Upper member

The Upper member of the Expedition Formation, of which only the lower 140 m are exposed along Kanguk River, contains the same facies types as Map Unit 1. Thus, detailed description and interpretation of the sedimentology, as illustrated in Figure 15, can also be referred to previous discussions. Strata belonging to the *coarsening-upward facies* and *thick bedded sandstone facies* are shown in Figure 16. The lower coarsening-upward unit is 40 m thick and contains eight (stacked) smaller-scale shale-sandstone cycles (3-8 m thick), in which wave generated structures predominate (parallel laminae, low-angle planar, some tabular planar and ripple crossbeds). Bioturbation in the clean sandstones is dominated by *Skolithos* burrows; counts on some bedding surfaces indicate between 3000 and 5000 burrows per square metre. Like its counterpart in the Lower member, the facies is interpreted as a succession of wave-dominated, prograding shorefaces and foreshores within a general delta strandplain setting.

Deposition on the strandplain was abruptly terminated by the *thick bedded sandstone facies* (Fig. 15). The following characteristics are indicative of a channel that was filled and subsequently abandoned with similar abruptness: abrupt, locally eroded base, also marked by thin lags of mudchips and wood fragments; large planar crossbeds (up to 1.2 m thick) and trough crossbeds of similar dimensions; a thin, rippled interval at the top indicating a rapid cut-off in sediment transport; and a sharp upper boundary. Following abandonment of the channel, deeper water offshore conditions resumed, with further development of prograding shelf or prodelta, and shoreface sequences (Fig. 15).

A second thick sandstone, or channel facies, occurs at the top of the section illustrated in Figure 16, but exhibits some different features from the preceding examples. Over its 10 m thickness, the sandstone changes from medium to fine grained upward, and beds thin from about 50 cm to a few centimetres. Like previous examples, large planar and trough crossbeds occur in the lower beds; a 30 cm thick basal lag contains mostly indurated sandstone, chert, and argillite pebbles, and scattered clasts of granite and dacite—this is the only conglomerate bed observed in the Strand Fiord area. Upper beds contain smaller bedforms, carbonaceous partings and abundant *Skolithos*. This unit bears some resemblance to the upper part of the coarsening- then fining-upward facies of the Lower member (i.e., barrier-tidal inlet facies), except that it lacks the back barrier coal, rooted zone, and lagoonal muds. Therefore, the thick sandstone is interpreted as the fill of a channel that migrated laterally rather than one that was abandoned rapidly.

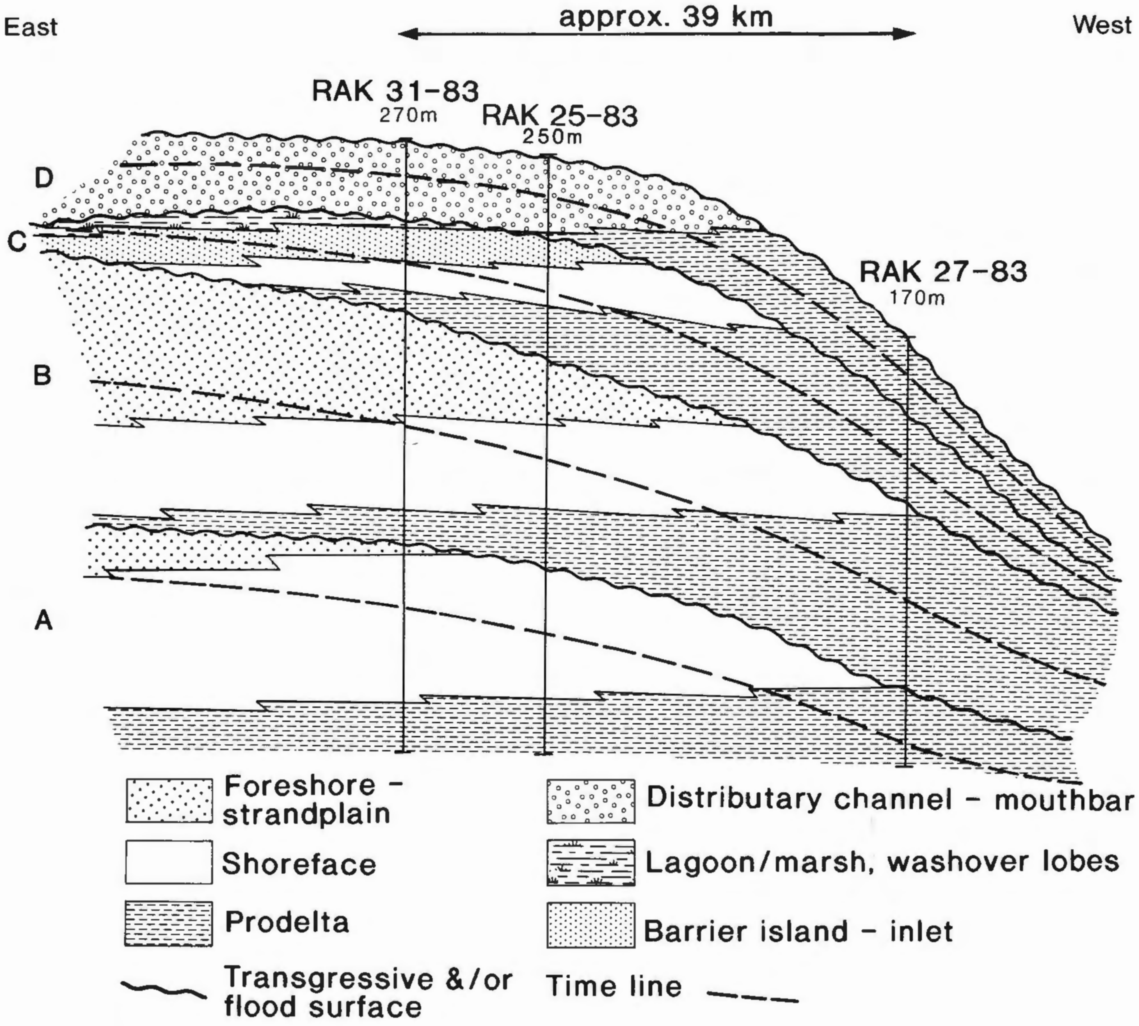


Figure 13. A schematic representation of facies relationships, hiatal surfaces, and time lines for Units A to D of the Lower member of the Expedition Formation. Each unit is comparable to a depositional event described by Frazier (1974), and is depicted as a west to southwest prograding delta lobe or barrier complex. The paleogeographic distance between Sections 31–83 and RAK 27–83 is about 45 km.

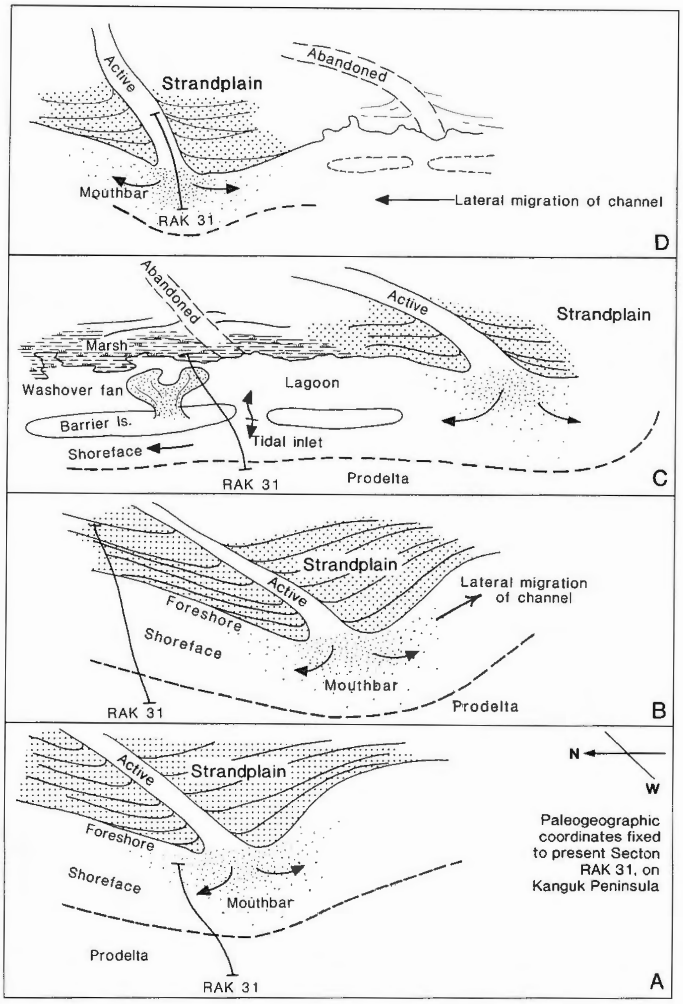


Figure 14. *An interpretation of paleogeography for Units A to D of the Lower member, Expedition Formation, relative to Section RAK 31. Progradation is approximately to the west. Units A and B represent different positions on a wave dominated delta/strandplain. Unit C represents the development of barrier islands on an abandoned segment of the delta. A resumption of distributary channel and mouthbar deposition, resulting from lateral migration or switching of the sediment conduit, is indicated in Unit D.*

Exposure of Upper member strata westward along Kanguk Peninsula (RAK 25) is discontinuous. However, the sandstone beds that do occur tend to be thinner, and the proportion of shaly intervals is greater, as indicated by talus and weathering profiles. Detailed mapping has shown that the unit is missing at the western end of Kanguk Peninsula.

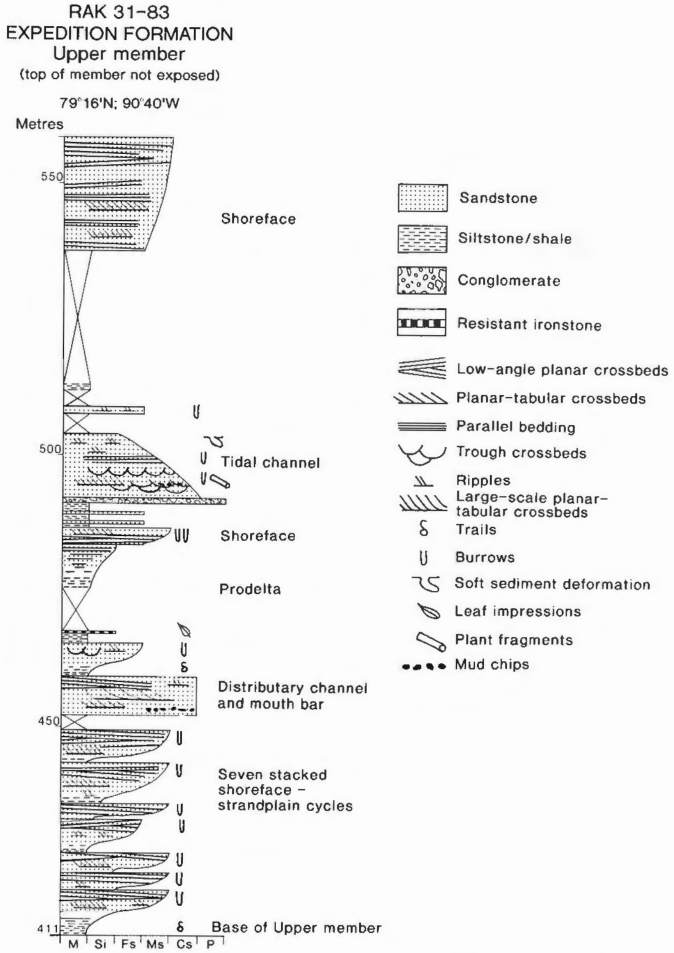


Figure 15. *Schematic representation of the Upper member of the Expedition Formation at Section RAK 31–83; only the lower 150 m are exposed. Depths (in metres) are measured from the base of the Kanguk Formation. The conglomerate bed at 492 m is the only example known from the Eureka Sound Group in the Strand Fiord area.*

In summary, the Upper member appears to be a westward fining and thinning clastic wedge. The succession of facies indicates that periods of shoreface and strandplain progradation within a wave dominated delta system were interrupted by major shifts in distributary channels and therefore sediment supply. Significant facies changes such as these probably took place in response to differential subsidence in the basin, resulting, from sediment loading, and also in response to sediment compaction within the delta. Distributary channels switched to parts of the delta that previously were inactive and had greater slope. Thus the facies changes are largely controlled by basin-wide and perhaps extra-basin processes (and correspond to the allocycles of

Figure 16. Panorama of the Upper member of the Expedition Formation at Section RAK 31 – 83 (Kanguk River, facing south), as portrayed schematically in Figure 15. The contact between the Lower and Upper members is marked by an arrow. The 7 m thick, tabular bedded, thick sandstone facies (at 455 m) corresponds to the resistant unit in the middle of the photograph, and the fining-upward unit (500 m) is at the top of the ridge—the conglomerate bed (cg) occurs at the base of this unit. GSC photo. 2045 – 309.

Beerbower, 1964). The smaller-scale cycles (a few metres thick) that occur in each of the facies are more likely to have been a response to local changes in sediment supply, variations in wave and current energy, and possibly even storm frequency (autocycles). These far more local variations are superimposed on the large-scale, delta-wide changes.

Strand Bay Formation

At Section RAK 25, the Strand Bay shale overlies sandstone of the Expedition Formation with abrupt contact (Fig. 17). The previously reported disconformity (Ricketts, 1986) has now been shown to be incorrect. At the west end of Kanguk Peninsula (RAK 27) the shale rests disconformably on a black, coaly shale at the top of the Lower member (Expedition Formation). The basal contact at most other localities is obscured by talus. The sedimentology of the Strand Bay Formation is fully described in terms of two major facies (Table 1).

Shale facies

Thick, dark to medium grey shale accounts for about 90 per cent of the formation. Detailed examination reveals a subtle colour banding in shades of grey, steel-blue and, rarely, pale yellow-brown. Different colour bands range in thickness from a few centimetres to one or two metres. On weathered surfaces the shale has a friable, blocky character. No bioturbation was observed except at the top of the unit near the contact with the Iceberg Bay Formation. In general, the shale facies possesses lithological characteristics similar to those of the older Cretaceous shales, such as the Lower Cretaceous Christopher Formation, but is quite distinct from the papery, sulphurous shale of the Kanguk Formation.

Figure 17. Panorama of the Strand Bay Formation at the type section (RAK 25 – 83), showing its contact with sandstone of the Upper member of the Expedition Formation (arrow). Basal strata of the Iceberg Bay Formation (Lower member) are located on the right, but the upper contact of the Strand Bay Formation is hidden from view. Resistant, tabular sandstone beds occur approximately 114 m above the base of the formation. At this location the Strand Bay Formation is 287 m thick. GSC photo. 2045 – 163.

Sheet sandstone facies

A number of thin, tabular sandstone beds occur about one third of the way through the shale unit; the beds are well exposed at the type section on Kanguk Peninsula and on the north side of Expedition Fiord. Four sandstone beds at Section RAK 25 are separated by intervals of dark grey and black carbonaceous shale comprising a total stratigraphic thickness of 31 m (Fig. 18) Individual beds range from 1.3 m to 10.2 m thick, have abrupt tops and bases, and a distinctive rectangular weathering profile. Basal contacts commonly have an erosional relief of 10 to 20 cm, and lags of coarse, pebbly sandstone and coalified wood fragments. The bulk of the sandstone, however, is compositionally and texturally supermature, displaying excellent sorting and well rounded quartz grains. Trough and planar crossbed sets abound, commonly as thick as 60 cm. Coalified fragments and impressions of wood also are common, some more than two metres in length (Fig. 19). Bioturbation is rare.

Sandstone beds in sections farther west tend to be thinner and fewer in number (Fig. 18). At Sections RAK 27 and 29, two beds, totalling 7 m in thickness, are separated by a thin coal seam (5 cm). Each bed contains a basal lag of pebbly sand and wood fragments, a lower sandstone interval containing parallel laminae and low-angle planar crossbeds, and a slightly finer upper interval that has trough crossbeds, ripples and abundant wood fragments. The upper sandstone bed is capped by a sulphurous-weathering coal almost one metre thick, accompanied by shallow-penetrating roots and some bioturbation. The two sandstone beds are almost pure white and standout in marked contrast to the dark grey shale.

Interpretation of facies

The thickness and uniformity of shale in this unit indicate prolonged relatively deep water conditions, and a low influx of clastic sediment. Interpretation of the shale unit as a prodelta deposit is reasonable given the coarsening- and thickening-upward trends in the upper few metres, and the conformable relationship with the overlying Iceberg Bay Formation. Thus, the bulk of the shale should be considered as part of a thick prograding delta wedge. Given the lateral extent of the shale unit, the initial transgression is thought to have been part of a basin-wide event.

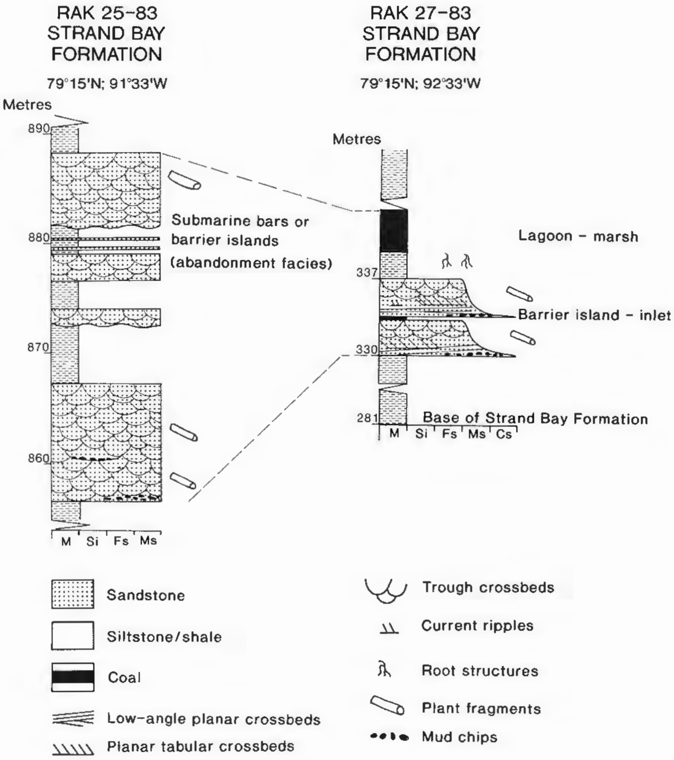


Figure 18. *Schematic stratigraphic columns of the sheet sandstone facies in the Strand Bay Formation at Sections RAK 25–83 and RAK 27–83, illustrating the predominance of trough-crossbedded facies, and the abrupt nature of upper and lower sandstone contacts. The stratigraphic intervals correspond to those shown in Figure 49.*

Figure 19. *Casts of large wood fragments in the trough-crossbedded sheet sandstone facies of the Strand Bay Formation at Section RAK 25–83. The hammer is 33 cm long. GSC photo. 2045–164.*

The abrupt contact at the base of the Strand Bay Formation corresponds to a surface of maximum transgression. A coarsening-upward sandstone unit at the top of the Expedition Formation contains a prominent pebble lag in erosional hollows that cut into the shoreface succession. This lag surface may represent the initial transgressive ravinement. There is no evidence of subaerial exposure here. However, given the position of the lag within the shoreface facies, its seems likely that the subaerial unconformity, which if present would signify a major sequence boundary, was removed during initial transgression.

The abrupt appearance of mature sandstones about midway through the thick shale unit presents something of a dilemma for paleoenvironmental interpretation. Sandstones of this type indicate relatively high-energy deposition. The nature of the upper and lower contacts of the sandstone beds demonstrates that the influx and subsequent starving of sand supply was sudden. There is no indication that any of the sandstone beds constitute part of a progradational sequence. The high sulphur coal and associated root zone at the west end of Kanguk Peninsula provide evidence of at least local subaerial exposure, probably in a lagoon or marsh environment. However, even there, such exposure must have been temporary because the sandstone-coal sequence is overlain by almost 100 m of shale.

Two types of depositional setting are entertained here: offshore sand bars on a marine shelf or platform, and transgressive wave-dominated barrier bars. Thin sandstone beds possessing a sheet geometry are the expected preserved remnants of barrier sands that accumulated upon an abandoned delta lobe. An excellent modern example is the Breton-Chandeleur Island chain, made up of reworked distributary mouthbar sand on the St. Bernard delta that was abandoned about 1800 years ago (Frazier, 1967). Alternatively, sand could have been reworked into shelf bars. Like the abandoned delta analogue, the supply of sand would decrease abruptly as relative sea level rose; supply of new sediment from rivers would also decrease because of rising base levels. Thus, sand transported around the drowned delta platform as sand bars would give rise to isolated sandstone bodies completely encased in shale (Fig. 20). Periodic emergence of barrier islands and associated lagoons could produce the kind of sequence seen at the western tip of Kanguk Peninsula, provided that subsequent drowning and burial by shale was rapid enough to ensure preservation. Even where evidence of exposure is lacking in the sandstone beds, proximity to land is implied by the abundance and size of wood fragments. Some comparison can be made to migrating shelf bar sandstones that are encased in the Upper Cretaceous Mancos Shale of Colorado, although none of the Mancos bars were ever emergent (Boyles and Scott, 1982).

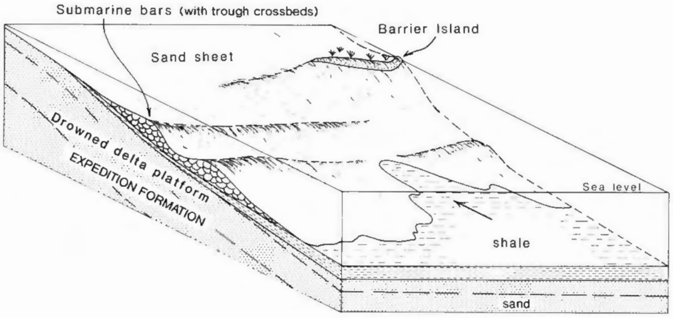


Figure 20. *An interpretation of the paleogeographic setting of the sheet sandstone facies – as submarine bars and ephemeral barrier islands developed on abandoned, local delta tongues later enveloped by the progradational shale of the Strand Bay Formation. The orientation of the paleoslope was to the west-southwest.*

Iceberg Bay Formation – Lower member

Coarsening-upward shale-sandstone facies – Type 2

Although almost 900 m thick at its reference section, the Lower member of the Iceberg Bay Formation can be adequately described in terms of a single facies (Table 1).

The coarsening-upward units are similar in scale to those of the Expedition Formation, but differ in their internal organization. In the lower half of the formation, units consisting of about 30 to 50 per cent sandstone range in thickness from 15 to 45 m (Fig. 21). The range of thickness decreases toward the top of the member to 5 to 15 m, but this is compensated by an increase in the number of sequences. A total of 42 major sequences was measured. Some of the thickest examples may be composite (Fig. 22).

Many of the internal features of each coarsening-upward unit persist throughout the entire unit. However, there are some important vertical and lateral facies changes. In all the units, basal shales are dark grey, moderately carbonaceous and blocky weathering. The sandstone component, along with bed thickness, increase upward. Sandstone beds usually are less than 50 cm thick, and rarely exceed 2 m (Figs. 23, 24). Beds are tabular, commonly have abrupt bases and graded tops, and are separated by shale veneers. Parallel laminae lined with carbonaceous debris predominate in the lower sandstones

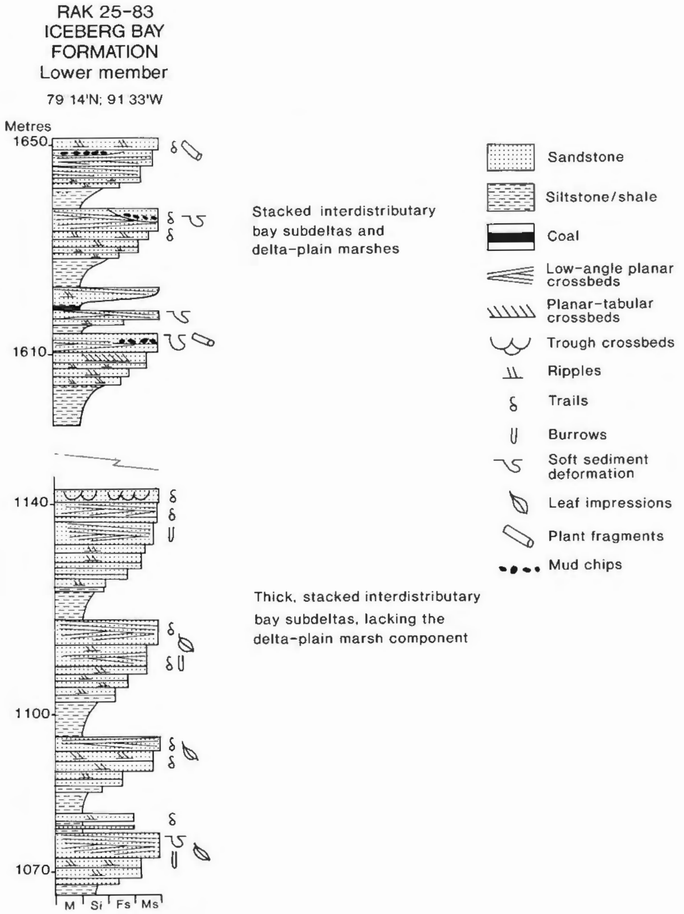


Figure 21. *Schematic representation of coarsening-upward facies at two stratigraphic levels of the Lower member of the Iceberg Bay Formation at Section RAK 25–83. Toward the top of the member the coarsening-upward units become thinner and some are capped by thin, shaly coal seams. Depths in metres correspond to intervals in Figure 49.*

of each sequence and weather to wafer-thin slabs; current and symmetrical wave ripples, and small planar crossbeds become more prominent at the top. Interference ripples occur locally (Fig. 25). Low-angle planar crossbeds are generally restricted to a few beds at the tops of sequences and, on exposed bedding, are associated with parting lineations (Fig. 26). Sole structures are particularly well developed in this facies, and consist of groove casts and a variety of flutes (Figs. 27, 28); flute casts consistently parallel the grooves and indicate sediment transport toward the west and southwest. Bioturbation is generally restricted to the upper, cleaner sandstones of the sequences, where the most common trace fossils are *Planolites, Paleophycus* and *Gyrochorte*; *Skolithos* occurs locally. The upper sandstones also tend to be slightly or moderately calcareous.

Toward the top of Section RAK 25, subtle but important changes in internal organization of coarsening-upward units are present, in concert with their decreasing thickness. The proportion of sandstone increases to 60 per cent of unit thickness. A few of the sequences are capped by thin coal or coaly shale beds and associated root zones. Low-angle planar crossbeds become more frequent and are associated with planar tabular and trough crossbeds up to 10 cm thick; thin mudchip lags occur locally. Soft sediment deformation also becomes more prominent in the crossbedded sandstones and usually takes the form of ball-and-pillow structures, although dish structures and oversteepened cross-strata also are found.

Lateral facies changes occur toward the western tip of Kanguk Peninsula. Coarsening-upward units show a distinct thinning trend, averaging 3 to 5 m and rarely exceeding 10 m (Figs. 29, 30). Individual sandstone beds also are very thin but retain their tabular geometry. The top of each unit is defined by a more massive weathering sandstone up to one metre thick, which contains parallel laminae, low-angle planar and tabular planar crossbeds. Measured ripple, flute, and groove cast azimuths indicate a spread of transport directions from southwest to north within individual coarsening-upward units. Unlike sequences farther east, the lower shaly components contain a few *Chondrites* burrows. Fine carbonaceous debris and wood fragments are common. Contacts between successive units are abrupt.

Strata exposed in a stream cut (RAK 34) about 9 km due north of the type section, exhibit quite different lateral facies changes from those seen at the end of Kanguk Peninsula. This stratigraphic interval is approximately equivalent to the top of this member at RAK 25 (Fig. 31). Coarsening-upward units exhibit characteristics similar to those of sequences elsewhere (Fig. 32): bedding is tabular and thickens to 80 cm; parallel laminae, current and symmetrical wave ripples abound; and planar crossbeds up to 30 cm thick occur at the top. Current ripples are straight crested. Detached load balls are common but are found in discrete beds that can be traced laterally for several tens of metres (Fig. 33), and commonly are associated with climbing ripples. Sandstones are moderately calcareous. Capping several of the units are coal seams, some as thick as 2 m, that are made up of blocky and banded vitrain, and a few thin shaly coal and silty sandstone interbeds. Tree stumps in growth position protrude into the overlying sandstone or shale, and rooted intervals extend to depths of 1.5 m into subjacent sandstone. The silty interbeds contain lenticular and wavy ripple bedding, where ripples are draped by carbonaceous mudstone flasers and thin root zones (Fig. 34). The seams are commonly split by rippled and bioturbated (*Skolithos*) sandstone beds up to 1.5 m thick. These too contain root intervals, have sharp bases, and have a tendency to fine upward. An additional component not found elsewhere in the Lower member is represented by two tabular sandstone sequences about 7 m thick; neither of the sequences show coarsening- or fining-upward trends. The tabular sandstones contain abundant ripple and small planar crossbeds, wood fragments, and small lenses of shell hash.

Interpretation of facies

Like the Type 1 coarsening-upward units of the Expedition Formation, the vertical association of lithologies and sedimentary structures in the Lower member of the Iceberg Bay Formation indicates progressively shallower and higher energy conditions. However, the significant difference in Type 2 units is the paucity of bedforms indicative of upper flow regime and high-energy, lower flow regime sediment transport. Except for the upper metre of a Type 2 sequence, all sedimentary structures denote lower flow regime, ripple and plane bed flow. Planar crossbeds and low-angle planar sets, which are representative of upper shoreface or foreshore settings, are restricted to a thin interval in the upper few centimetres. Thus, Type 2 sequences can be interpreted as representing the transition from offshore, below wave base (or prodelta), to shoreface, but where the shoreface zone was relatively narrow. Coal seams capping Type 2 units in the upper part of the Lower member indicate brief periods of exposure and local development of vegetation cover, and further imply the transition through a strand line.

The shoreface/strand transition is best developed at Section RAK 34, where thick coals overlie crossbedded sandstones, and likely represent coastal marshes. Sandstone beds that split the seams appear to have formed during single depositional events and possibly developed as local crevasse splays from adjacent channels, or as storm washover sand lobes. Local development of muddy tidal flats adjacent to the marshes is evident from thin, silty, sandstone interbeds that contain lenticular and flaser bedding. The only evidence of channelling in the entire map unit is also found at this section, as tabular sandstones up to 7 m thick that contain small-scale crossbeds and abundant wood fragments.

Figure 22. A panorama of the lower part of the Lower member of the Iceberg Bay Formation, showing the cyclical nature of coarsening- and thickening-upward delta-front lobes that accumulated in interdistributary bay settings. At least 21 cycles are preserved in this view, the largest being 45 m thick. Section RAK 25 – 83, north side of Strand Fiord, facing southeast. GSC photo. 2045 – 176.

The wave dominated coast scenario that was interpreted for deltaic deposits of the Expedition Formation cannot be used here; there is no evidence of barrier islands, tidal inlets, or extensive strandplains. On the other hand, it is evident that the sedimentation rate must have been rapid, given the cyclical nature of the coarsening-upward units, the almost 900 m total thickness, and a time frame that was probably restricted to the Late Paleocene. Therefore, the Lower member is best regarded as the product of transition to a delta system subjected to greater fluvial influence. Two possible explanations are proffered, based on alternative analogues of modern deltas.

First, the coarsening-upward units represent a series of stacked subdeltas that accumulated in an interdistributary bay. Subdeltas were fed by semi-permanent crevasse channels that led off a major distributary channel, in a manner similar to the modern Mississippi birdfoot delta. The vertical sequence resulting from each period of progradation into the bay resembles cored intervals from the Mississippi, as well as the sequence predicted from observations of (recent) laterally associated facies (Elliott, 1974; Coleman, 1981). During progradation each subdelta lobe fills part of the interdistributary bay until the local gradient advantage is lowered to the point where growth ceases. Subsidence over the delta continues and the subdelta is subsequently inundated by marine water. Continual shifting of the crevasse channels and subsidence give rise to the succession of progradational sequences characteristic of this member. The lateral facies changes observed along Kanguk Peninsula indicate progressive shoaling toward the east and north, and together with the paleocurrent indicators show that the direction of progradation varied between northwest and southwest.

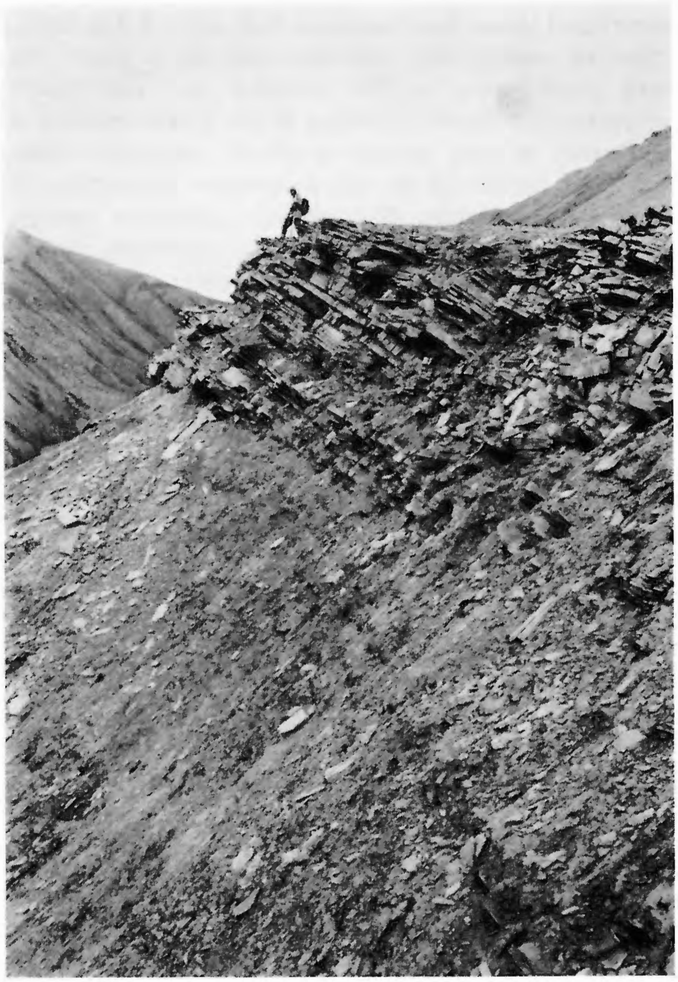


Figure 23. *An example of a coarsening- and thickening-upward sandstone unit in the Lower member of the Iceberg Bay Formation at Section RAK 25 – 83. Note the tabular bedding style that in general is much thinner than that in coarsening-upward units in the Expedition Formation. The exposed part of this unit is about 8 m thick. GSC photo. 2045 – 172.*

One of the unsettling aspects of the Mississippi Delta analogy is the absence of major distributary channels anywhere in the 900 m thick succession. For example, several significant shifts in the major distributary channel of the Mississippi Delta have taken place over the last 6000 years (Frazier, 1967). One explanation for this, albeit unsatisfactory, might be that the main distributary channels were relatively stable and never migrated far from their locus of deposition. However, if this had been the case, an extremely thick (and resistant) interval of stacked channel sandstone should be preserved. To circumvent the problem, it may be more appropriate to consider a slightly different modern analogue, from the Tabasco coastal plain of southeastern Mexico. The modern Tabasco lower delta plain contains two major rivers that give rise to radial distributary channel systems (West et al., 1969). Because wave energies are slightly higher than those impinging on the Mississippi Delta front, the Tabasco coastline is arcuate rather than of the birdfoot type. Consequently, the littoral zone contains small barrier spits and narrow standplains and, hence, is not directly analogous to the Unit 4 facies. Therefore, an analogy closer to the Eureka Sound Group might involve elements from both modern examples and a hybrid example illustrated in Figures 35 and 36. In the hybrid reconstruction, a broad coastal plain is envisaged that contained numerous, semi-permanent channels from which subdelta lobes prograded. Because the Late Paleocene delta system was built on a broad platform that had been constructed during the previous late Campanian to Maastrichtian stages of delta accumulation (Expedition Formation), wave activity was attenuated, such that only narrow beach zones developed. The degree of fluvial dominance was less than that in the modern Mississippi system.

Figure 24. Detailed view of tabular bedding in coarsening-upward units of the Lower member of the Iceberg Bay Formation at Section RAK 25–83. The "massive" weathering part of individual beds contains low-angle planar and small tabular planar crossbeds and parallel laminae, and commonly is capped by more rubbly weathered, ripple bedded and bioturbated sandstone. The hammer is 33 cm long.

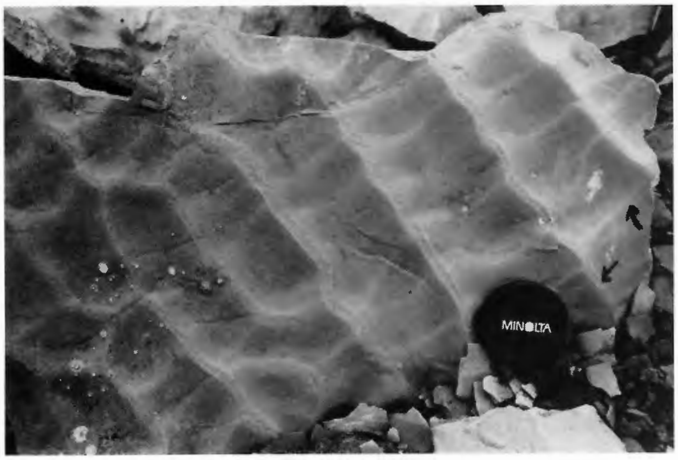


Figure 25. Interference ripples in sandstone near the top of a coarsening-upward unit in the Lower member of the Iceberg Bay Formation at Section RAK 25–83. The lens cap is 6 cm in diameter. GSC photo. 2045–186.

Figure 26. Parting lineation (trending due west) in sandstone near the top of a coarsening-upward unit in the Lower member of the Iceberg Bay Formation at Section RAK 25–83. The lens cap is 6 cm in diameter. GSC photo. 2045–273.

Figure 27. Flute casts in coarsening-upward sandstones of the Lower member of the Iceberg Bay Formation at Section RAK 25 – 83. Paleoflow was to the west (top left). The lens cap is 6 cm in diameter. GSC photo. 2045 – 169.

Figure 29. A more distal example of a coarsening-upward sandstone cycle in the Lower member of the Iceberg Bay Formation at the west end of Kanguk Peninsula (Section RAK 28 – 38). The approximate paleogeographic distance from Section RAK 25 – 83 is 30 km. The unit is about 4.5 m thick and contains thin, but regularly bedded sandstone in beds up to 30 cm thick. The basal shale also contains a few **Chondrites***. GSC loc. 2045 – 267.*

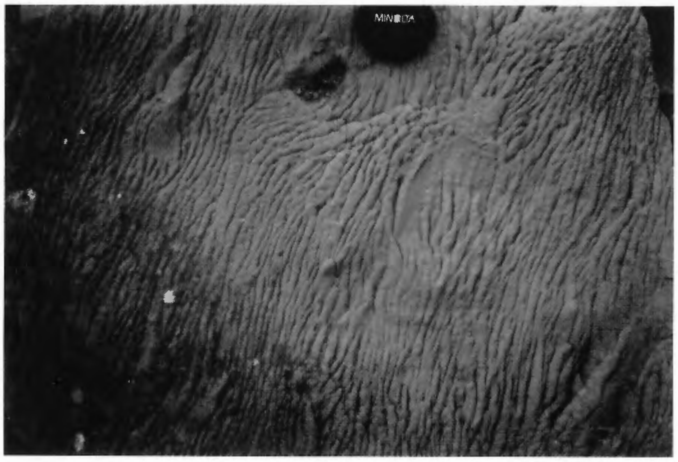


Figure 28. Longitudinal and polygonal ridge patterns in coarsening-upward sandstones of the Lower member of the Iceberg Bay Formation, commonly associated with flute and groove casts (as in Figure 27). These structures are identical to examples produced experimentally by Dzulynski and Simpson (1966; their figures 20-23), and result from convection-like shear at a sediment/water (suspension) interface. Section RAK 25–83.

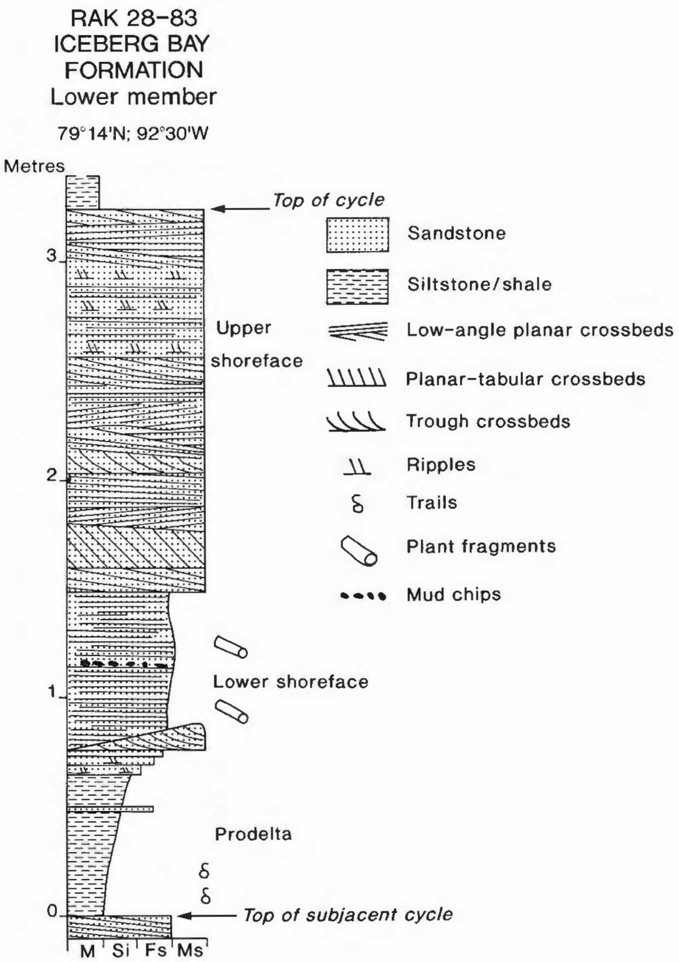


Figure 30. Schematic representation of the coarsening- and thickening-upward cycle in the Lower member of Iceberg Bay Formation, shown in Figure 29. Section RAK 28–83 at the west end of Kanguk Peninsula. The facies is considered to be the downslope equivalent of thicker examples illustrated in Figures 21 and 23.

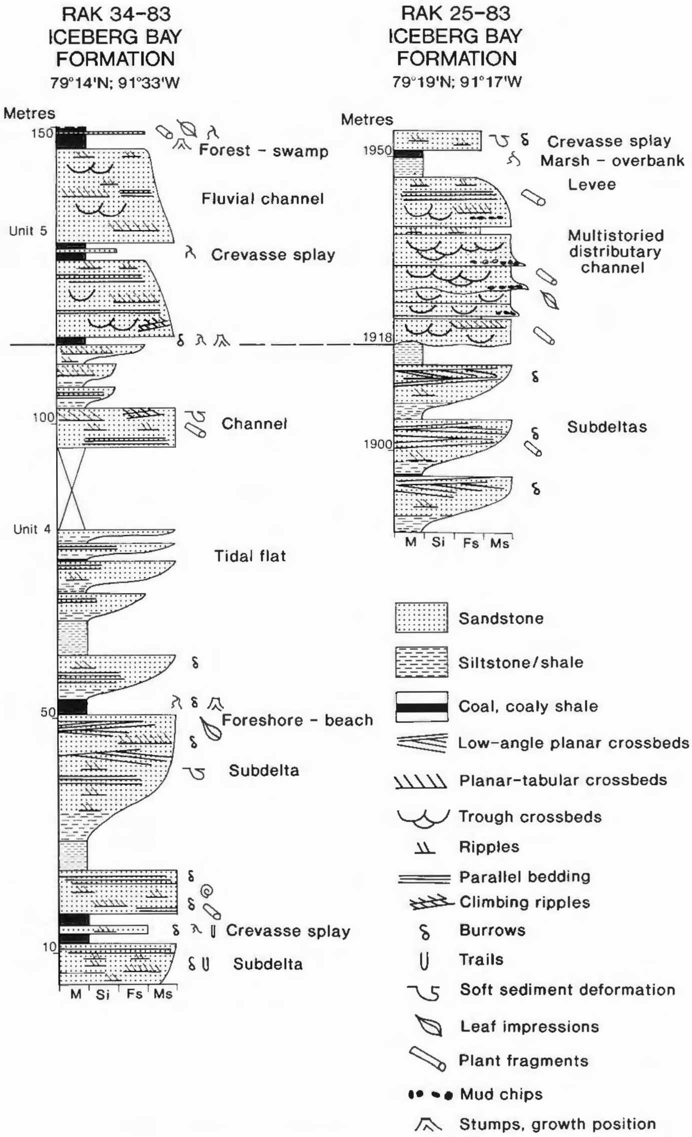


Figure 31. Facies transitions between the Lower and Coal members of the Iceberg Bay Formation at Sections RAK 25–83 and RAK 34–83. At Section 34, the transition is gradual with increasingly thicker coal seams and a change from coarsening-upward to fining-upward units and the appearance of abundant tree trunks in growth position. The transition at Section 25 is more abrupt, owing to the appearance of a thick distributary channel sandstone.

Figure 32. *General view of Section RAK 34–83, showing the transition from coarsening-upward units and associated coal seams of the Lower member, Iceberg Bay Formation, to fining-upward sandstone/coal units in the Coal member at the top of the cliff. A discordant surface in one coarsening-upward unit (arrow) is interpreted as a tidal channel that is overlain by thin, tidal flat mudrocks. GSC photo 2045–368.*

Figure 33. *Detached load balls and current ripples in a shoreface sandstone bed in the Lower member of the Iceberg Bay Formation at Section RAK 34–83. The lens cap is 6 cm in diameter. GSC photo. 2045–357.*

Figure 34. Interbedded shaly coal, mudstone, and fine sandstone containing flaser and lenticular bedding, root structures and minor bioturbation, at the top of the Lower member of the Iceberg Bay Formation. The fine grained lithologies overlie coarsening-upward sandstone. The hammer is 33 cm long. GSC photo. 2045 – 370.

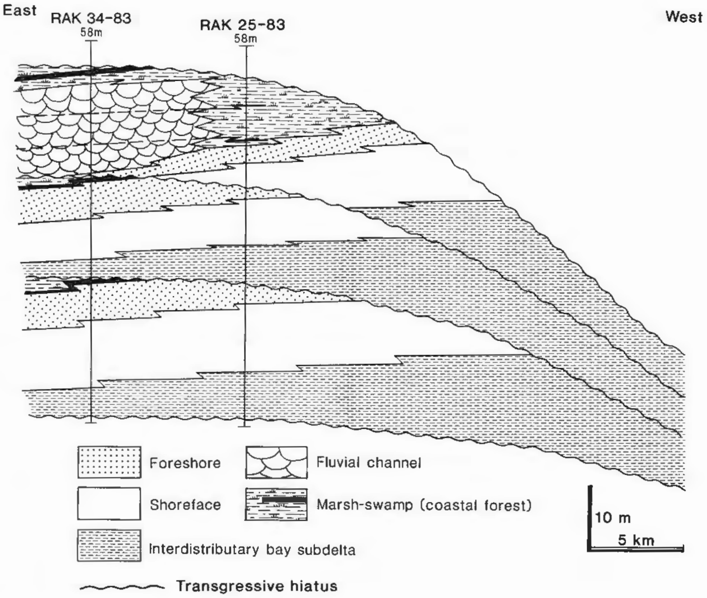


Figure 35. A schematic representation of three interdistrbutary bay subdelta and transition tidal channel/marsh/tidal flat units, and their inferred hiatal surfaces, in the upper part of the Lower member of the Iceberg Bay Formation at Sections RAK 25 – 83 and RAK 34 – 83. Delta progradation was toward the west or southwest.

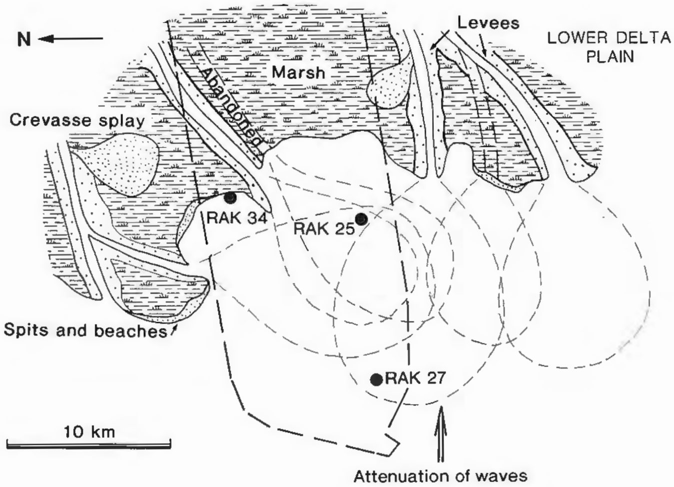


Figure 36. A paleogeographic reconstruction for the stratigraphic interval portrayed in Figure 35, with coordinates fixed to the present geographic positions of Sections RAK 25 – 83, 27 – 83, and 34 – 83 on Kanguk Peninsula (outlined by the heavy broken line). The vertical repetition of coarsening-upward units was a result of numerous overlapping crevasse splay and interdistributary bay subdeltas.

Iceberg Bay Formation – Coal member

At +1060 m, the coal-bearing member is the thickest of all map units in the Eureka Sound Group at Strand Fiord. The member can be described in terms of three lithofacies, of which the *fining-upward sandstone-coal facies* accounts for 95 per cent of the total thickness, and two minor, but nonetheless important, sandstone facies make up the remaining 5 per cent (Table 1).

Thick, trough crossbedded, sandstone facies

Contact between the Lower and Upper members of the Iceberg Bay Formation at Section RAK 25 is placed at the base of a bluff-forming sandstone, 26 m thick. The base of the sandstone is abrupt and locally erosional. The upper few metres of this sandstone facies show gradual fining and thinning trends (Fig. 31). Overall, the bluff-forming sandstone consists of several intervals of trough crossbedded, medium grained sandstone, up to 4.5 m thick, with basal lags of wood fragments and mudchips. Crossbed sets average about 60 cm and occasionally exceed one metre in thickness. Planar tabular crossbeds occur at the top of some intervals. The sandstones are texturally and compositionally mature. Capping two of the crossbedded intervals, and in gradational contact with them, are very thin bedded, parallel laminated and rippled, medium to fine grained sandstones with veneers of carbonaceous debris (Fig. 37). Upper contacts of the laminated sandstones have been eroded by the overlying crossbedded sandstones.

The upper beds of this facies contain fining-upward trends where thick, trough crossbedded sandstone gives way to progressively thinner beds with smaller bedforms at the top (mostly ripples). Bedding is lined with wood and mudchips. The entire facies is capped by grey shale and coal.

Figure 37. *Stacked planar tabular and trough crossbed sets (arrows) in the thick trough-crossbedded sandstone facies at the base of the Coal member at Section RAK 25 – 83. The interval of thin bedded, carbonaceous sandstone (about 50 cm thick) has been partly eroded by the overlying channel sandstone (note the discordant contact). The jacob's staff is 1.5 m long. GSC photo. 2045 – 188.*

Fining-upward sandstone-coal facies

Most of the Coal member consists of moderately to poorly indurated sandstones in fining-upward units that are capped by shale and coal seams. Compared to subjacent map units, exposure here is poor—weathering has produced a subdued relief but also resulted in a distinctive colour banding (Fig. 38). A representative section from Section RAK 25 is illustrated in Figure 39 and contains several resistant sandstone and coal beds. On the other hand, sections at the west end of Kanguk Peninsula have only weakly consolidated sand, less resistant than the coal seams.

Fining-upward units range in thickness from 3 to 10 m. Sandstone/shale ratios in each unit range from about 40 to 60 per cent. Bases are abrupt, locally erosional, and commonly are lined with mudchip and wood fragment lags. Trough crossbeds predominate; set thickness rarely exceeds 50 cm and gradually becomes thinner toward the top of the unit, together with the appearance of ripples and parallel laminae (Fig. 40). Soft sediment deformation is common. In the thicker sequences, crossbeds occur in intervals one or two metres thick, each having a basal lag and bearing some resemblance to crossbedded intervals in the underlying *thick, trough crossbedded, sandstone facies.*

The tops of the fining-upward units are of two types: abrupt contacts, where sandstone passes directly to shale or coal; and gradational contacts, where fining and thinning trends are more complete. Coal seams vary in thickness from a few centimetres to six metres, and consist mainly of banded vitrain and durain. Root structures are ubiquitous, and orange-brown resin is disseminated throughout. Thick seams near the base of the Coal member at Section RAK 34 contain numerous mineralized tree stumps (calcite plus silica), up to one metre in diameter and in growth position (Fig. 41). Within the shale-coal intervals are single beds of sandstone (0.5 to 1.5 m) with sharp bases and tops that grade into the overlying shale. Some are overlain directly by thin coal seams and root zones. Most contain only small-scale crossbeds, ripples and parallel laminae. The lateral extent of these beds is unknown.

Figure 38. *Panorama of typical subdued topography and striped colour banding in weathered exposures of the Coal member of the Iceberg Bay Formation. The view is due west, with the stream downcutting through the syncline axis near Section RAK 25 – 83. GSC photo. 2045 – 212.*

Stratigraphic variations in the facies are subtle. There appears to be a gradual thinning trend in the thickness of fining-upward units and, in concert with this, coal seams tend to become thinner higher up in the member. Two additional features are deemed important with regard to the overall paleogeographic interpretation of the Coal member. In the lower 400 to 500 m, beds of white calcareous sandstone up to one metre thick are found overlying sandstones in several fining-upward cycles. They in turn are overlain by shale or coal seams. The colour and calcite cemented character are in marked contrast to the brown colour and clay cement of sandstones that underlie them. In addition to abundant ripple bedding, the white sandstones contain moderate to intense bioturbation, usually in the form of *Planolites* and *Gyrochorte*; again in contrast to the underlying *thick, trough crossbedded sandstone facies.* Upper and lower bed contacts are abrupt.

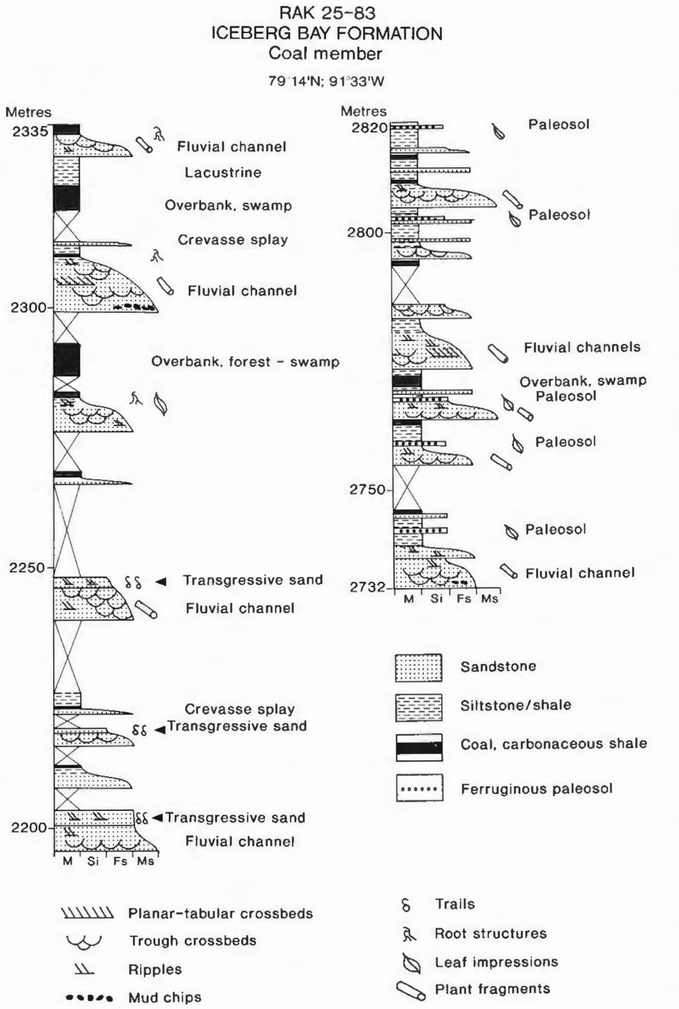


Figure 39. *Stratigraphic columns of representative intervals of the Coal member of the Iceberg Bay Formation at Section RAK 25 – 83. Coal seams in the upper part of the unit tend to be thin and commonly are associated with nodular weathering, calcareous, ferruginous paleosols, reflecting an overall increase in upper delta plain/fluvial conditions. The stratigraphic intervals correspond to those in Figure 49.*

Figure 40. *The sandstone component of a typical fining-upward unit in the Coal member of the Iceberg Bay Formation, showing abundant stacked, trough crossbedding and mudchip lags. Section RAK 25 – 83. The hammer (centre) is 33 cm long. GSC photo. 2045 – 210.*

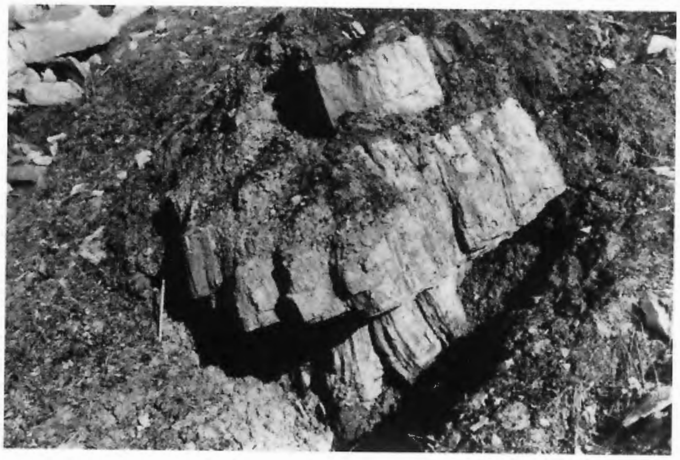


Figure 41. A large mineralized tree stump in growth position, embedded in a coal seam in the Coal member of the Iceberg Bay Formation at Section RAK 34 – 83. Leaf impressions of ***Metasequoia*** *are common in the sandstone rubble that surrounds the trees. The pencil is 15 cm long. GSC photo. 2045 – 374.*

Concomitant with the thinning of coal seams in the upper half of the member is the appearance of distinctive orange-brown weathering beds of calcite and siderite. These rubbly beds occur within shale, or overlie coal seams or sandstone in the higher levels of fining-upward units. The beds are usually less than 10 cm thick and have a 'rubbly', almost nodular character. Upper contacts of these beds are abrupt but lower contacts are commonly diffuse. Fragmented plant material abounds and is preserved either as thin carbonaceous films or as impressions, many of which have the structure of roots. On a microscopic scale, ubiquitous millimetre-sized voids are scattered through a matrix of fine crystalline ferruginous calcite, siderite, and very fine, angular quartz grains; the quartz grains commonly appear to "float" in the darker matrix. The voids have angular and ovate boundaries and are filled with fine, clear, sparry calcite. Some contain relict carbonaceous material. Void development probably resulted from oxidation and subsequent removal of plant fragments.

Coarsening- then fining-upward facies

Approximately 300 m below the eroded top of the Coal member (RAK 25) lies a single coarsening- then fining-upward unit totalling 25 m in thickness. The unit is bounded above and below by *fining-upward sandstone-coal facies*. Ninety per cent of the facies consists of the coarsening-upward component that abruptly overlies a thick seam of coal (Fig. 42). The upper contact is also marked by a shaly coal bed. Thinly bedded calcareous shale and siltstone at the base pass upward into sandstone interbeds that contain ripples and parallel laminae. Bioturbation by *Planolites* is common, as are load casts at sandstone/shale contacts. Sandstones higher in the facies are tabular and increase in thickness to about 60 cm. Crossbedding is largely planar tabular and low-angle planar, with sets rarely exceeding 30 cm, and becomes more prominent in the higher, thicker sandstones. An interval of shale and coal about 2 m thick constitutes the fining-upward component of the facies. A thin zone of root structures underlies the coal.

Figure 42. One of the few indications of marine incursion in a coarsening-upward unit near the top of the Coal member of the Iceberg Bay Formation at Section RAK 25 – 83. The unit overlies a 60 cm thick coal seam (arrow) and in turn is overlain by a more recessive shale/coal interval. Total unit thickness is about 25 m. GSC photo. 2045 – 218.

The facies can be traced laterally for at least several hundred metres. An important variation in the succession is illustrated in Figure 43, where horizontal, interbedded sandstone and shale pass laterally into slightly thicker, more steeply dipping beds (up to 10°); thus, bedding appears to diverge toward the west. Internally, the sandstones possess the same organization as those in the more typical coarsening-upward sequence. Crossbed azimuths also indicate flow to the west. The upper contact is obscure. The basal contact is abrupt, as described above.

Interpretation of facies

Sandstone thickness, the abundance of trough crossbeds (which indicate some degree of confined flow), stacking of crossbedded units, and basal lags in the *thick, trough crossbedded, sandstone facies*, are identical to many examples of ancient stacked, or multi-storied channels. Thin, laminated, carbonaceous sandstones capping some of the crossbedded units (Fig. 37) point to considerably lower stream competence, as might be encountered on channel levees, and provide some evidence of lateral channel migration. Certainly, the fining-upward character at the top of the facies suggests a gradual shift in channel thalweg rather than avulsion. Approximately 10 km north of Section RAK 25 (at RAK 34), a similar stratigraphic position is occupied by thin, fining-upward, sandstone-coal cycles, some of which contain large tree trunks in growth position; the sequence here is conformable. This places some constraints on the lateral extent of the channel facies but, more importantly, demonstrates that there is no significant hiatus between the Lower member and Coal member of the Iceberg Bay Formation. This means that any paleogeographic reconstruction must take into account the transition from the delta-front facies of the Lower member to the more fluvial part of the lower delta-plain, as shown in Figure 44. It is conjectured that the coarsening-upward delta facies in the upper part of the Lower member at Section RAK 27 is approximately time equivalent to the basal channel facies of the Coal member. The *thick, trough crossbedded, sandstone facies* therefore represents the first indication of a major fluvial or distributary channel following the apparently channel-free succession of the Lower member.

The *fining-upward sandstone-coal facies* of the Coal member closely resembles classic fining-upward fluvial sequences that are attributed to deposition in high sinuosity rivers (e.g., Allen, 1970). Abundant trough crossbedding indicates relatively high-energy deposition within channels. Gradual upward fining and decreasing bedform size denote lateral migration of channel thalwegs and deposition of overbank muds and possibly point bars. However, no direct evidence of point bars in the form of epsilon crossbeds was seen. Sandstone sequences that lack the fine component are more likely to represent rapidly abandoned channels. Planar tabular crossbeds are relatively scarce, indicating that within-channel bars or side bars, which might be expected in braided or low sinuosity channels, also were uncommon. The high proportion of mudrocks in the fining-upward sequences is

Figure 43. *A panorama of an equivalent stratigraphic interval to that shown in Figure 42, illustrating the transition from flat-lying to divergent, shallow dipping (west) sandstone/shale interbeds. A coal seam at the base of the sequence (arrow) is the one illustrated in Figure 42. Geologist on the right for scale (circled). GSC photos. 2045 – 213, 214.*

consistent with the concept of channels separated by wide areas of floodplain. Floodplain swamps gave rise to coal seams up to 6 m thick, implying prolonged, stable conditions of plant growth and organic accumulation. It appears that forest conditions prevailed in some areas, including floras such as *Metasequoia* and broadleaf angiosperms. Peat and mud deposition on the floodplain was interrupted briefly by thin overbank and crevasse splay sands. The general thinning trend of fining-upward sequences and coal seams toward the top of the Coal member indicates a progressive change to less extensive swamps and floodplains.

Rubbly weathered, orange-brown beds of ferruginous calcite and siderite that also appear in the upper half of the Coal member possess some of the characteristics of calcareous paleosols, including: diffuse lower contacts, root structures, calcite-filled fractures in a rubbly, sometimes brecciated matrix, and voids filled by calcite spar that formed around oxidized plant or root structures. These criteria are consistent with previous descriptions of some paleosols (e.g., Reeves, 1976; Retallack, 1983). The absence of well developed nodules or pisoliths suggests an immature type of soil. Restriction of the paleosols to the upper level of the Coal member provides additional evidence of deposition on the upper, fluvial dominated portion of the delta-plain.

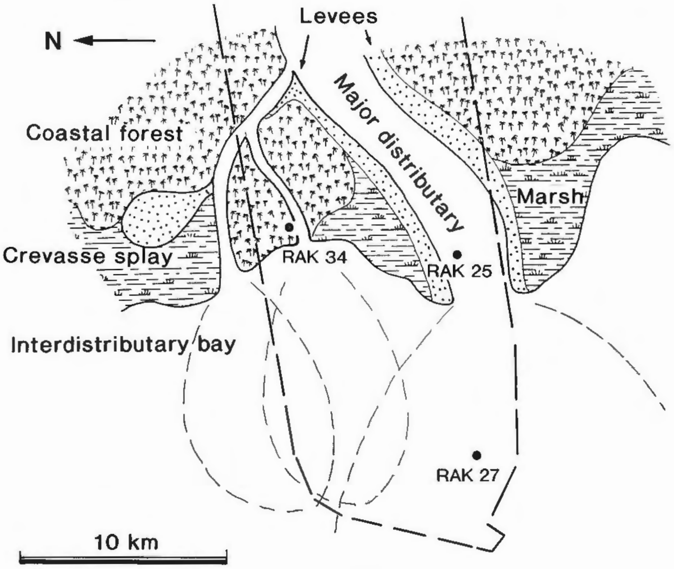


Figure 44. A paleogeographic reconstruction of the lower portion of the Coal member of the Iceberg Bay Formation, showing a major distributary channel (Section RAK 25 – 83), and laterally associated lower delta plain crevasse splay, channel and marsh settings (Section RAK 34 – 83). Downslope equivalents of these deposits are probably represented by thin subdelta cycles in the upper part of the Lower member, Iceberg Bay Formation at Section RAK 27 – 83. The paleogeographic coordinates are fixed to the present position of Kanguk Peninsula (heavy broken line).

Two explanations are considered for the thin, white sandstone beds found capping some of the fining-upward sandstones in the lower part of the Coal member. In humid, temperate climates, leaching of sandstone that underlies coal or peat seams commonly produces a thin zone of bleached white sand (e.g., as in podsols); here, sedimentary structures will generally remain continuous with those below the leached zone, and the lower contact of leaching will be diffuse. However, most of the criteria pertinent to the present examples do not support this explanation; the white sandstones occur in discrete beds with abrupt bases, and sedimentary structures are not continuous into the subjacent sandstones. In addition, the intensity of bioturbation is unusual in the fining-upward fluvial facies, and the degree of calcite cementation is inconsistent with a pervasive leaching process. As an alternative explanation, the sandstones are considered to represent local marine incursions and subsequent reworking of delta-plain sands (Fig. 45). Local transgression is possible over portions of an inactive lower delta-plain lobe, where sedimentation rates are less than the rate of delta subsidence. Because the fluvial facies developed near the inland limit of the lower delta-plain, or even the upper delta-plain, the sandstones likely approximate the landward limit of transgression. Increased bioturbation would also correspond with elevated salinities resulting from these brief marine incursions.

The *coarsening- then fining-upward facies* near the top of the Coal member is also interpreted as the product of marine incursion but, because of its thickness, of a more extensive transgressive event that probably involved the inundation of a complete delta lobe. Features such as the tabular geometry of bedding, style of crossbedding, basal calcareous mudstone, and the degree of bioturbation, are comparable to those of a similar facies in the Lower member of the Expedition Formation, except that bedforms are smaller scale, suggesting lower depositional energies. Therefore, the vertical succession can reasonably be interpreted as the transition from shoreface to foreshore (beach), overlain by thin lagoonal mudrocks and marsh coals, within a barrier island/lagoon setting. An additional feature not observed in the Expedition Formation example is the sequence of gently dipping and divergent accretionary sandstone beds. Interbedding of the sandstone with thin beds of shale indicates periodic sedimentation. The concordant style of bedding and absence of trough crossbeds and scoured bases are inconsistent with an interpretation of channel-thalweg deposition. However, the accretionary foreset beds bear some resemblance to fluvial point bars or, more likely, estuarine channel point bars (e.g., Smith, 1988). Alternatively, comparison can be made with modern storm washover sand lobes that breached barrier island foreshores and spilled into the adjacent lagoon, or with tidal-inlet deltas. Both modern and ancient examples of these have been well documented (excellent examples are found in the Mississippian of eastern Kentucky; Horne and Ferm, 1978). Because the accretionary beds dip west, and therefore parallel the regional paleoslope, the accretionary sequence is tentatively compared to a small ebb tidal delta.

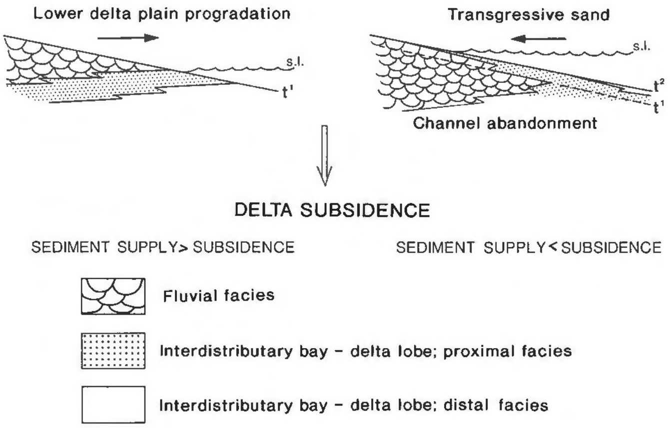


Figure 45. *An hypothesis to explain the origin of the thin, white, calcareous sandstone beds that cap some of the fining-upward units in the Coal member of the Iceberg Bay Formation. Time* t^1 *to* t^2 *probably represents a span of tens or hundreds of years, if comparison is made to similar processes observed on some modern lower delta plains (e.g., Gagliano and Van Beek, 1975). Subsidence during this period is assumed to be constant. Sediment supply is terminated when the fluvial channel avulses or migrates laterally, and sand is locally reworked during the subsequent marine incursion.*

TRACE FOSSILS

Trace fossils occur in every formation of the Eureka Sound Group on western Axel Heiberg Island. To date, twelve ichnogenera have been recognized with the most diverse assemblages occurring in Expedition Formation strata, and decreasing in diversity in the Iceberg Bay Formation. The differences in diversity can be attributed directly to changes in lithofacies. Classification schemes and descriptive terminology have been summarized by Frey (1973), Frey and Seilacher (1980), and Pemberton and Frey (1983). In the following discussion of species, reference will be made to their trophic group (feeding habit) ethological behavioural group, and likely producing organisms.

Trace fossil assemblages

The stratigraphic distribution of ichnogenera in Eureka Sound strata shows two distinct trends (Table 2): maximum faunal diversity in the Expedition Formation, decreasing in stratigraphically higher formations; and a relatively restricted range for most trace fossils except for widely dispersed forms such as *Planolites* and *Gyrochorte*. In fact, the trends can be related directly to major changes in paleoenvironments (facies), and the transition to lower diversity and also lower numbers of individuals parallels the transition from marine to nonmarine facies. On western Axel Heiberg Island, this transition encompasses basal strata of wave dominated delta origin, and higher formations of mixed wave-fluvial and possibly fluvial dominated delta origin. The Strand Bay Formation in this area appears almost devoid of trace fossils.

A fourfold subdivision of trace fossil assemblages has been identified, based on common associations of burrows within lithofacies. Each assemblage contains one or two dominant forms and represents a different set of sedimentological conditions, and ethological and trophic attributes (Fig. 47, Table 3).

The *Chondrites* assemblage consists predominantly of sedimentary-fabric destructive *Chondrites* burrow networks, and subordinate *Terebellina, Teichichnus* and *Planolites*. The most prolific development is found in interbedded fine grained sandstone and shale in the Kanguk Formation/Eureka Sound Group transition, and in the shaly component of coarsening-upward sequences in the Lower member, Expedition Formation. The assemblage is less well developed in the upper part of the Expedition sequence and is rare in the Iceberg Bay Formation. Sedimentologically, the assemblage thrived in argillaceous substrates where bedload transport of sediment was limited, and was situated in prodelta or lower shoreface environments (generally below storm wave-base). Moderately oxygenated water, and salinities approaching those of normal sea water can be inferred from the degree of bioturbation and the association with a marine molluscan fauna. This association provides an interesting contrast to prodelta sequences that are well developed in the Lower member of the Iceberg Bay Formation, where the ichnofauna assemblage is sparse and no corresponding macrofauna occur. It is reasonable

TABLE 2

The general stratigraphic and paleoenvironmental distribution of trace fossils within the five map units of the Eureka Sound Group

		MAP UNITS				
Ichnogenus	**Kanguk Fm.**	**Lower mbr., Expedition Fm.**	**Upper mbr., Expedition Fm.**	**Strand Bay Fm.**	**Lower mbr., Iceberg Bay Fm.**	**Coal mbr., Iceberg Bay Fm.**
Chondrites	— — ———	———			—	
Terebellina	— — ———	———				
Teichichnus	— — ———	———				
Planolites	— ———	———	———		———	——— — * ———
Skolithos		———	———		— —	
Muensteria		———	———			
Ophiomorpha		———	———			
Thalassinoides		———	———		— —	
Gyrochorte			— —		——— —	——— — * ———
Paleophycus			— —		———	— —
Pelecypodichnus					——— — —	
Escape burrow		———	———		— —	
	Restricted Marine	Wave dominated: delta	Wave dominated: delta	Marine transgression	Fluvial dominated: interdistributary Bay	Fluvial dominated: delta plain

——— Common
— — Uncommon
* Minor marine incursion

TABLE 3

Summary of trace fossils assemblages and their trophic and ethological classifications

Assemblages	*Chondrites*	*Skolithos*	*Ophiomorpha*	*Paleophycus*	Ethological Class	Trophic Group
Chondrites	x				Fodinichnia	Deposit
Terebellina	x				Domichnia	Suspension
Teichichnus	x			x	Fodinichnia	Deposit
Planolites	x	u		u	Fodinichnia	Deposit
Skolithos		x			Domichnia	Suspension
Muensteria		x	u		Fodinichnia	Deposit
Ophiomorpha					Domichnia	Suspension
Thalassinoides			u x		Domichnia (Fodinichnia)	Deposit
Gyrochorte			x	x	Repichnia	Deposit
Paleophycus		u		x	Domichnia	Carnivore
Pelecypodichnus					Cubichnia	Suspension
Escape burrows		x	x	u	Fugichnia	

x = common
u = uncommon

to infer that higher rates of sedimentation and more brackish conditions persisted during Iceberg Bay deposition and were not conducive to population by the *Chondrites* assemblage; except on the seaward margins of prodelta lobes, now preserved at the west end of Kanguk Peninsula. This interpretation is consistent with the decreasing diversity of trace fossils, and the inferred paleogeographic setting.

Relatively low diversity but high numbers of individual burrows characterize the *Skolithos* assemblage. The assemblage is made up of abundant *Skolithos* and associated escape burrows (Fig. 46) (*Muensteria* and a few *Paleophycus*). Ichnogenera in the *Chondrites* and *Skolithos* assemblages appear to be mutually exclusive.

Skolithos is usually found in crossbedded, medium grained, moderately to well sorted sandstones comprising the high-energy shoreface and beach facies of coarsening-upward cycles in the Expedition Formation. They represent suspension feeders in a setting that was continually subjected to water turbulence, rapid erosion and deposition. Horizons that contain *Skolithos* burrows are commonly truncated by overlying crossbedded sandstones populated by similar organisms. It may be appropriate to consider the *Skolithos* here as an opportunistic species, analogous to modern *Callianassa,* which have been observed by Frey et al. (1978) occupying successive foreshore surfaces on a rapidly prograding beach.

Unlike the *Skolithos* assemblage, the *Ophiomorpha* assemblage developed in lower energy conditions and is found in medium grained sandstones that possess only small-scale crossbeds and ripples. Burrows here are predominantly horizontal rather than vertical, consisting mostly of *Ophiomorpha, Thalassinoides* and a few *Planolites* and *Muensteria.* The sandy substrate here was probably more stable than that of the *Skolithos* assemblage. Although the assemblage also occurs in coarsening-upward sequences, it seems to have developed in lower energy shoreface facies than did the *Skolithos* assemblage, either laterally associated with it, or at greater water depths on the shoreface. Both the *Skolithos* and *Ophiomorpha* assemblages are present in the lower part of the Iceberg Bay Formation and must have been more tolerant of the increasingly brackish water conditions. However, the assemblages disappear in the middle and upper parts of the Lower member of the Iceberg Bay Formation where they are replaced by the *Paleophycus* assemblage.

Figure 46. *Escape burrows at the base of a crossbedded sandstone associated with the barrier island facies, in the Lower member of the Expedition Formation at Section RAK 31 – 83. The lens cap is 6 cm in diameter. GSC photo. 2045 – 302.*

The *Paleophycus* assemblage is particularly prominent in Lower member strata of the Iceberg Bay Formation and is made up of its namesake plus *Gyrochorte, Planolites* and *Pelecypodichnus*, with subordinate *Skolithos* and escape burrows in the lower part of the unit. Typically it occurs in thin bedded, fine grained sandstone in coarsening-upward (Type 2), delta lobe/interdistributary bay facies. The grain size, small bedforms and regular interbedding of mudrocks indicate relatively low rates of sedimentation (greater than the *Chondrites*, but less than the *Skolithos* and *Ophiomorpha* assemblages). Most of the trails occur on or immediately below bedding, further indicating stable substrates. The assemblage persists into the lower part of the essentially nonmarine, fluvial dominated Coal member, occurring in thin sandstone beds that periodically transgressed riverine deposits on the delta plain.

Summary

The stratigraphic distribution of trace fossils and their assemblages in the Eureka Sound Group reflect temporal facies changes in a variety of delta environments. A transition from wave dominated to more fluvial dominated delta settings also implies concomitant changes from conditions approaching normal marine, to brackish water and nonmarine conditions. A marine influence is indicated by the low-energy, lower shoreface to prodelta *Chondrites* assemblage, and ichnofaunal diversity in the high-energy shoreface and beach assemblages of *Skolithos* and *Ophiomorpha*. Although shoreface facies exist in the mixed wave-fluvial dominated delta succession of lower Iceberg Bay strata, their more brackish water character is reflected in the paucity of *Chondrites* assemblages, and the gradual disappearance of *Skolithos* and *Ophiomorpha* assemblages. The *Paleophycus* assemblage becomes dominant but it too dies out with the encroachment of the upper delta-plain fluvial deposits of the Coal member.

Many of the trace fossils encountered in the Eureka Sound strata are usually associated with normal, fully marine sedimentary conditions. However, it is clear that the same structures persist in marginal marine settings, especially those associated with deltas. Other well documented examples include an extensive list of ichnogenera that occur in offshore and nearshore sequences, and marginal marine equivalents (e.g., lagoons) in Upper Cretaceous strata of east-central Utah (Howard and Frey, 1984; Kamola, 1984). All of the forms found on western Axel Heiberg Island also occur in the Utah examples.

PETROLOGY OF THE SANDSTONES

Sandstones that compose the bulk of the Eureka Sound Group are generally fine to medium grained. Coarse grained sandstone was found only in the area around Glacier Fiord Syncline, and one thin, pebble conglomerate bed near Kanguk River. Most of the sandstones are texturally and compositionally mature, and even supermature. Although variations in the level of maturity are subtle, field and petrographic observations reveal some differences amongst facies. For example, sandstones interpreted as barrier island facies exhibit the best level of sorting, grain roundness, and the highest proportion of quartz grains as framework, regardless of their stratigraphic position. This is a function of the degree of mechanical reworking that is common to barrier island systems, and is observed in the extensive

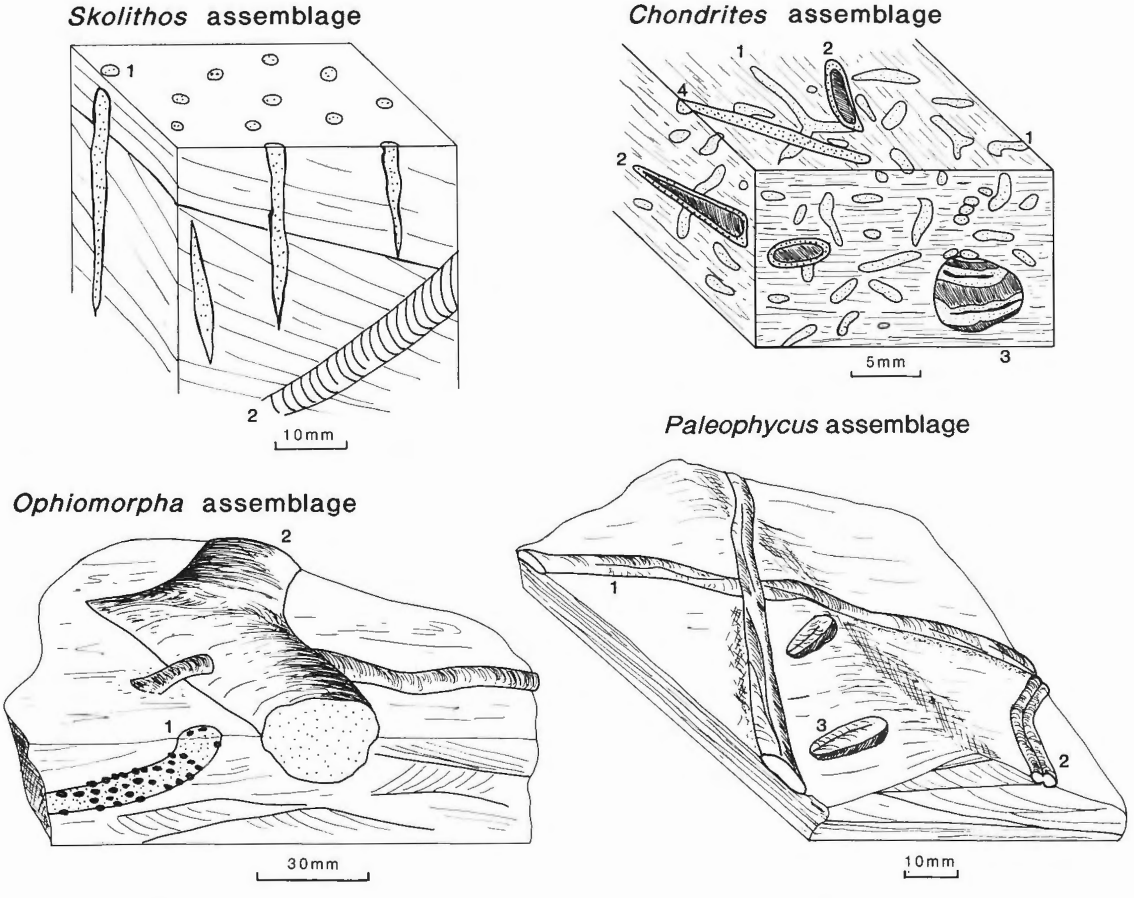


Figure 47. *Typical trace fossil associations in the four main assemblages found at Strand Fiord; sketched from slabbed hand samples.*

Skolithos *Assemblage: 1 =* ***Skolithos*** *2 =* ***Muensteria.*** ***Chondrites*** *Assemblage: 1 =* ***Chondrites*** *2 =* ***Terebellina*** *3 =* ***Teichichnus*** *4 =* ***Planolites.*** ***Ophiomorpha*** *Assemblage: 1 =* ***Ophiomorpha*** *2 =* ***Thalassinoides.*** ***Paleophycus*** *Assemblage: 1 =* ***Paleophycus*** *2 =* ***Gyrochorte*** *3 =* ***Pelecypodichnus.***

prograding barrier island facies of the Expedition Formation as well as the thinner, transgressive sandstone sheets in the Strand Bay Formation and Coal member of the Iceberg Bay Formation (i.e., developed on abandoned delta lobes). The high-energy, wave dominated delta and strandplain sandstones of the Expedition Formation also show a high degree of maturity, whereas lithotypes in the lower depositional energy, mixed wave-fluvial delta facies of the lower Iceberg Bay member are somewhat less mature.

Mineralogical compositions of representative samples are summarized in Table 4 and Figure 48. Most contain 90 to 95 per cent (number %) quartz, most of it monocrystalline with undulose extinction; less than 5 per cent has a distinct polycrystalline habit. Well formed, syntaxial quartz overgrowths are common and interpenetration occurs at some grain contacts. Tourmaline inclusions in quartz occur sporadically. Feldspar and lithic fragments are clearly subordinate, with potassium feldspar being the most prominent at 5 per cent or less (up to 9.5 per cent in one sample). A few plagioclase grains were seen but commonly are highly altered; some may have been counted as potassic varieties. Chert and mudstone lithics rarely form more than 5 per cent of the framework. Rare lithics appear to have a felted texture of plagioclase laths similar to volcanic or diabasic rocks, but are too highly altered to be identified more precisely. The heavy mineral assemblage, in addition to being sparse, is also limited in diversity and consists of approximately equal amounts of green tourmaline, muscovite and olive-green hornblende. No major stratigraphic changes in composition have been noted.

Sandstone cements consist of three principal types. Most abundant are the clay cements of kaolinite and chlorite, followed by quartz cement as syntaxial overgrowths, and (generally) minor calcite (and some siderite). The relatively high proportion of cement in samples 40 to 25 is a result of calcite replacement of the quartz and feldspar framework and matrix – the corresponding quartz value is also low (Table 4). The paragenetic sequence is similar to that found in many sandstones (determined by superposition), with quartz overgrowths as the first phase, followed by pore filling kaolinite and chlorite, and a later diagenetic phase of calcite replacing the earlier cements. Minor diagenetic siderite and pyrite also occur. A more detailed account of diagenesis is presented in Allen (1986).

A single lens of pebble conglomerate that is present along Kanguk River (RAK 31) provides further insight into the provenance of Eureka Sound siliciclastic rocks. Pebble compositions include a predominance of black chert, a variety of indurated sandstones (mainly quartz and lithic arenites), and, surprisingly, numerous pebbles (up to 4 cm long) of aphanitic dacite (quartz and plagioclase phenocrysts in a pale brown groundmass). Red and green chert pebbles are much less common.

The compositional maturity of Eureka Sound Group sandstones can be partly explained in terms of sedimentary reworking in relatively high-energy marine environments, especially reworking associated with wave dominated delta lobes and barrier islands. However, the fluvial deposits exhibit similar levels of maturity and yet they are not associated with the same type or degree of reworking. Therefore, an additional factor that must be considered is source rock composition. Based on regional geology of the Axel Heiberg/Ellesmere Island area, several principal source terranes are possible: older Mesozoic and upper Paleozoic strata of the Sverdrup Basin; deformed sedimentary rocks of the lower Paleozoic Franklinian foldbelt; and crystalline basement present along the northern edge of the Precambrian Shield.

The primary source for the bulk of the monocrystalline quartz is most likely granitic and gneissic rocks of the Precambrian Shield. Potassium feldspars, although relatively minor, are unaltered and were probably derived

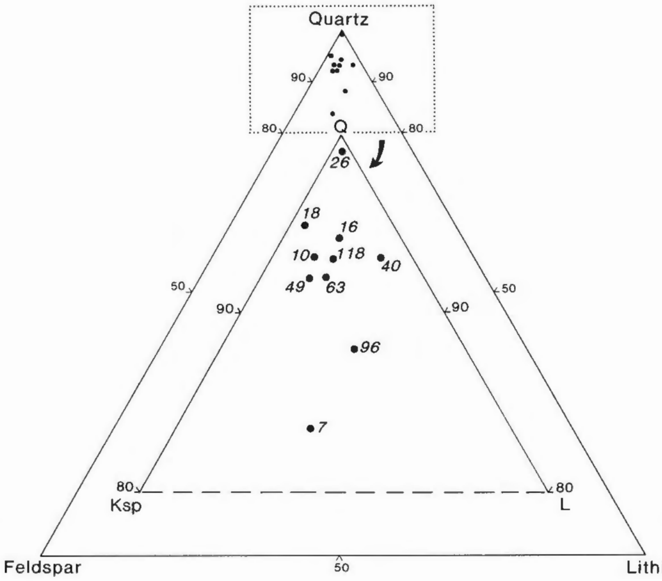


Figure 48. *Triangular plot of sandstone compositions for ten representative samples from the Eureka Sound Group at Strand Fiord. Sample numbers correspond to those in Table 4. Values have been recalculated to 100 per cent from Table 4. Q = quartz; Ksp. = potassic feldspar; L = lithic fragments.*

TABLE 4

Point-count data of Eureka Sound Group sandstones, in number per cent

Sample numbers: GSC locality numbers:	7-25 C-111774	10-25 C-111777	16-25 C-111786	18-25 C-111795	26-25 C-111795	40-25 C-111207	49-25 C-111830	63-25 C-111830	96-25 C-112313	118-25 C-112336
Framework:	70.7	73.6	73.3	72.8	78.4	57.3	68.7	71.7	63.7	70.3
Monocrystalline quartz	tr.	4.3	1.0	3.3	1.7	0.7	0.7	2.3	3.0	3.0
Polycrystalline quartz	8.0	4.0	2.7	3.4	tr.	1.0	4.3	3.7	3.3	2.7
Potassium feldspar	-	-	-	-	-	-	tr.	0.3	0.7	0.3
Plagioclase	1.0	0.9	1.2	-	tr.	0.7	1.0	0.7	2.3	0.7
Chert	4.6	0.9	0.7	0.7	-	2.7	0.7	1.7	2.7	1.3
Mudstone	1.0	0.6	tr.	tr.	-	0.3	0.3	tr.	tr.	tr.
Heavy minerals	0.7	-	-	-	-	-	tr.	-	tr.	tr.
Glauconite										
Matrix:										
Clay cements (kaolinite and chlorite) and fine quartz/feldspar	12.3	8.0	13.3	11.8	7.6	-	11.0	12.3	14.3	16.7
Quartz cement	1.3	7.7	8.0	8.0	12.3	tr.	9.3	7.3	3.7	4.7
Calcite cement	0.4	-	-	-	-	37.3	4.0	tr.	6.3	0.3

All samples collected from Section RAK 25 - 1983. At least 300 points were counted in each sample; reports as number per cent.

Samples 7 – 25, 10 – 25, 16 – 25, 18 – 25 are from the Expedition Formation; 40 – 25, 49 – 25, 63 – 25, 96 – 25, 118 – 25 from the Iceberg Bay Formation.

from the same source. The heavy mineral assemblage could have been derived from a wide variety of igneous rocks. Older sedimentary rocks appear to have made some contribution, as evidenced by the pebbles of chert and indurated sandstone. In general, however, the paucity of chert in the sandstones suggests a chert-deficient source terrane, given the mechanical and chemical stability of this clast type. The presence of dacite pebbles presents something of a dilemma because no obvious source area is known. Acid volcanics of limited extent have been reported from the lower Upper Cretaceous Hansen Point volcanics at Yelverton Bay, Ellesmere Island (Trettin and Parrish, 1987), and in the Silurian Lands Lokk Formation and Devonian Svartevaeg Formation on northern Axel Heiberg and Ellesmere islands (Thorsteinsson and Trettin, 1972). Sands derived from the older Sverdrup Basin strata would in fact represent recycling of sediment originally supplied by Precambrian sources. However, this would imply uplift and erosion of the Mesozoic basin fill prior to, or during, the earliest phase of tectonism of the Eurekan Orogeny. A structural high, known as the ancestral Princess Margaret Arch, was inferred to have developed in late Maastrichtian or Paleocene time (Gould and de Mille, 1964; Balkwill, 1978; Balkwill and Bustin, 1980), resulting in the fragmentation of eastern Sverdrup Basin into structural subbasins, named Meighen and Remus basins (Bustin, 1977; Miall, 1981). An evaluation of this hypothesis is presented by Ricketts (1987). Several points should be noted (based on stratigraphic, sedimentological and petrographic information) that raise serious questions about earlier estimates of the timing of arch formation:

1. Clastic debris was being shed into Sverdrup Basin as early as middle Campanian and continued at least until Middle Eocene.

2. Consistent sandstone composition throughout this period indicates that there was no major change in source rock type.

3. If sediments were derived by erosion of older strata on the arch, then the structure must also have had its origins as early as middle Campanian. If the arch did not exist at that time, then sediment must have been shed from adjacent uplifted Sverdrup Basin strata marginal to the Eureka Sound basin, and also from the Precambrian shield.

4. The consistent level of maturity of marine and fluvial rock types throughout the Eureka Sound Group at Strand Fiord casts some doubt on the proximity of an actively eroding structural-topographic high. Considerable thicknesses of shale and fine grained rock occur in the Mesozoic succession on Axel Heiberg Island, and yet virtually none of this debris is preserved as a lithic component in the Eureka Sound Group. Furthermore, formations such as the Heiberg contain huge volumes of diabase and gabbro dykes that must also have been eroded but, like the argillaceous rock types, none of this material found its way into the succession at Strand Fiord. Even though such clast types are mechanically less stable than quartz and chert, the proximity to the supposed arch, and the relatively low degree of reworking in fluvial deposits, indicate that this type of sediment should have survived.

5. There is no doubt that some erosion of Upper Cretaceous beds did occur because Maastrichtian palynomorphs are common in shales of Paleocene age and younger, particularly in the Strand Bay Formation. This is ascribed to periodic, local uplift of evaporite diapirs, which are common in the area. The effects of halokinesis on local sedimentation patterns throughout Mesozoic deposition in Sverdrup Basin have been documented elsewhere (see Ricketts, 1987).

6. Detailed mapping of lithostratigraphic units at Strand Fiord do not reveal any thinning trends toward the hypothetical ancestral Princess Margaret Arch. If the arch were present as a positive feature during much of the history of the basin, such trends should exist.

In summary, sand making up the Eureka Sound Group at Strand Fiord was originally derived from a variety of sources including Mesozoic, Franklinian and Precambrian terranes. However, none of this sediment was supplied directly by erosion of an ancestral Princess Margaret Arch. An important consequence of this conclusion is that the region of Axel Heiberg and western Ellesmere islands was occupied by a single contiguous basin (Ricketts, 1987, 1988), rather than the separate Remus and Strand Fiord basins hypothesized by Bustin (1977) and Miall (1984, 1985, 1986).

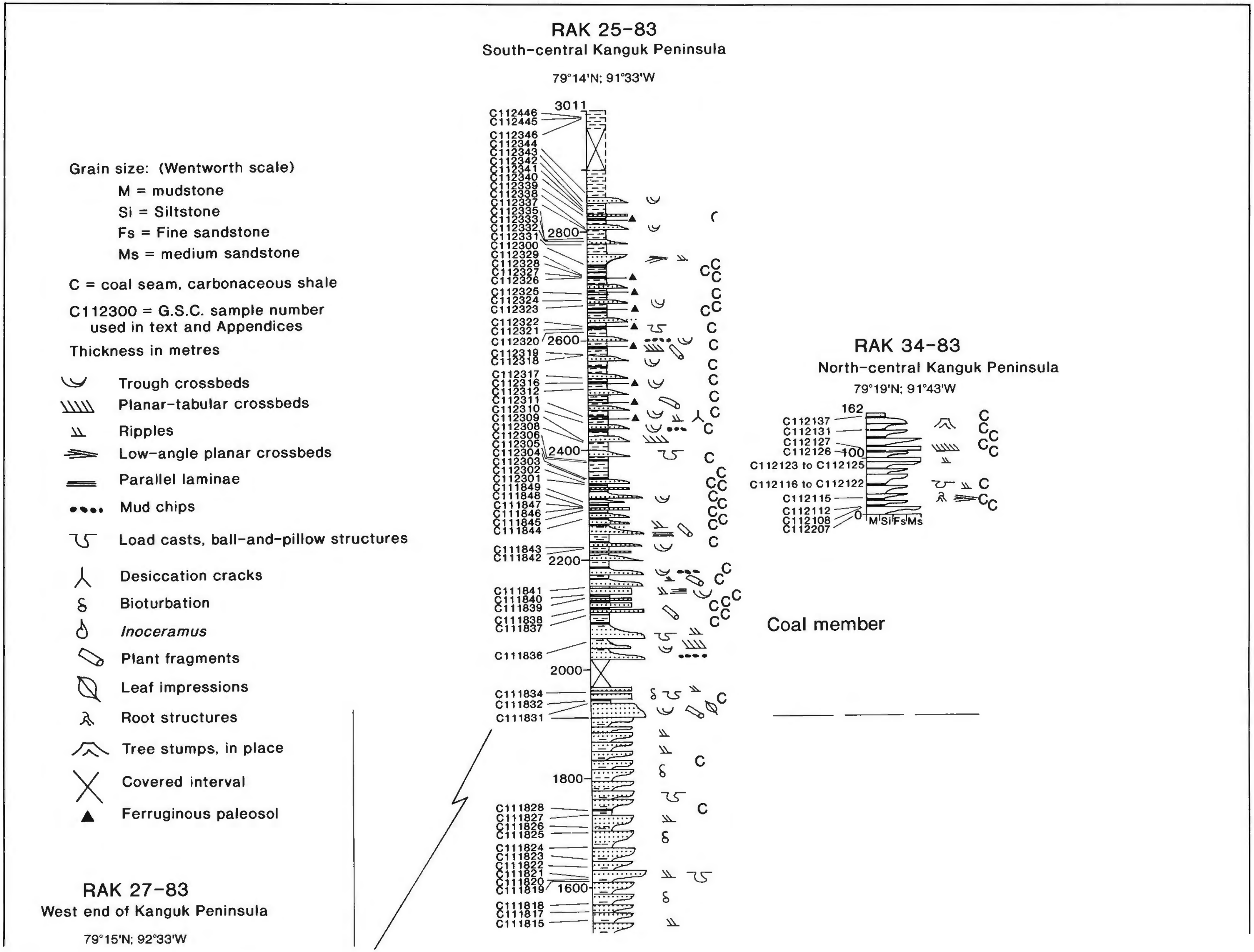
PALEOGEOGRAPHY AND DELTA EVOLUTION

During late Turonian to early or middle Campanian time, the Kanguk Sea extended over the entire Sverdrup Basin and beyond, to areas including Bylot Island and southwest Greenland, and west toward the Beaufort-Mackenzie region of northwestern Canada. This drowning event is recorded in many parts of North America (e.g., Hancock and Kauffman, 1979); for example, the Wapiabi Formation in the Foothills of Alberta and British Columbia (Stott, 1984), and the widespread Mancos Shale and its equivalents in central and northwestern U.S.A. In the Strand Fiord area, the Kanguk Formation disconformably overlies the Strand Fiord volcanics, although the duration of the hiatus may only reflect the initial Kanguk transgression over a subaerial volcanic edifice.

The principal depocentre of eastern Sverdrup Basin is located on central Axel Heiberg Island (Balkwill, 1978). At Strand Fiord, the first influx of coarse clastic debris composing the basal Eureka Sound strata occurred in the middle and possibly even early Campanian. Ages are based on palynology and a well preserved Inoceramid fauna. Previous estimates placed the base of the Eureka Sound Group in the Maastrichtian. However, it is clear that the final stage of Sverdrup Basin filling commenced considerably earlier. The Eureka Sound Group along western Axel Heiberg Island represents two major episodes of delta progradation. A wave dominated delta (Expedition Formation) and a second, more fluvial dominated delta system represented by the progradational portion of the Strand Bay Formation, and the Iceberg Bay Formation. By early Maastrichtian time, large volumes of quartz-rich sand had been supplied to the basin, and are preserved in two members of the Expedition Formation. Strata consist of coarsening-upward shale-sandstone units that record the transition from prodelta (below wave base) and lower shoreface conditions, to upper shoreface and foreshore (beach) settings. The units are interpreted as (approximately) westward prograding lobes of a wave dominated delta strandplain. High depositional energies are reflected, not only in the vertical facies associations and bedforms but also in the style of bioturbation, where *Chondrites* assemblages in the argillaceous components give way to abundant *Skolithos* in the crossbedded sandstones, representing a more opportunistic assemblage. Evidence of marine conditions is provided by the molluscan fauna together with the abundance and diversity of trace fossils. The relative paucity of major distributary channels along modern wave dominated coasts is also reflected here in the Eureka Sound Group by the lack of thick channel sandstones, except at the top of the lower Expedition Formation member. Repetition of the coarsening-upward units probably resulted from lateral migration of the few channels that were present, the accumulation of sand reflecting proximity to the sediment conduit. The single, well preserved example of barrier island development in the Lower member of the Expedition Formation is thought to represent reworked sand on a temporarily abandoned segment of the delta, and is analogous to the modern Brazos River delta and its adjacent barrier island system. Development of a wave dominated coast can be explained in terms of steep submarine slopes and relatively low sedimentation rates during the initial stages of basin filling. With steep slopes there is only minimal attenuation of waves, and nearshore marine processes are capable of completely reworking sediment supplied by the fluvial conduits. Notably, this situation is reversed in the younger members of the Eureka Sound Group.

The subsequent transgression during middle Paleocene time resulted in inundation of the entire Strand Fiord region (this event has now been traced over most of the Axel Heiberg and western Ellesmere Island region – Ricketts 1985, 1986). The abrupt Strand Bay/Expedition Formation contact represents the surface of maximum flooding. However, the sequence boundary is placed in sandstones in the uppermost Expedition Formation. Subsequent deposition of almost 300 m of shale took place during the second major episode of delta progradation that gave rise to the Strand Bay and Iceberg Bay formations. Thin sheet sandstones intercalated with the shale are interpreted as shallow offshore sand bars and narrow barrier islands that accumulated by reworking of sand on the drowned delta. Comparison is made with the modern Chandeleur Island chain that contains sandstone reworked from the abandoned St. Bernard lobe of the Mississippi Delta.

The Lower member of the Iceberg Bay Formation represents renewed delta progradation and rapid sedimentation, although the sedimentary processes were different from those of the subjacent deltas. The Lower member can be described in terms of a single coarsening-upward facies that contains a style of bedding, bedforms and trace fossil assemblage indicative of depositional regimes of lower energy than those encountered in the wave dominated systems. Each coarsening-upward succession (corresponding to the parasequence of Haq et al., 1987) represents a prograding, interdistributary bay/subdelta lobe that contained shoreface and foreshore deposits. Thin coal seams in the upper part of the member provide evidence of subaerial exposure and growth of vegetation, and the transition through a strand line. Lateral facies changes indicate that coastal marshes and narrow, muddy tidal flats formed along the inner margins of some lobes. The lobes were fed by several, semi-permanent crevasse channels. Channel switching was probably a consequence of flooding or the loss of gradient advantage during progradation, and eventually, with continued subsidence, gave rise to the thick, cyclic sequence. Thus, the lower Iceberg Bay Formation deposits are thought to reflect the transition from wave to increasingly fluvial dominated conditions. A modern analogy is less easy to establish, but an appropriate scenario might include elements from both the Mississippi birdfoot delta, and the modern


RAK 25-83
South-central Kanguk Peninsula
79°14'N; 91°33'W
3011
2800
2600
2400
2200
2000
1800
1600
C112446
C112445
C112346
C112344
C112343
C112342
C112341
C112340
C112339
C112338
C112337
C112335
C112333
C112332
C112331
C112300
C112329
C112328
C112327
C112326
C112325
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C112309
C112308
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C112304
C112303
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C112301
C111849
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C111827
C111826
C111825
C111824
C111823
C111822
C111821
C111820
C111819
C111818
C111817
C111815
RAK 34-83
North-central Kanguk Peninsula
79°19'N; 91°43'W
162
100
0
C112137
C112131
C112127
C112126
C112123 to C112125
C112116 to C112122
C112115
C112112
C112108
C112207
M Si Fs Ms
Coal member
Grain size: (Wentworth scale)
M = mudstone
Si = Siltstone
Fs = Fine sandstone
Ms = medium sandstone
C = coal seam, carbonaceous shale
C112300 = G.S.C. sample number used in text and Appendices
Thickness in metres
Trough crossbeds
Planar-tabular crossbeds
Ripples
Low-angle planar crossbeds
Parallel laminae
Mud chips
Load casts, ball-and-pillow structures
Desiccation cracks
Bioturbation
Inoceramus
Plant fragments
Leaf impressions
Root structures
Tree stumps, in place
Covered interval
Ferruginous paleosol
RAK 27-83
West end of Kanguk Peninsula
79°15'N; 92°33'W

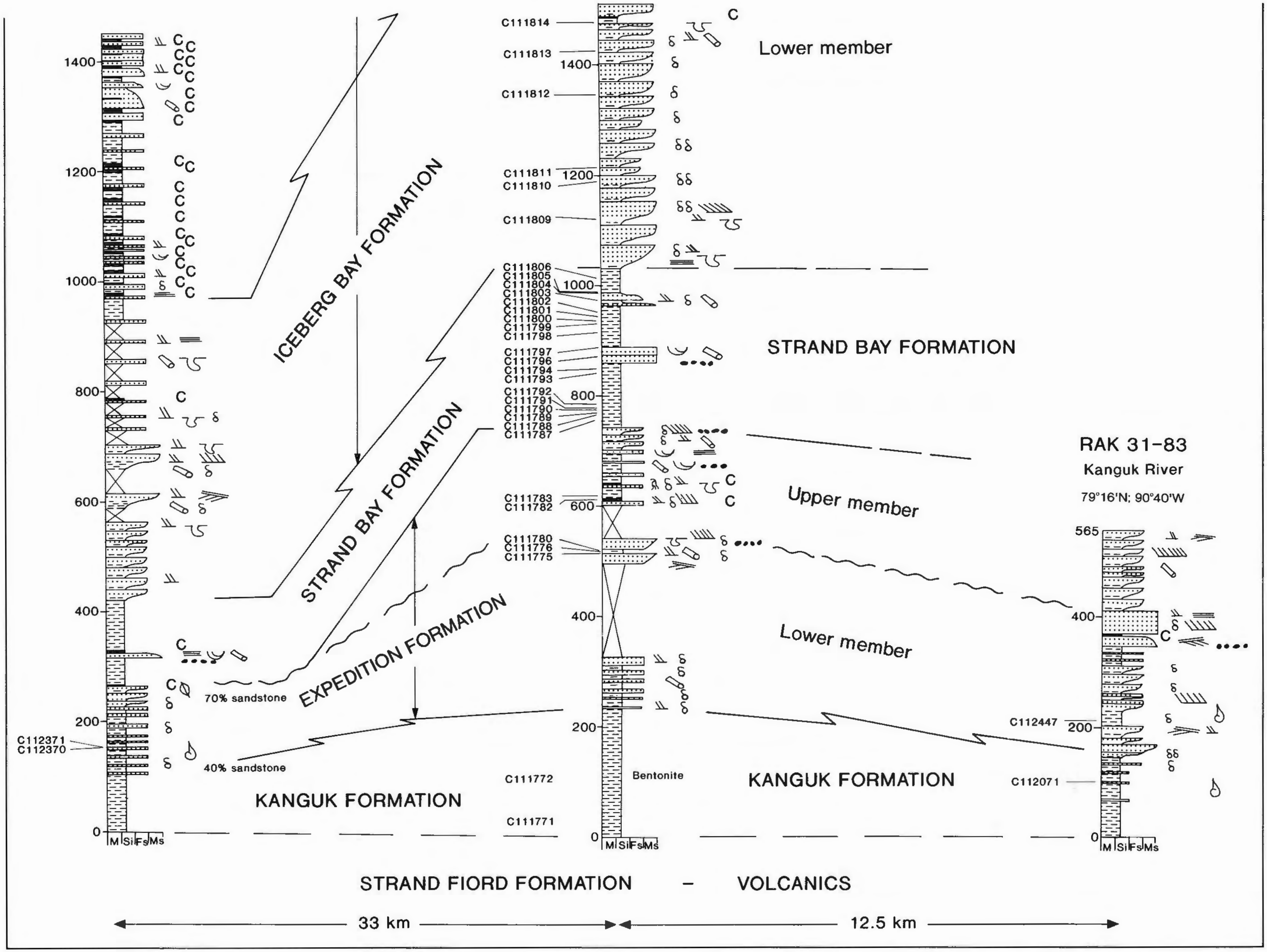

Figure 49. *Details of four measured sections of the Eureka Sound Group on Kanguk Peninsula, showing all map units, principal sedimentary structures, and sample locations and numbers (C-numbers, referred to in Appendices 2 and 3). Stratigraphic thicknesses, in metres, are measured from the base of the Kanguk Formation.*

Tabasco delta plain of southeastern Mexico. The latter possesses an arcuate coastline and slightly higher wave energies than does the Mississippi.

The increase in fluvial dominance and sedimentation rates in the second delta system are further evident from the Coal member of the Iceberg Bay Formation. These strata are the youngest at Strand Fiord, and have been dated by palynology as Early and Middle Eocene. Ninety-five per cent of the Coal member consists of fining-upward sandstone-coal units that originated from lateral migration of high sinuosity fluvial channels. Forest conditions developed in some areas of the overbank realm, reflected by large mineralized tree trunks in growth position, and the common occurrence of coals. Coal seams tend to be thickest in the lower half of the unit, thinning toward the top, a sequence that may reflect a transition from lower to upper delta plain. This transition is further reflected in two additional features: 1) calcareous, ferruginous paleosols are interbedded with overbank coals and shale in the upper half of the Coal member; 2) several fluvial sequences lower down in the member are capped by thin, white, calcareous sandstones that represent local marine incursions and reworking of sand near abandoned channels. These minor transgressive events can be regarded as initiating the succeeding delta plain sequence. A thicker barrier island/tidal delta sequence occurs near the top of the member and indicates a marine incursion that probably extended over an entire abandoned delta lobe.

The transition from a wave dominated to more fluvial dominated delta following the middle Paleocene transgression can be explained in terms of the steadily decreasing slope of the submarine profile and concomitant shoaling conditions (where the younger delta prograded over the drowned platform of sandstone and shale comprising the Expedition Formation), together with a rapid increase in sedimentation rates. The changing conditions further reflect increased rates of subsidence within the depocentre of Sverdrup Basin, and uplift of the adjacent foreland. Thus, the Eureka Sound basin, referred to as Fosheim Basin (Ricketts, 1987), can be viewed as developing adjacent to a terrane that was uplifted during the early stages of the Eurekan Orogeny, with the climactic phase of tectonism (folding and thrusting) postdating the Middle Eocene strata at Strand Fiord. As basin filling proceeded, fluvial processes became increasingly dominant, ultimately giving rise to an extensive, vegetated delta plain, that can be correlated from Strand Fiord to Fosheim Peninsula and Strathcona Fiord. In fact, the degree of forestation in some places (especially the Strathcona area) was capable of supporting a diverse vertebrate fauna, including primates, rodents, turtles, crocodiles, and several other species (West et al., 1977).

DEPOSITIONAL SEQUENCES

Brief references to depositional sequences and sequence boundaries in the Eureka Sound Group succession have been made throughout this text. Three principal orders of cyclicity, or sequence, are recognized herein, and these are summarized below — the conceptual framework for depositional sequences has been discussed by Frazier (1974), Vail et al. (1977), Haq et al. (1988), and Embry and Podruski (1988). The important question as to what controls the development of such sequences (for example, the interplay between eustacy and tectonics) will be addressed in greater detail in future papers dealing with the Eureka Sound Group basin as a whole. Only the general nature of the processes involved in basin formation and consequent relative sea level changes will be discussed here. The processes include:

1. A component of thermal subsidence, a remnant of the main phase of Sverdup Basin subsidence (e.g., Stephenson et al., 1987).
2. The increasing effects of subsidence due to tectonic loading, as ocean-opening (Baffin Bay) and attendant crustal shortening signalled the Eurekan Orogeny.
3. Rapid sediment loading at the basin depocentre (Strand Fiord area), decreasing toward the basin margin.
4. Eustatic sea-level changes.
5. Clearly, there was a major tectonic influence on basin development (i.e., Fosheim Basin), which must have increased as the main phase of deformation was approached in the Middle Eocene. It is possible that, in the region of maximum subsidence, eustatic sea-level changes would be overshadowed by these other effects, whereas, toward the basin margins where subsidence was less, eustatic changes would have had more influence on the stratigraphic succession. Nummedal and Swift (1987) have suggested this kind of scenario for the foreland basin of the Rocky Mountain region.

The entire Eureka Sound Group succession on western Axel Heiberg Island comprises two major sequences (second-order sequences, spanning 20 to 30 million years).

Second-order sequences

Sequence 1. Kanguk and Expedition formations

Contact between the Kanguk Formation and the predominantly subaerially extruded Strand Fiord volcanics is probably a hiatal surface. Volcaniclastic rubble exposed in a few places at the contact may be the product of subaerial weathering. The basal 40 to 50 m of the Kanguk Formation at Surveyor Mountain are rich in dinoflagellates and foraminifera and may have accumulated during the initial transgression. The bulk of the Kanguk, however, along with the sandy Expedition Formation, constitutes the regressive component of the sequence.

Sequence 2. Uppermost Expedition Formation, Strand Bay, and Iceberg Bay formations (middle Paleocene to Middle Eocene)

The basal sequence boundary appears to be a conformity, although there is equivocal evidence of a ravinement surface in the uppermost Expedition Formation. Distinction between the transgressive and regressive parts of this sequence is difficult. Most of the shale appears to be part of the regressive phase, which culminated in a very thick sandstone succession (various fluvial dominated delta front and delta plain facies). The Strand Bay/Expedition Formation contact is a surface representing maximum flooding. A succession of shoreface sandstones at the top at the Expedition Formation contains a basal pebble lag that appears to cut deep into the underlying shoreface strata. This conglomerate is more likely to be a ravinement fill, rather than a subaerial lag; the subaerial sequence boundary is therefore missing.

Third-order sequences

At present, the most definitive examples of this category are the Lower and Upper members of the Expedition Formation. In thickness (300 m and 200 m, respectively) and duration (approximately 4 to 8 million years), they correspond with the Mesozoic third-order depositional sequences in Sverdrup Basin (Embry and Podruski, 1988). The bulk of each sequence is regressive, although the transition from Lower to Upper member (transgressive component) represents an overall 'landward' shift in the locus of deposition. In other parts of Fosheim Basin, the Lower/Upper member contact is marked by a significant unconformity (e.g., western Ellesmere Island), beneath which all or part of the Maastrichtian has been removed. Third-order sequences are made up of many smaller-scale units.

Fourth- or fifth-order sequences

Coarsening- and fining-upward sequences, metres to a few tens of metres thick, are readily identifiable in the field. In the Strand Fiord area, these include more than 40 coarsening-upward units in the Expedition Formation and Lower member of the Iceberg Bay Formation, and many fining-upward units in the uppermost Coal member.

Excellent examples of prograding prodelta-shoreface sequences in the lower Expedition Formation (Figs. 6, 7) preserve the initial transgressive component, preserved as thin, green, bioturbated sandstones at the top of each underlying sequence. Subaerial unconformities are not obvious, although the transgressive green sandstone layers may have cut into the subjacent shoreface deposits (ravinement surface). This transgressive ravinement surface probably removed most of the subaerial unconformity. Thus, in Figure 6, the actual upper sequence boundary of Unit A (lower sequence boundary of Unit B) occurs a few tens of centimetres below the top of the coarsening-upward profile. Above the transgressive sandstone resistant, sideritic, fossiliferous ironstone ribs occur. These beds indicate low rates of sedimentation and correspond to a condensed stratigraphic section. The ironstone layers are common at or immediately above the boundaries of third- and higher-order sequences. The remainder of each coarsening-upward sequence is the sand-dominated regressive component.

COAL RESOURCES

The resource potential of coal deposits in the Canadian Arctic Archipelago has been summarized by Ricketts and Embry (1984). Significant resources occur at Strand Fiord in the Eureka Sound Group and coal deposits are moderately well exposed along Kanguk Peninsula and Expedition Fiord. However, access by shipping is limited because of semi-permanent sea ice.

All coal seams encountered in measured sections and greater than 0.5 m thick have been listed in Appendix 1. The inferred paleoenvironmental setting of the coal has also been included, because this will determine the lateral extent and thickness of seams likely to be encountered in that facies. For example, lower delta plain fluvial systems appear to contain thick, laterally extensive seams that accumulated in overbank, marsh and lacustrine settings, whereas seams associated with strandplains in a wave dominated delta are less extensive. Thus, the Coal member contains the bulk of the potentially mineable coal and has been mapped in five areas along Kanguk Peninsula and northern Expedition Fiord. At Section RAK 25, at least 30 seams thicker than 0.1 m are exposed, capping fining-upward sequences, within a stratigraphic interval of 745 m (i.e., 5%). Because many of the fine grained strata are weathered recessively, the proportion of coal in the sequence could be as high as 10 per cent. The thickest seam is six metres in thickness, and several exceed two metres.

Resource calculations made for coals in the Coal member on Kanguk Peninsula are based on measured seam thickness, observed lateral extent of some but not all seams, and structural geometry of the areas in which the Coal member has been mapped. These calculations fall into the 'speculative' category, as outlined in EMR Report ER 79 – 9 (Bielenstein et al., 1979). A cut-off value of 0.5 m has been used. For the area encompassing Section RAK 25, the total cumulative thickness of seams is 33 m. Other parameters used in the calculation include: average structural dip of 45 degrees, a maximum vertical depth of 100 m, and an average specific gravity of 1.35 for subbituminous coals (G.G. Smith, pers. comm., Resource Evaluation Section, I.S.P.G.). The amount of coal calculated here is 109 million tonnes. If a seam thickness cut-off value of 1.0 m is used, the tonnage is reduced to 93 million tonnes.

The thickness of the Coal member exposed on the west end of Kanguk Peninsula is only 461 m, with 20 seams present; maximum seam thickness is 3.5 m. Because of the proximity of the exposures to the shoreline, a vertical depth of only 30 m is used. Total tonnage here is about 3 million tonnes.

Two areas of the Coal member facing the south shore of Expedition Fiord contain minor amounts of coal. The cumulative thickness at Section RAK 34 is 12.7 m, the thickest seam being 2.5 m. Together, these two areas account for 4 to 6 million tonnes. The amount of coal present along the north shore of Expedition Fiord is unknown.

Thus, the total speculative coal resource present in the Eureka Sound Group along Kanguk Peninsula is 115 to 118 million tonnes. This figure does not take into account ash content or recovery factors.

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APPENDIX 1

Location of coal seams in measured sections in the region of Kanguk Peninsula

SECTION RAK 25-83. Co-ordinates at base of formation, lat. 79°14′N; long. 91°29′W (Kanguk-Eureka Sound contact.)

Eureka Sound Group

Height above base (m)	Seam thickness (m)	Map unit	Assessed paleoenvironment
363	0.5	2[2]	Delta strandplain
373	0.5	2	Delta strandplain
1243	0.2	4[4]	Interdistributary bay
1372	0.1	4	Interdistributary bay
1418	0.1	4	Interdistributary bay
1555	0.2	4	Interdistributary bay
1706	1.0	5[5]	Lower delta plain
1848	0.2	5	Lower delta plain
1887	0.2	5	Lower delta plain
1898	0.1	5	Lower delta plain
1918	0.2	5	Lower delta plain
1983	0.5	5	Fluvial overbank, swamp
2029	0.5	5	Fluvial overbank, swamp
2045	0.2	5	Fluvial overbank, swamp
2054	6.0	5	Fluvial overbank, swamp
2084	4.5	5	Fluvial overbank, swamp
2096	1.5	5	Fluvial overbank, swamp
2107	4.0	5	Fluvial overbank, swamp
2131	2.4	5	Fluvial overbank, swamp
2164	3.8	5	Fluvial overbank, swamp
2209	1.0	5	Fluvial overbank, swamp
2225	1.4	5	Fluvial overbank, swamp
2278	0.5	5	Fluvial overbank, swamp
2290	0.2	5	Fluvial overbank, swamp
2344	0.2	5	Fluvial overbank, swamp
2378	2.0	5	Fluvial overbank, swamp
2395	2.0	5	Fluvial overbank, swamp
2465	0.5	5	Fluvial overbank, swamp
2489	2.1	5	Fluvial overbank, swamp
2504	0.7	5	Upper delta plain, fluvial overbank swamp
2501	0.5	5	Fluvial overbank, swamp
2530	1.7	5	Fluvial overbank, swamp
2551	0.3	5	Fluvial overbank, swamp
2558	0.2	5	Fluvial overbank, swamp
2570	0.1	5	Fluvial overbank, swamp
2632	1.0	5	Fluvial overbank, swamp

Top of measured section. An additional 100 m (approx.) may contain several thin coal seams.

SECTION RAK-26-83. Strand Fiord volcanics. Co-ordinates at base of formation, lat. 79°29.5′N; long. 91°33′W.

Height above base (m)	Seam thickness (m)	Assessed paleoenvironment
78	0.1	Lacustrine, in a volcanic terrane

SECTION RAK 27-83. Eureka Sound Group. Co-ordinates at base of formation, lat. 79°15′N; long. 92°26′W.

Height above base (m)	Seam thickness (m)	Map unit	Assessed paleoenvironment
171	2.0	1[1]	Delta strandplain
230	1.0	3[3]	Back barrier marsh
678	0.1	4	Interdistributary bay
867	0.1	5	Fluvial overbank, swamp
890	0.2	5	Fluvial overbank, swamp
908	1.0	5	Fluvial overbank, swamp
929	1.5	5	Fluvial overbank, swamp
1000	1.0	5	Fluvial overbank, swamp
1016	1.5	5	Fluvial overbank, swamp
1044	1.5	5	Fluvial overbank, swamp
1056	0.5	5	Fluvial overbank, swamp
1125	2.0	5	Fluvial overbank, swamp
1137	3.5	5	Fluvial overbank, swamp
1170	1.0	5	Fluvial overbank, swamp
1228	3.0	5	Fluvial overbank, swamp

SECTION RAK 30-83. Eureka Sound Group. Coordinates at base of formation, lat. 79°08′N; long. 90°14′W.

Inclement weather prevented measurement of this section. The lower two thirds consists of Map Unit 1 and only a few shaly coals occur, representing organic accumulation in wave dominated, delta strandplain settings.

SECTION RAK 31-83. Eureka Sound Group. Coordinates at base of formation, lat. 79°16′N; long. 90°41′W.

Height above base (m)	Seam thickness (m)	Map unit	Assessed paleoenvironment
219	1.0	1	Back barrier lagoon

SECTION RAK 34-83. Eureka Sound Group. Coordinates at base section, lat. 79°18′N; long. 91°14′W.

Height above base (m)	Seam thickness (m)	Map unit	Assessed paleoenvironment
13	1.5	4	Interdistributary bay
17	2.0	4	Interdistributary bay
51	1.0	4	Interdistributary bay
52.5	0.5	4	Interdistributary bay
116	1.0	5	Interdistributary bay, overbank
130	1.0	5	Interdistributary bay, overbank
132	1.2	5	Interdistributary bay
149	1.0	5	Fluvial overbank, coastal forest
162	2.5	5	Fluvial overbank, coastal forest
172	1.0	5	Fluvial overbank, swamp

Map units

[1] Expedition Formation – Lower member
[2] Expedition Formation – Upper member
[3] Strand Bay Formation
[4] Iceberg Bay Formation – Lower member
[5] Iceberg Bay Formation – Coal member

APPENDIX 2

Micropaleontology

J.H. Wall

PART A

Kanguk Formation from three different measured sections

Field no. and stratigraphy	Locality and microfossils
GSC loc. C-111771 83 RAK – 25 – 4 30.2 m above base of formation (Fig. 49)	South shore of Kanguk Peninsula, Strand Fiord, 79°14′N, 91°32′W; NTS 59 H Foraminifera: *Saccammina* sp. – one *Ammodiscus* sp. – three *Miliammina* sp. – two *Haplophragmoides* sp. – spp., siliceous, thin-walled, much compressed poorly preserved *Pseudobolivina rollaensis* (Stelck and Wall) – prominent *Trochammina* sp. – spp., siliceous, thin-walled, much compressed, poorly preserved *Verneuilinoides*(?) sp., poorly preserved *Radiolaria*(?): questionable spherical form *Porifera*: siliceous spicules Algal(?) cysts: circular form

Age: Late Cretaceous, stage uncertain, but the microfauna suggests equivalence with the lower part of the range of the *Dorothia smokyensis* assemblage of Wall (1983 p. 264); that is, Turonian to early Santonian.

Environment: Marine, neritic.

Field no. and stratigraphy	Locality and microfossils
GSC loc. C-112430 83 RAK – 29 – 15 42.0 m above base of formation	Surveyor Mountain, 79°22′N, 92°20′W; NTS 59 G Foraminifera: *Saccammina* spp. *Ammodiscus* sp. *Scherochorella pepperensis* (Loeblich) *Haplophragmoides* bonanzaense Stelck and Wall *H. howardense manifestum* Stelck and Wall *H.* sp. *Texturlaria* sp., tiny *Trochammina* sp. – spp. *Dorothia smokyensis* Wall *Massilina*(?) sp., small – one *Nodosaria* sp. – one large chamber *Globulina* sp. *Neobulimina albertensis* (Stelck and Wall) *N.* sp. cf. *N. canadensis* Cushman and Wickenden *N.* sp. of Wall, 1960, 1967 *Guembelitria* sp. of Wall, 1960, 1967 *Nonionella* sp., tiny *Diatomacea*: *Coscinodiscus* sp. – spp. unidentified forms *Bivalvia* (*Peleycoda*): *Inoceramus* sp. – presence indicated by clusters of aragonite prisms Pisces: traces of bone

Age: Late Cretaceous, Turonian to early Campanian, *Dorothia smokyensis* assemblage of Wall (1983 p. 264). Stage cannot be determined, but is probably in lower to middle range of the assemblage; that is, about late Turonian to early Santonian.

Environment: Marine, moderate depth on shelf.

Field no. and stratigraphy	Locality and microfossils
GCS loc. C-100566 83 EL – 3 – 128 9.0 m below base of overlying Eureka Sound Group	Kanguk River, 79°16′N, 90°38′W; NTS 59 H Foraminifera: *Ammodiscus* sp. *Reophax* spp. – two *Haplopragmoides* sp. cf. *H. hendersonense* Stelck and Wall *H. howardense* Stelck and Wall – prominent *H. kirki* Wickenden *H.* spp. *Recurvoides* spp. *Pseudobolivina rollaensis* (Stelck and Wall) – prominent *Trochammina albertensis* Wickenden *Verneuilinoides bearpawensis* (Wickenden) *V.* sp., small, elongate – two *Arenobulimina* sp. cf. *A. torula* Tappan *Dorothia smokyensis* Wall

Age: Late Cretaceous, probably within the Santonian to early Campanian time span. As the fauna contains elements of both the Turonian to early Campanian *Dorothia smokyensis* assemblage and the late Campanian *Verneuilinoides bearpawensis* assemblage of Wall (1983 p. 265), it is difficult to make a precise age assignment. A similar situation with an overlap of these assemblages has been observed by the writer from the upper part of the Kanguk Formation at Slidre Fiord, west-central Ellesmere Island, B.D. Ricketts, Section 85 RAK – 13, GSC loc. C – 131379.

Environment: Marine, neritic, shallow to moderate depth.

Comments

The above samples were selected for discussion because they have yielded the most diversified assemblages at their respective localities. Nevertheless, age assignment at stage level is difficult as the ranges of specific components are somewhat extensive in southern regions of Canada. On western Axel Heiberg Island, the foraminiferal data are interpreted as being indicative of a Turonian to early Campanian interval for the Kanguk Formation.

PART B

Strand Bay Formation, Eureka Sound Group

Locality: 83 RAK – 25, Strand Fiord, as in Part A.

Sample positions are quoted in metres above the base of Section RAK – 25 (Fig. 49), corresponding to the base of the Kanguk Formation.

Field no. and stratigraphy	Microfossils
GSC loc. C-111788 83 RAK – 25 – 20 760.1 m above base of section	Foraminifera (common, about 70 specimens): *Saccammina* spp. – prominent *Hippocrepina* spp. *Miliammina*(?) sp. – one Ostracoda: genus indeterminate – two poorly preserved fragment
GSC loc. C-111792 83 RAK – 25 – 23 787.1 m above base of section	Foraminifera (about 50 specimens): *Saccammina* spp. *Hippocrepina* spp. *Haplophragmoides*(?) sp. – one *Cyclogyra* sp. – one incomplete specimen *Fissurina*(?) sp. – one *Cassidulina*(?) sp., small – one *Nonion*(?) sp. – one incomplete specimen Ostracoda: genus indeterminate – six specimens
GSC loc. C-111800 83 RAK – 25 – 32 934.8 m above base of section	Foraminifera: *Saccammina* spp. – 12 specimens *Miliammina*(?) sp. – a fragment of a large species *Haplophragmoides* sp. – one *Haplophragmoides* or *Trochammina* sp., poorly preserved – two
GSC loc C-111805 83 RAK – 25 – 38 988.7 m above base of section	Foraminifera: *Saccammina* spp. *Hippocrepina* sp. – one *Miliammina*(?) sp. Ostracoda: genus indeterminate – valve fragments

Field no. and stratigraphy	Microfossils

Age: Although the microfossil recovery varies greatly over the approximately 250 m interval examined, the general character of the microfossils is basically the same in the bottom and top beds. The species of *Saccammina* in this section match closely those from the *Saccammina – Trochammina* spp. assemblage in the Aklak Member of the Reindeer Formation of the Mackenzie Delta. An age of Late Paleocene to Early Eocene is assigned to the latter on the basis of associated palynomorphs (McNeil, 1985, p. 36). However, from a recent palynological study of the Strand Bay Formation at the same locality, by D.J. McIntrye (reported herein in Appendix 3), a mid to Late Paleocene age has been interpreted.

Environment: With few exceptions, the assemblages are dominated by simple arenaceous foraminifera, such as *Saccammina* and *Hippocrepina*, suggesting a relatively shallow, probably brackish water depositional environment. The richest foraminiferal populations are observed in the lower 50 m of section, which indicates that the marine influence was more pronounced in the early transgressive stage.

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APPENDIX 3

Palynology

D.J. McIntyre

Samples positions are quoted in metres from the base of Section RAK 25 (Fig. 49), corresponding to the base of the Kanguk Formation

SECTION RAK 25

NTS 59 H, 79°14′N, 91°30-39′W. Strand Fiord, 16 miles west of the head of the fiord

Kanguk Formation

30.2-107.8

C-111771, P2614-1, 25-4, 30.2 m; C-111772, P2614-2, 25-5, 107.8 m

These samples contain abundant dinoflagellates, including the following species:

Chatangiella ditissima (McIntyre) Lentin and Williams
C. granulifera (Manum) Lentin and Williams
Chlamydophorella nyei Cookson and Eisenack
Dorocysta litotes Davey
Heterosphaeridium difficile (Manum and Cookson) Ioannides
Isabelidinium acuminatum (Cookson and Eisenack) Stover and Evitt
I. cooksoniae (Alberti) Lentin and Williams
Laciniadinium arcticum (Manum and Cookson) Lentin and Williams
Odontochitina operculata (Wetzel) Deflandre and Cookson
Spongodinium delitiense (Ehrenberg) Deflandre
Trithyrodinium suspectum (Manum and Cookson) Davey
Wallodinium luna (Cookson and Eisenack) Lentin and Williams

Age: The dinoflagellate assemblage indicates that this interval is of Turonian to Santonian age. The presence of *Dorocysta litotes* together with few specimens and species of *Chatangiella* indicates that the interval is not younger than Santonian. A Turonian or younger age is indicated by the presence of *Chatangiella granulifera* and abundant *Heterosphaeridium difficile* and *Isabelidinium cooksoniae*. The presence of abundant *Spongodinium delitiense* suggests that the interval is no older than Santonian, but this cannot be conclusively demonstrated at present.

Expedition Formation – Lower member

No samples examined

Expedition Formation – Upper member

510.2-616.8 m

C-111775, P2614-3, 25-8, 510.2 m; C-111776, P2614-4, 25-9, 523.8 m; C-111780, P2614-5, 25-12, 533.4 m; C-111782, P2614-6, 25-14, 605.5 m; C-111783, P2614-7, 25-15, 616.8 m

The five samples from this interval contain pollen assemblages of terrestrial origin. The more important and abundant species are as follows:

Aquilapollenites asper Mtchedlishvili
A. augustus Srivastava
A. quadrilobus Rouse
A. senonicus (Mtchedlishvili) Tschudy and Leopold
Callistopollenites radiatostriatus (Mtchedlishvili) Srivastava
Expressipollis ocliferius Chlonova emend. Bondarenko
Fibulapollis mirificus (Chlonova) Chlonova
Protointegricorpus protrusum Takahashi and Shimono
Loranthacites pilatus Mtchedlishvili
Mancicorpus notabile Mtchedlishvili
Orbiculapollis globosus (Chlonova) Chlonova
Triprojectus magnus (Mtchedlishvili) Stanley
Tumidulipollis accuratus (Chlonova) Bondarenko
Wodehouseia edmontonicola Wiggins

Age: The pollen assemblages from the samples in this interval of the Expedition Formation are all closely similar and clearly indicate an early Maastrichtian age. *Wodehouseia edmontonicola* and *Protointegricorpus protrusum* are restricted to the early Maastrichtian, and *Orbiculapollis globosus* and *Callistopollenites radiatostriatus* first appear in the early Maastrichtian. Some of the other species first appear in the Campanian (e.g., *Tumidulipollis accuratus* and *Expressipollis ocliferius*), but are now known to occur above the early Maastrichtian. Similar assemblages have been recorded from the northern mainland of Canada (McIntyre, 1974), Ellef Ringnes Island (Felix and Burbridge, 1973), and Banks Island (Doerenkamp et al., 1976). The authors referenced also concluded that floras of this type were of Maastrichtian age, and discussed their similarity to assemblages from West Siberia. The assemblages from this interval are mainly of terrestrial origin. The lower samples contain sparse dinoflagellate assemblages consisting of Late Cretaceous species, which may be reworked from the Campanian or Santonian.

Expedition Formation

(Part of Section RAK 25, but collected again later and referred to as Section RAK 15)

C-153156, P3319-1, 15-1, 733.1 m; C-153157, P3319-2, 15-2, 717.1 m; C-153158, P3319-3, 15-3, 707.1 m

These three samples are from the top of the Expedition Formation, immediately below the Strand Bay Formation (samples 19-24 of Section RAK 25). All samples contain abundant pollen and spores but the palynofloras have rather low diversity. The abundant pollen and spore species are different for each samples. Sample C-153158 (707.1 m) is dominated by pollen of the Taxodiaceae-Cupressaceae complex and spores of *Sphagnum*. Sample C-153157 (717.1 m) is dominated by spores of *Osmunda* and has abundant *Lycopodium, Sphagnum* and *Hazaria shepoparii* spores and bisaccate conifer pollen, while the stratigraphically highest sample (C-153156, 733.1 m) is dominated by Taxodiaceae-Cupressaceae and has abundant bisaccate pollen. Taxa present include:

Osmunda sp.
Hazaria sheoparii Srivastava
Sphagnum spp.
Picea sp.
Pinus sp.
Taxodiaceae-Cupressaceae
Metasequoia sp.
Sequoiapollenites sp.
Alnus sp.
Betula sp.
Corylus sp.
Triporopollenites mullensis (Simpson) Rouse and Srivastava
Betulaceous pollen undifferentiated
Paraalnipollenites alterniporus (Simpson) Srivastava
Ericaceae
Fraxinoipollenites variabilis Stanley
Momipites wyomingensis Nichols and Ott
Momipites anellus Nichols and Ott
Insulapollenites rugulatus Leffingwell

Age: All three samples contain angiosperm pollen of betulaceous type including *Betula, Alnus, Paraalnipollenites alterniporus*, and *Triporopollenites mullensis*, which may be abundant but form only a small percentage of the total palynoflora. The presence of *P. alterniporus T. mullensis* and *Momipites* spp. indicates a Paleocene age. A probable Late Paleocene age is indicated by the presence of *Momipites anellus*, which occurs in the P3 to P6 zones of Nichols and Ott (1978), and *Insulapollenites rugulatus*, which was first recorded in their P5 Zone by Nichols and Ott. According to Pocknall (1987), the work of Leffingwell (1971) suggests, however, that the latter may occur slightly earlier, in the P4 Zone, in some areas. The palynological results clearly indicate that this part of the Expedition Formation and the overlying Strand Bay Formation are of similar age; that is, Late Paleocene.

Strand Bay Formation

754.1-842.6 m

C-111787, P2614-7A, 25-19, 754.1 m; C-111788, P2614-8, 25-20, 760.1 m; C-111789, P2614-9, 25-20A, 766.1 m; C-111790, P2614-9A, 25-21, 770.6 m; C-111791, P2614-10, 25-22, 778.1 m; C-111792, P2614-11, 25-23, 787.1 m; C-111793, P2614-12, 25-24, 842.6 m

The samples from this interval yielded pollen assemblages with few species, generally represented by few specimens. Conifer pollen of *Picea* and *Pinus* types is usually common. Other pollen identified include:

Taxodiaceae/Cupressaceae (including *Metasequoia* sp.)
Alnus sp.
Betula sp.
Caryapollenites imparalis Nichols and Ott
Ericaceae
Momipites wyomingensis Nichols and Ott
Paraalnipollenites alterniporus (Simpson) Srivastava
Triporopollenites mullensis (Simpson) Rouse and Srivastava

Age and comments: The sparse pollen floras recovered from this interval are of Paleocene age. *Triporopollenites mullensis* and *Paraalnipollenites alterniporus* range from late Maastrichtian through the Paleocene, while *Alnus* pollen, which is common in some of these samples, is not prominent before the Paleocene, and there is doubt that this taxon occurs in the Maastrichtian. Doerenkamp et al. (1976) did not record *Alnus* in the Maastrichtian in the Arctic and it is possible that records of *Alnus* in the Late Cretaceous of the Arctic are erroneous. The presence of *Momipites wyomingensis* indicates a Paleocene age, and rare specimens of *Caryapollenites imparalis* suggest that the interval is not older than the P4 zone of Nichols and Ott (1978); that is, middle Paleocene, where this species first appears. Pollen floras similar to those from the Strand Bay Formation occur in outcrop and well samples of the Paleocene of the Beaufort Sea/Mackenzie Delta area where species and specimen numbers are also limited.

The palynological assemblages show that the middle Maastrichtian through Early Paleocene, and therefore, the Cretaceous – Tertiary boundary, is not represented in Section RAK 25, unless this substantial period of time occurs in the unsampled interval between 616.8 and 707.1 m.

All samples from the interval 753.8 to 842.6 m contain abundant reworked pollen and dinoflagellates, but the amount of reworked material decreases toward the top of the interval. The dinoflagellates are of Turonian to Santonian age from the Kanguk Formation, and the reworked pollen is from the early Maastrichtian part of the Eureka Sound Group. The species observed are the same as those recorded from the Upper member of the Expedition Formation. Paleocene dinoflagellates are not present in any of the samples from this part of the Strand Bay Formation and it is not possible to confirm whether any part of the formation in this section was deposited in a marine environment.

Strand Bay Formation – Upper part

850.1-1006.7 m

C-111794, P2614-12A, 25-25, 850.1 m; C-111796, P2614-13, 25-27, 872.8 m; C-111797, P2614-14, 25-29, 880.1 m; C-111798, P2614-15, 25-30, 925.8 m; C-111799, P2614-16, 25-31, 930.3 m; C-111800, P2614-17, 25-32, 934.8 m; C-111801, P2614-18, 25-33, 937.8 m; C-111802, P2614-19, 25-34, 945.3 m; C-111803, P2614-19A, 25-36, 973.2 m; C-111804, P2614-19B, 25-37, 982.7 m; C-111805, P2614-20, 25-38, 988.7 m; C-111806, P2614-21, 25-39, 1006.7 m

Pollen assemblages from this interval of the Strand Bay Formation are similar to those of the lower part of the formation in Section RAK 25 in having few poorly preserved specimens and species and being dominated by pollen of the *Picea* and *Pinus* type. Pollen of Taxodiaceae/Cupressaceae is usually common and other species present are:

Alnus sp.
Betula sp.
Caryapollenites imparalis Nichols and Ott
Caryapollenites inelegans Nichols and Ott
Ericaceae
Momipites wyomingensis Nichols and Ott
Paraalnipollenites alterniporus (Simpson) Srivastava
Saxonipollis sp. of Ioannides and McIntyre
Triporopollenites mullensis (Simpson) Rouse and Srivastava
Trudopollis sp. of Manum
Pesavis tagluensis Elsik and Jansonius
Cicatricosisporites cicatricosoides Krutzsch

Age and comments: The pollen floras of the upper part the Strand Bay Formation in this section also indicate a Paleocene age. *Paraalnipollenites alterniporus* and *Triporopollenites mullensis* are present through the Paleocene, and *Momipite wyomingensis* is known only from the Paleocene. *Caryapollenites imparalis* does not occur before the middle Paleocene (see discussion on lower part of Strand Bay Formation) while *C. inelegans* first occurs in Zone P5 of Nichols and Ott (1978). *Saxonipollis* sp. was recorded from the Late Paleocene of the Mackenzie Delta by Ioannides and McIntyre (1980). Thus, a Late Paleocene age for the upper part of the Strand Bay Formation is indicated by the pollen floras, which also suggest correlation with the Late Paleocene Zone P5 of Nichols and Ott (1978). Pollen floras from the upper Strand Bay Formation are also similar to those from the lower Reindeer Formation, of Late Paleocene age, from the Mackenzie Delta area.

There are considerably fewer reworked pollen and dinoflagellates in the upper part of the Strand Bay Formation than in the lower part, but the reworked forms in each are derived from the same intervals.

Paleocene dinoflagellates were not found in this interval of the Strand Bay Formation either, and as was the case for the lower part of the formation, it is not possible to determine on palynological evidence if deposition occurred in a marine environment.

Iceberg Formation – Lower member

1136.0-1671.3 m

C-111809, P2614-22, 25-42, 1136.0 m; C-11810, P2614-23, 25-43, 1197.8 m; C-111811, P2614-24, 25-44, 1221.0 m; C-111812, P2614-25, 25-45, 1358.4 m; C-111813, P2614-26, 25-46, 1420.8 m; C-111814, P2614-27, 25-47, 1486.4 m; C-111815, P2614-28, 25-48, 1557.8 m; C-111817, P2614-29, 25-50, 1568.8 m; C-111818, P2614-30, 25-51, 1574.2 m; C-111819, P2614-31, 25-52, 1614.8 m; C-111820, P2614-32, 25-53, 1622.8 m; C-111821, P2614-33, 25-54, 1624.8 m; C-111822, P2614-34, 25-55, 1645.3 m; C-111823, P2614-35, 25-56, 1660.8 m; C-111824, P2614-36, 25-57, 1671.3 m

The pollen floras of the lower part of the Iceberg Bay Formation are similar to those of the underlying Strand Bay formation and are usually dominated by pollen of the *Picea* and *Pinus* type. Taxodiaceae/Cupressaceae pollen (including *Metasequoia*) is abundant and spores of *Osmunda* and *Sphagnum* occur commonly. The assemblages are more varied than those of the Strand Bay Formation and taxa present include:

Cicatricosisporites cicatricosoides Krutzch
Sparganium sp.
Liliacidites sp.
Alnus sp.
Betula sp.
other betulaceous type pollen
Triporopollenites mullensis (Simpson) Rouse and Srivastava
Ulmus spp.
Ericaceae
Paraalnipollenites alterniporus (Simpson) Srivastava
Momipites wyomingensis Nichols and Ott
Caryapollenites inelegans Nichols and Ott
Caryapollenites imparalis Nichols and Ott
Liquidambar sp.
Onagraceous pollen (of Ioannides and McIntyre)
Pistillipollenites macgregorii Rouse
Trudopollis barentsii Manum
Aquilapollenites tumanganicus Bolotnikova
Insulapollenites rugulatus Leffingwell
Platycarya sp.
Ovoidites sp.

Age and comments: The pollen floras of this part of the Iceberg Bay Formation in Section RAK 25 are also of Late Paleocene age but are somewhat more varied than those of the Strand Bay Formation. The continued presence of *Momipites wyomingensis, Caryapollenites inelegans, C. imparalis* and *Triporopollenites mullensis* indicates a Late Paleocene age for this interval. *Pistillipollenites mcgregorii*, a Late Paleocene to Middle Eocene species, first appears near the base of this interval and *Insulapollenites regulatus* occurs very rarely. Both these species were first recorded in their Zone P5 by Nichols and Ott, and *I. rugulatus* was recorded in Late Paleocene samples from Somerset Island by McIntyre (1989), together with species of *Momipites* and *Caryapollenites*. Rouse (1977), in his study of Arctic Tertiary floras, first recorded *P. mcgregorii* from the Late Paleocene. The presence of *Trudopollis barentsii* in the interval also indicates floral similarities with Somerset Island and especially with floras described from Spitsbergen by Manum (1962) where this species is common. The onagraceous pollen recorded here first appears in the Late Paleocene of the Mackenzie Delta area (Ioannides and McIntyre, 1980) as also do *Aquilapollenites tumanganicus* (*Aquilapollenites* sp. of Staplin, 1976 and *A. echinatus* of Choi, 1983) and *P. mcgregorii*. The extremely rare specimens of *Platycarya* and *Tsuga* found in this interval also suggest Late Paleocene as neither of these became common elsewhere before the Eocene. The pollen evidence from this interval of the Iceberg Bay formation thus indicates a Late Paleocene age and a probable correlation with Zone P5 of Nichols and Ott (1978).

Reworked Late Cretaceous pollen and dinoflagellates occur in the samples from this interval but are not abundant.

Iceberg Bay Formation – Top of Lower member

1704.8-1756.6 m

C-111825, P2614-37, 25-58, 1704.8 m; C-111826, P2614-38, 25-59, 1710.8 m; C-111827, P2614-39, 25-60, 1734.3 m; C-111828, P2614-40, 25-61, 1756.6 m

Lower part of Coal member

1798.2-2288 m

C-111829, P2614-41, 25-62, 1930.4-1930.6 m; C-111831, P2614-42, 25-64, 1925.5 m; C-111832, P2614-43, 25-65, 1948.3-1949.3 m; C-111834, P2614-44, 25-67, 1968.3 m; C-111836, P2614-46, 25-69, 2040.3 m; C-111837, P2614-47, 25-70, 2090.7 m; C-111838, P2614-48, 25-71, 2107.2-2111.7 m; C-111839, P2614-49, 25-72, 2130.2 m; C-111840, P2614-50, 25-73, 2141.2-2141.6 m; C-111841, P2614-51, 25-74, 2160.9 m; C-111842, P2614-52, 25-75, 2224.8-2225.3 m; C-111843, P2614-53, 25-76, 2226.3 m; C-111844, P2614-54, 25-77, 2271.8-2272.3 m; C-111845, P2614-55, 25-78, 2287.6 m; C-111846, P2614-56, 25-79, 2287.7-2288 m

The pollen floras from these intervals are essentially similar to those of the preceding interval and have abundant *Picea, Pinus* and Taxodiaceae/Cupressaceae (including *Metasequoia*). Spores of *Osmunda* and *Sphagnum* are also abundant. As in the preceding interval, tricolpate and tricolporate angiosperm pollen is rare. Other pollen present includes:

Alnus sp.
Betula sp.
other betulaceous pollen
Paraalnipollenites alterniporus (Simpson) Srivastava
Triporopollenites mullensis (Simpson) Rouse and Srivastava
Triporopollenites bituitus (Potonié) Elsik
Ulmus spp.
Ericaceae
Onagraceous pollen (of Ioannides and McIntyre)
Liquidambar sp.
Pterocarya sp.
Tilia sp. (cf. *T. vescipites* Wodehouse)
Pistillipollenites mcgregorii Rouse
Aquilapollenites tumanganicus Bolotnikova
Momipites wyomingensis Nichols and Ott
Caryapollenites inelegans Nichols and Ott
Caryapollenites imparalis Nichols and Ott
Caryapollenites wodehousei Nichols and Ott
Trudopollis rotundus Manum
Sparganium sp.
Liliacidites sp.
Monocolpopollenites sp.

Age and comments: The continued presence of *Caryapollenites inelegans, C. imparalis, C. wodehousei, Momipites wyomingensis* and *Triporopollenites mullensis* indicates a Paleocene age for this interval also. *Pistillipollenites mcgregorii* and *Aquilapollenites tumanganicus* are consistently present and occur abundantly in a few samples. The main difference between this and the preceding interval is the appearance of *Tilia* sp., which occurs in many samples but is very rare. Doerenkamp et al. (1976) and Rouse (1977) did not record *Tilia* in strata they considered Paleocene from the Arctic, but this pollen type occurs as early as middle Paleocene in Wyoming (Nichols and Ott, 1978) and west-central Alberta (D.J. McIntyre, unpublished data), and as rare specimens in the Late Paleocene of Spitsbergen (M.J. Head, pers. comm., 1987). Because of these occurrences and the presence of the typical Paleocene taxa noted above, this interval is considered to be of Paleocene age.

Iceberg Bay Formation – Coal member

2293-2672.8 m

C-111847, P2614-57, 25-80, 2293 m; C-111848, P2614-58, 25-81, 2296 m; C- 111849, P2614-59, 25-82, 2322.8-2323.3 m; C-112301, P2614-61, 25-84, 2337.3 m; C-112302, P2614-62, 25-85, 2338.3 m; C-112303, P2614-63, 25-86, 2346.3-2347.3 m; C-112304, P2614-64, 25-87, 2347.8-2350.3 m; C-112305, P2614-65, 25-88, 2371.3-2371.8 m; C-112306, P2614-66, 25-89, 2373.2-2373.7 m; C-112308, P2614-67, 25-91, 2403.2-2404.2 m; C-112309, P2614-68, 25-92, 2406.0-2407.0 m; C-112310, P2614-69, 25-93, 2451.0-2452.0 m; C-112311, P2614-70, 25-94, 2467.0-2468.4 m; C-112312, P2614-71, 25-95, 2520.9-2521.3 m; C-112316, P2614-72, 25-99, 2532.8 m; C-112317, P2614-73, 25-100, 2544.8 m; C-112318, P2614-74, 25-101, 2586.8 m; C-112319, P2614-75, 25-102, 2586.9 m; C-112320, P2614-76, 25-103, 2619.4-2621.4 m; C-112321, P2614-77, 25-104, 2636.4-2638.4 m; C-112322, P2614-78, 25-105, 2638.8 m; C-112323, P2614-79, 25-106, 2672.8 m

The pollen assemblages in the mainly coaly samples of this interval have considerable variation in species abundances. *Picea* and *Pinus* are abundant in a few samples but are rare in others. Taxodiaceae/Cupressaceae (including *Metasequoia*) occur commonly in most samples. Spores of *Osmunda* are abundant and non-diagnostic tricolpate pollen is abundant in a few samples. The following taxa are present in most samples.

Alnus sp.
Betula sp.
other betulaceous pollen
Paraalnipollenites alterniporus (Simpson) Srivastava
Ulmus spp.
Ericaceae
Liquidambar sp.
Quercus sp.
Ilex sp.
Pterocarya sp.
Pistillipollenites mcgregorii Rouse
Aquilapollenites tumanganicus Bolotnikova
Onagraceous pollen (of Ioannides and McIntyre)
Trudopollis sp. B of Manum
Tricolporopollenites kruschii (Potonié) Thomson and Pflug
Tilia sp. (cf. *T. vescipites* Wodehouse)
Caryapollenites spp.
Liliacidites sp.
Sparganium sp.
Monocolpopollenites sp.
Ovoidites sp.

Age and comments: Pollen of *Tilia* sp. (probably *T. vescipites*) is considerably more abundant in this interval than in the previous interval but was not seen in every sample. Some *Tilia* specimens have a slightly coarser reticulate surface and may belong to *T. crassipites* Wodehouse. *Caryapollenites imparalis* and *C. wodehousei* occur very rarely at the base of the interval but most *Caryapollenites* seen is of the Eocene types recorded by Doerenkamp et al. (1976), Ioannides and

McIntyre (1980) and Choi (1983). The increase in abundance of *Tilia* and the appearance of the younger forms of *Caryapollenites* indicate that this interval is Early Eocene. Further evidence of an Eocene age is provided by the appearance of *Tricolporopollenites kruschii* and *Ilex* sp. The Paleocene – Eocene boundary in this interval is in agreement with that determined in western and northern North America by Nichols and Ott (1978), Rouse (1977), wing (1984), Doerenkamp (1976), Ioannides and McIntyre (1980), Pocknall (1987), and McIntyre (1987). Not all of the significant taxa discussed by these authors (e.g., *Platycarya*) are present but the evidence available from the Strand Fiord section is sufficient to indicate that the determination of the Paleocene-Eocene boundary is accurate and comparable with that in other areas.

Iceberg Bay Formation – Coal member

2678.9-2874.8 m

C-112324, P2614-80, 25-107, 2678.9 m; C-112325, P2614-81, 25-108, 2686.4 m; C-112326, P2614-82, 25-109, 2729.9-2730.3 m; C-112327, P2614-83, 25-110, 2730.3-2730.5 m; C-112328, P2614-84, 25-111, 2730.5-2731.6 m; C-112329, P2614-85, 25-112, 2731.6-2732.0 m; C-112330, P2614-86, 25-113, 2746.6-2747.3 m; C-112331, P2614-87, 25-114, 2763.8-2764.3 m; C-112332, P2614-88, 25-115, 2771.6-2773.0 m; C-112333, P2614-89, 25-116, 2782.3-2782.5 m; C-112335, P2614-90, 25-117, 2795.9 m; C-112337, P2614-91, 25-119, 2801.0 m; C-112338, P2614-92, 25-120, 2802.2 m; C-112339, P2614-93, 25-121, 2813.7 m; C-112340, P2614-94, 25-122, 2819.5 m; C-112341, P2614-95, 25-123, 2826.5 m; C-112342, P2614-96, 25-124, 2828.5 m; C-112343, P2614-97, 25-125, 2835.0 m; C-112344, P2614-98, 25-126, 2874.8 m

As in the preceding part of the Eocene, in this interval there is considerable difference between samples, in the abundances of the main pollen and spore species. In most samples, pollen of *Picea* and *Pinus* is rare but in a few it is abundant. Taxodiaceae/Cupressaceae pollen is commonly present. Spores of *Osmunda* are abundant in many samples and *Deltoidospora* sp. is common to abundant. Some of the angiosperm pollen types in the following list are abundant to dominant in some samples but none are consistently abundant. The main forms present are:

Alnus sp.
Betula sp.
other betulaceous pollen
Ulmus spp.
Ericaceae
Onagraceous pollen (of Ioannides and McIntyre)
Liquidambar sp.
Pterocarya sp.
Caryapollenites spp. (as for previous interval)
Pistillipollenites mcgregorii Rouse
Tilia sp. (T. vescipites Wodehouse)
Tricolporopollenites kruschii (Potonié) Thomson and Pflug
Novemprojectus traversii Choi
Liliacidites sp.
Sparganium sp.
Monocolpopollenites sp.
Tricolpate pollen (non-diagnostic forms)

Age and comments: The pollen floras of this and the preceding interval are very similar and indicate an Eocene (Early to ?Middle) age. A significant difference between the two intervals is the appearance of the distinctive species *Novemprojectus traversii* in the 2678.9 to 2874.3 m interval. It is undoubtedly closely related to *Aquilapollenites tumanganicus*, which is common in the preceding interval but does not occur with *N. traversii*. The top part of the Strand Fiord Section (RAK 25) can be correlated with the top part of the nearby section of Choi (1983), based on the presence in both of *Novemprojectus traversii*. Choi considered this interval to be Middle Eocene, but the absence of many elements of the rich Middle Eocene pollen floras of eastern Axel Heiberg Island suggests it may not be quite so young.

The following three samples were collected from the top of the section (all at 2879 m):

C-112346, P2614-99, 25-128; C-112445, P2614-100, 25-130; C-112446, P2614-101, 25-131

The only Tertiary pollen in these samples appears to be Paleocene. Pollen and dinoflagellates of Cretaceous age are also present.

Summary of age determinations for Section RAK 25, Strand Fiord

30.2-107.8 m	probably Santonian (lower Kanguk Formation)
510.2-616.8 m	early Maastrichtian (Upper member, Expedition Formation
754.1-842.6 m	middle Paleocene (lower Strand Bay Formation)
850.1-1006.7 m	Late Paleocene (upper Strand Bay Formation)
1136.0-1671.3 m	Late Paleocene (Lower member, Iceberg Bay Formation)

1704.8-2288 m	Late Paleocene (Lower member, and basal Coal member, Iceberg Bay Formation)
2293-2672.8 m	Early Eocene
2678.9-2874.8 m	Early to (?)Middle Eocene (Coal member, Iceberg Bay Formation)

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