PALYNOSTRATIGRAPHY AND HYDROCARBON POTENTIAL OF THE UPPER CRETACEOUS KANGUK FORMATION: AN INTEGRATED MULTIDSCIPLINARY ANALYSIS OF THE NORTHEASTERN CANADIAN ARCTIC ARCHIPELAGO

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ABSTRACT

The Kanguk Formation has been studied in detail on Axel Heiberg and Ellesmere Islands, northeastern Sverdrup Basin, utilizing sedimentology, palynology, and organic matter analyses. This Upper Cretaceous unit comprises organic-rich mudstones, bentonite beds, and silt-rich sandstones, and a rich paleontological association with a well-preserved and divers marine and terrestrial palynomorph assemblage.

The sedimentological analysis of this unit includes the definition and interpretation of its facies. According to this analysis the Kanguk Formation was deposited in an anoxic, low shear-stress environment with very low rates of deposition that increased with the influx of coarser sediments into the basin and the establishment of deltaic sedimentation.

Base on rich and divers palynomorph assemblages the Kanguk sections have been precisely dated and correlated. These assemblages present variations in terrestrial versus marine ratios and in diversity values. They are used for a basic recognition of the environments of deposition. Similar variations occur in organic matter values but not in sedimentological features.

Organic matter is abundant anf fairly immature with variable Rock-Eval/TOC pyrolysis values. This formation is mainly a gas-prone unit although some intervals from the lower part of the unit are within the oil window. The features of the organic matter also help broadly with the interpretation of the environment of deposition.

A combination of the sedimentological, palynological, and organic matter analyses has etsablished the nature of the Kanguk Formation and also the hydrocarbon potential. This can be used as a model of reference for the Kanguk Formation in other areas of the Sverdrup Basin.

INTRODUCTION: STUDY AREA AND GEOLOGICAL BACKGROUND

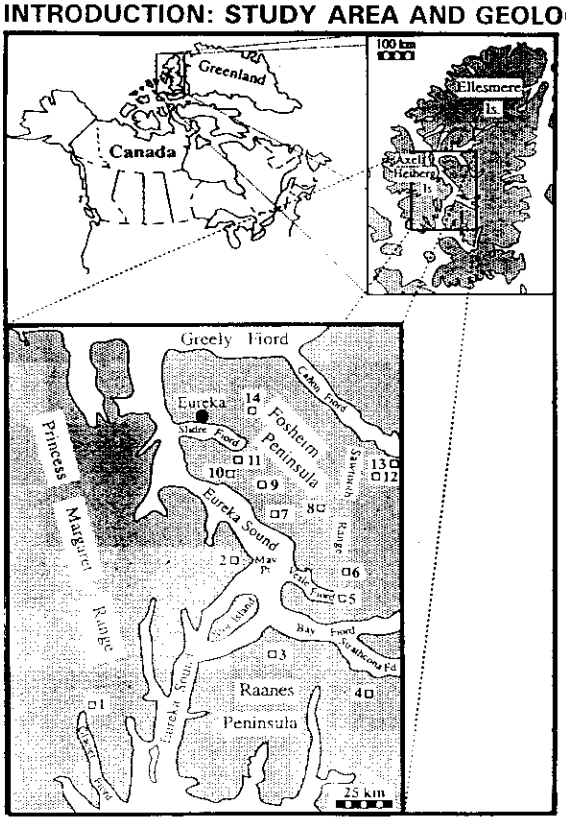
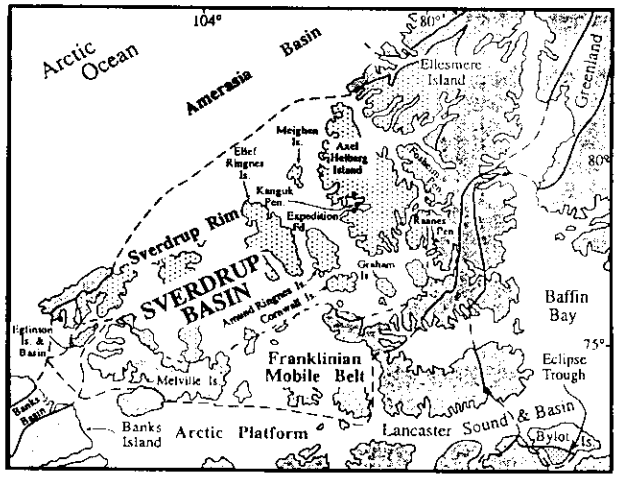


Fig. 1. Study area: southeastern Axel Heiberg and west-central Ellesmere Island. Reference numbers indicate sections included in this study and are located as follows:
A. Sections on Axel Heiberg Island:
1 - Glecier Fiord, 78° 38' N, 89° 55' W;
2 - May Point, 79° 19' 39" N, 85° 32' 27" W.
B. Sections on Ellesmere Island:
3 - Strathcona Fiord, 78° 32' 70" N, 82 54' 55" W;
4 - Bay Fiord, 78° 50' N, 86° 28' W;
5 - Vesle Fiord, 79° 02' 07" N, 83° 09' 36" W;
6 - Mount James, 79° 10' 42" N, 83° 00' 45" W;
7 - Fosheim South, 79° 26'59" N, 84° 09' 28" W;
8 - Sawtooth Range, 79° 35' 47" N, 83° 33' 58" W;
9 - Fosheim Anticline, 79° 42' N, 84° 45' W;
10 - Eureka Sound, 79° 45' N, 85° 36' W;
11 - Romulus Lake, 79° 51' 49", 85° 19' 16" W; and
12 - Mount Bridgeman, 79° 45' 11" N, 82° 39' 12" W;
13 - Canon Fiord, 79° 52' 33" N, 82° 14' 16" W;
14 - Remus Creek, 79° 56' N, 85° 09' W.

This study is aimed at the geological characterization of the Kanguk Formation in the northeastern part of the Sverdrup Basin utilizing a multidisciplinary approach based on palynology, sedimentology, and organic matter analyses. In spite of the singular characteristics of the Kanguk Formation and of large aerial extent covered by it, little research has been conducted in this Upper Cretaceous stratigraphic unit. This formation is present in the remote Canadian Arctic and has neither outstanding lithological features nor any known economic prospects. Yet, the study of this formation will provide data on the stratigraphic framework and on the hydrocarbon. This is important for the interpretation of

the final stages of the Sverdrup Basin, a basin geologically active from the Carboniferous to the early Tertiary over a large Canadian area.



Fid.2. Geographic and geologic map of the Canadian Arctic Archipelago. Structural provinces compiled and modified after Balkwill (1978), De Paor et al. (1989), and Embry, (1991).

The study area covers a region of the Canadian Arctic Archipelago that basically includes part of Axel Heiberg and Ellesmere islands (Fig.1). Upper Cretaceous strata (Kanguk Formation and equivalent units) are widespread in the Canadian Arctic. These units crop out from the Mackenzie Delta to Ellesmere Island and down to Bylot Island. This area includes the Sverdrup, Banks, and Eglinton basins, and partially the Franklinian Mobile Belt, and the Arctic Platform (Fig.2). The Kanguk Formation is the main Upper Cretaceous Arctic unit and is widespread in the Sverdrup and Banks basin, and is also present outside these basins.

Due to the enormous aerial extent of the area covered by this formation only small portion was selected for this study, namely the northeastern coner of the Sverdrup Basin. Yet, the study area covers roughly 30,000 km^2 and includes south and east-central Axel Heiberg and west-central Ellesmere islands (Fosheim and northern Raanes peninsulas). Based on aerial photographs, information from other geologists (i.e. Embry, pers. comm. 1991, 1992) and personal search in the field the best outcrop sections of the Kanguk Formation in this area were measured, sampled and studied. Thereof, a total of 14 sections, two on Axel Heiberg Island and 12 on Ellesmere Island are included in this study (Fig.1).

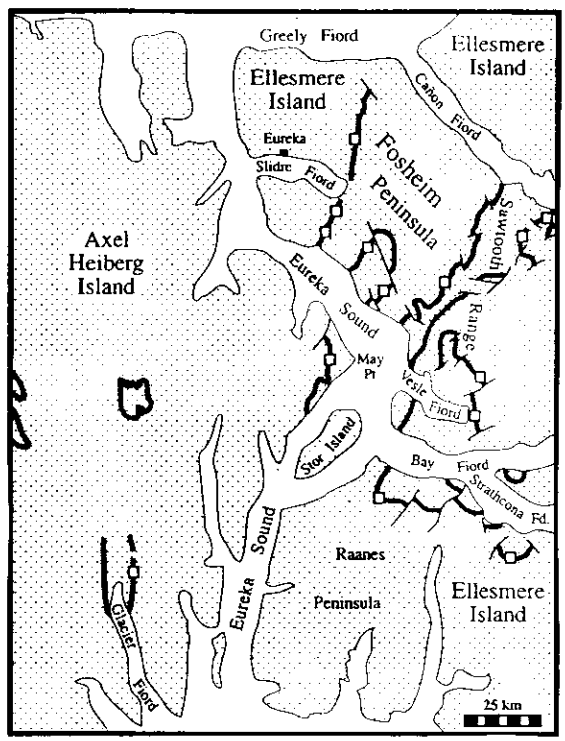


Fig.3. Distribution of Kanguk Formation (dark band) in the study area. Axel Heiberg and Ellesmere Islands, Canadian Arctic Archipelago.

The Albian to Maastrichtian stratigraphy of the northeastern Sverdrup Basin includes the Hassel, Bastion Ridge, Strand Fiord and Kanguk formations, and the Eureka Sound Group. The Bastion Ridge Formation and the overlying and intertonguing Strand Fiord volcanics are restricted to Axel Heiberg Island where they conformably to unconformably overlie the Hassel Formation and are unconformably overlain by the Kanguk Formation (MacRae, 1992; Núñez-Betelu et al., In press). The Strand Fiord Formation is not present within the study area of this theses (east-central and southern Axel Heiberg Island, and west-central Ellemere Island), and the Bastion Ridge is restricted to the Glacier Fiord locality (southern Axel Heiberg Island).

Outcrops of the Kanguk Formation occur in many areas of the Sverdrup Basin and other geological regions of the Canadian Arctic. In the study area most outcrops are located on the Fosheim Peninsula (Fig.3). Their distribution is controlled by tectonic and erosional constrains. The Kanguk Formation usually rests abruptly on the sandstones of the Hassel Formation. However, in some areas the Kanguk Formation overlies other stratigraphic units (Embry, 1991). For instance on Meighen Island (north-central Sverdrup Basin, Fig.2) the Kanguk mudstones rest unconformably on Upper Triassic strata, and on Banks Island (Banks Basin, Fig.2) the Kanguk Formation ovelies unconformably units ranging in age from Devonian to Cretaceous. On all localities but one (Glacier Fiord, southern Axel Heiberg Island) of the study area the Kanguk Formation directly and unconformably overlies the Hassel Formation. On

Glacier Fiord the Bastion Ridge Formation occurs between the underlying Hassel and the overlying Kanguk formations.

The Hassel Formation is widespread on the Canadian Arctic Archipelago and was first described by Heywood (1957) from Ellef Ringnes Island although he did not provide a type section. This formation commonly lies on marine silty mudstones of the Christopher Formation and is, in turn, unconformably overlain by dark, marine shales of the Kanguk Formation over most of the Sverdrup Basin area (Thorsteinsson and Tozer, 1970; Hopkins and Balkwill, 1973). The Hassel Formation consists of poorly to fairly endurated qiartzose sandstone and siltstone with some thin interbeds of mudstone. In most areas this formation can be subdivided into two units; a lower, fine- to medium-grained marine sandstone unit, and an upper fluvial to marginal marine unit consisting of interbedded fine- to coarse-grained sandstone, siltstone, mudstone, and minor coal (Embry, 1991). The Hassel Formation contains rare marine macrofossils such as bivalves and a few ammonites (Fricker, 1963; Plauchut, 1971). Based on terrestrial palynomorphs this formation is considered to be latest Albian and/or Early Cenomanian in age (Hopkins and Balkwill, 1973).

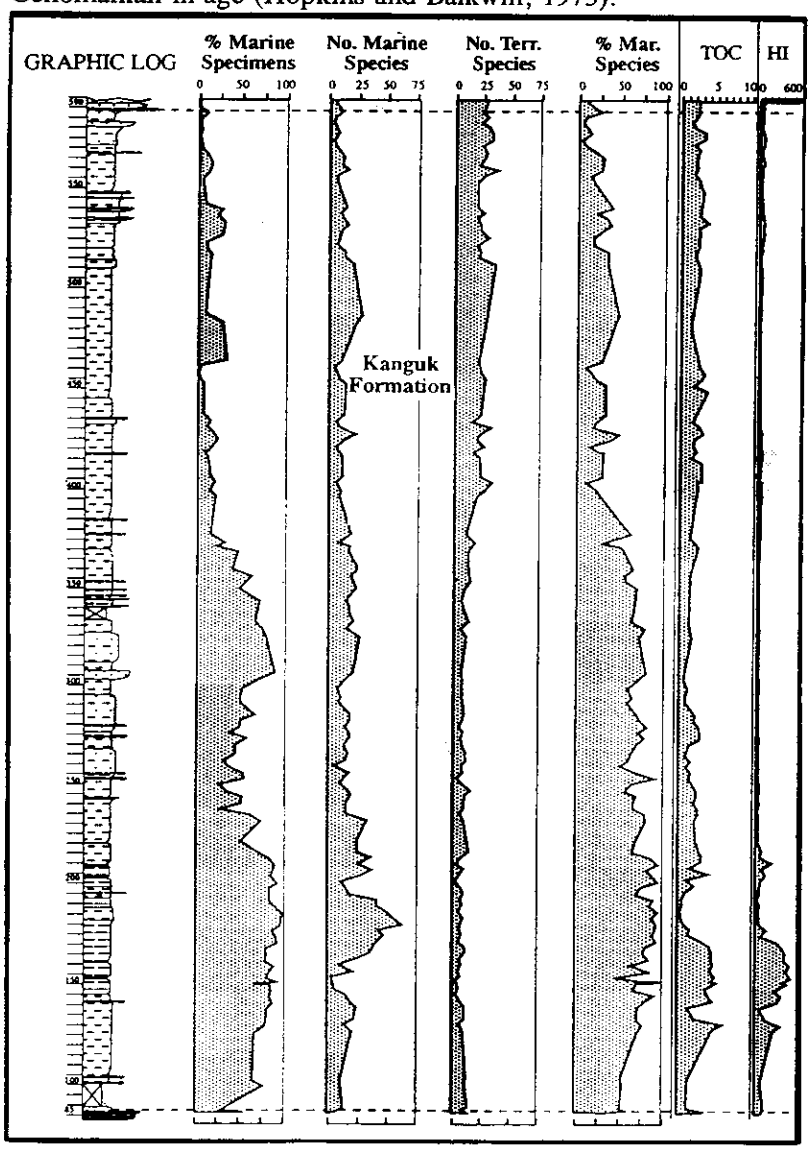


Fig.4. Lithology, palynology, and Rock-Eval/TOC pyrolysis data from the Kanguk Formation at Glacier Fiord, Axel Heiberg Island.

On western and southern Axel Heiberg Island (respectively Kanguk Peninsula and Glacier Fiord areas) the Hassel Formation is overlain by the dark mudstones of the Bastion Ridge Formation (Fricker, 1963; MacRae, 1992; pers. obs.). At Glacier Fiord, a sideritic sandstone with plant macrofossils at the top of the Hassel beds and an undulate contact between the Hassel and Bastion Ridge formations indicate that a local unconformity separates both formations. At this locality also, the Bastion Ridge Formation is capped by a 7 metre thick sandstone unit that is moderate- to well-bioturbated at its base. Prominent paleosol horizons are present in the upper part of this sandstone. Based on its relative position and character, this sandstone has been interpreted (Mac Rae, 1992) to be related possible to the Strand Fiord Formation. Based on palynological data the Bastion Ridge Formation is Late Albian in age (MacRae, 1992).

The Bastion Ridge and the overlying and intertonguing Strand Fiord Formation were first considered as lateral equivalent of the basal Kanguk Formation (Fricker, 1963; Thorsteinsson and Tozer, 1970). However, both formations are time equivalent to the upper Hassel Formation (Ricketts et al., 1985; Embry and Asadetz, 1988; MacRae, 1992).

Dark grey, organic-rich mudstones with rare to abundant interbeds of centimetre- to metre-thick bentonites, silty mudstones, and fine-grained sandstones constitute the main lithology of the Kanguk Formation. A prominent unit of black, bituminous mudstone is present at the base of this formation in most localities (Miall, 1979; pers.obs.). Most bentonite beds occur in this organic-rich part. The papery shales typical of the lower part are gradually replaced by silty mudstone, siltstones,

and interbedded sideritic beds in a progressively coarsening upward trend indicates the regressive shallowing of the basin.

The Eureka Sound Group is the higher Upper Cretaceous stratigraphic package and overlies the Kanguk Formation in all localities of the study area. In this part of the Sverdrup Basin, the Eureka Sound Group is subdivided into four units; the Expedition, Strand Bay, Iceberg Bay, and Buchanan Lake formations (Ricketts, 1986, 1991). The Expedition Formation usually rests conformably on the Kanguk Formation presenting a gradational contact. However, a major unconformity, usually within the Expedition Formation, situates the Iceberg Bay Formation directly and unconformably on the Kanguk Formation on most of the sections of west-central Ellesmere Island. The Expedition Formation consists predominantly of marine sandstone and minor mudstone whereas the Iceberg Bay Formation consists of white quartzose fluvial sanstone and coal (Ricketts, 1986; pers.obs.).

SEDIMENTOLOGICAL ANALYSIS

The 14 sections studied present abundant sedimentological similarities. However, no two sections are totally alike. The sections vary in thickness from 605 m on Glacier Fiord to 110 m on Remus Creek. The Bastion Ridge Formation, is only present at one section (Glacier Fiord) whereas the Expedition Formation is only present at Remus Creek. The rest of the sections include the Hassel, Kanguk, and Iceberg Bay formations. These three formations are separated by unconfomities.

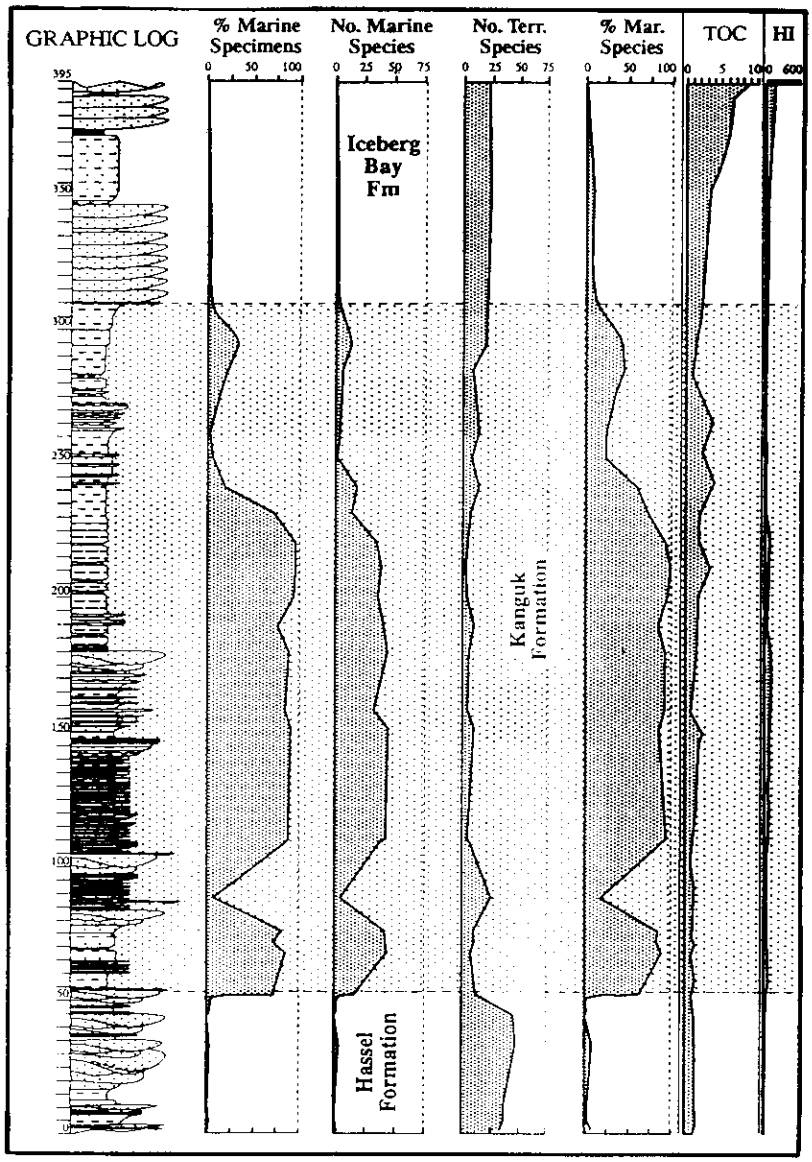


Fig.5. Lithology, palynology, and Rock-Eval/TOC pyrolysis data from the Hassel, Kanguk, and Iceberg Bay formations at Mount Bridgeman, Ellesmere Island.

The Hassel Formation includes facies representative of foreshore to beach deposition and includes soil development. The Bastion Ridge Formation facies indicate deposition in possibly brackish water, in restricted areas such a poorly communicated basins or estuaries.

The Kanguk Formation ranges in thickness from 85 m on Remus Creek to 503 on Glacier Fiord, but most sections are about 180-200 m thick. Offshore, disoxic mudstones are the most typical rocks of this formation. However, silty and sandy intervals also occur in the lower and upper parts of the formation. The lower sandstones are restricted to eastern sections (Mount Bridgeman, Canon Fiord, Sawtooth Range, etc.) and represent shallow water and coastal deposition. The upper Kanguk sandstones represent the initiation of deltalic sedimentation but are still within the marine realm of the Kanguk Sea. All bentonite beds and all inoceramids found in this study occur within the Kanguk Formation. In summary, the Kanguk mudstones and sandstones represent deposition from coastal to outer shelf settings that grade upwards into lower prodelta environments indicating a progressive shallowing of the basin. An unconformity is present at the top of this stratigraphic unit on all but one localities.

This unconformity truncates the upper Kanguk beds and, is in part responsible for the differnce in thickness from section to section.

The Expedition Formation is well developed at only one section, Remus Creek, and represents the peak of deltaic sedimentation. The other formation of the Eureka Sound Group included in this study, the Iceberg Bay Formation, reresents fully continental conditions of deposition in the study area as indicated by braided river deposits.

STRATIGRAPHIC PALYNOLOGY

The stratigraphic palynology is based on the distribution of both, single palynomorph species and assemblages, and on the relative abundance of each group. Núñez-Betelu and Hills (1994) present data on identified and counted taxa in each sample.

UNIT	LOCATION	Ro (%) (Te)*	TOC (wt.	HI (mg HC/g TOC	Tmax (°C) (avg.)	Kerogen Type	Hydrocarbon Potential
Kanguk Fm	Glacier Fiord	0.58	1.0--7.3 (3.4)	<100 to 400	429**	II or III	marginally mature **good oil potential**
	May Point	0.45	0.43--7.96 (2.14)	<100 to 373	421**	II or III	immature to marginally mature **some oil potential**
	Strathcona Fiord	0.45	0.29--2.30 (1.13)	up to 146	418	III	marginally mature **gas only**
	Bay Fiord	0.41	0.44--9.96 (3.0)	<100 to 420	416.5**	II or III	immature to marginally mature **some oil potential**
	Vesle Fiord	0.62	0.54--4.79 (1.95)	<100 to 350	423**	II or III	immature to marginally mature **some oil potential**
	Mount James	0.47	1.1--5.41 (2.50)	<100 to 434	428**	II or III	immature to marginally mature **some oil potential**
	Fosheim South	0.59	0.66--4.03 (1.85)	<100 to 276	422	III	marginally mature **gas only**

Fig.6. Summary of hydrocarbon potential from data collected from the Kanguk Formation at various localities
(*) Approximate reflectance values inferred from those of the Eureka Sound Group (Bustin, 1986)
(**) Average Tmax unreliable due to mixing of kerogen types. The first two sections are located on Axel Heiberg Island whereas the other sections are on Ellesmere Island, Canadian Arctic Archipelago.

One hundred and ninety samples were studied for taxonomic identification and count-analyses. A total of 83,364 palynomorphs were counted in this study. Of these 39,344 (47.2%) are marine and 43,915 (52.8%) are terrestrial. This represents and average of 446.1 specimens/sample, including an average of 214.1 marine specimens and 231.0 terrestrial individuals for each sample. Two section, namely the Mount Bridgeman and Glacier Fiord sections, were studied in detail, whereas only the base and tops of the rest of the sections were studied. The Remus Creek section had been studied previously (Núñez-Betelu, 1991; Núñez-Betelu and Hills, 1992a and 1992b) and, therefore, its palynological content was not restudied.

The relative ratios of marine versus terrestrial palynomorphs are very similar in all the sections, and the distribution of the diverse palynomorphs groups show a very similar pattern. A total of 12,371 palynomorphs were counted from the Mount Bridgeman section. Of these 5,992 (48.4%) are marine and 6,326 (51.6%) are terrestrial. Counts of 51,771 palynomorphs, including 23,859 (46.1%) marine specimens and 27,860 (53.9%) terrestrial palynomorphs were made on the Glacier Fiord section. Finelly, a total of 19,222 palynomorphs were counted from the rest of the sections and included 9,493 (49.4%) marine individuals and 9,729 (50.6%) terrestrial specimens. The palynomorph distributon at Glacier Fiord and Mount Bridgeman is very similar to that at Remus Creek (Núñez-Betelu, 1991; Núñez-Betelu and Hills, 1992a and 1992b). In spite of terrestrial palynomorphs being slightly more abundant than marine forms in the overall counts, the lower half of the Kanguk is highly dominated by marine palynomorphs (Figs.4 and 5), both in terms of individuals and species, whereas terrestrial form dominate in the samples from the Hassel Formation , upper part of the Kanguk Formation, and the Eureka Sound Group. The

marine palynomorphs dominated lower Kanguk Formation is also characterized by high TOC and HI values (Figs. 4 and 5).

UNIT	LOCATION	Ro (%) (Te)*	TOC (wt.	HI (mg HC/g TOC	Tmax (°C) (avg.)	Kerogen Type	Hydrocarbon Potential
Kanguk Fm	Sawtooth Range	0.70	0.84--3.99 (1.95)	<100 to 219	424	III	marginally mature gas only
	Fosheim Anticline	0.59	0.17-9.64 (3.1)	<100 to 500	421**	II or III	marginally mature good oil potential
	Eureka Sound	0.45	1.54--4.82 (2.39)	<150	416	III	marginally mature gas only
	Romulus Lake	0.51	0.6--3.58 (1.98)	up to 100	417.5	III	marginally mature gas only
	Mount Bridgeman	0.59	<1.0-4.2 (2.3)	<100	429	III or IV	marginally mature some (?) gas potential
	Cañón Fiord	0.59	0.41--2.31 (1.37)	<20	4427	III or IV	marginally mature no oil or gas potential
	Remus Creek	0.51	0.66-6.03 (2.99)	<20	424	III or IV	marginally mature no oil or gas potential

Fig.7. Summary of hydrocarbon potential from data collected from the Kanguk Formation at various localities.
(*) Approximate reflectance values inferred from those of the Eureka Sound Group (Bustin, 1986).
(**) Average Tmax unreliable due to mixing of kerogen types. All section located on Ellesmere Island, Canadian Arctic Archipelago.

The distribution of the number of palynomorph species and of the number of sepcimens and the relative percentages of each exhibit very similar trends at Mount Bridgeman and Glacier Fiord. The percentage of marine specimens, the percentage of marine species, and the number of marine species reach their maximum in the lower part of the sections and then decrease steadily to very low values towards the upper part of the Kanguk Formation. In contrast, the number of terrestrial species increases upwards.

HYDROCARBON POTENTIAL BASED ON ROCK-EVAL/TOC PYROLYSIS ANALYSIS

Upper Lower and Upper Cretaceous units of south-eastern Axel Heiberg and west-central Ellesmere islands have been assessed for their hydrocarbon generation potential. Rock-Eval/TOC pyrolysis data have been collected from the upper-Hassel, Bastion Ridge, Kanguk, and lower-Iceberg Bay formations. All 599 samples were collected from outcrops and their pyrolysis data indicate that all these units contain immature kerogen.

Sixteen samples from the mudstone and coaly intervals of the upper Hassel Formation were analysed for Rock-Eval/TOC pyrolysis. The coaly samples, obviously, exhibit the highest TOC values found in this study with up to 21.0 wt.%. These coaly samples also exibit high HI and low OI values indicating a possible marginal marine origin. The mudstone samples have lower TOC values, around 1.6 wt.%, and also low HI and low OI values. However, very few samples were analysed from this formation and, therefore, these results may not be completely characteristic of the nature of the organic matter usually present in the sandy and silty facies of the Hassel Formation.

The 86 Bastion Ridge Formation samples are thermally immature, and even though TOC values are as high as 4.43 wt.% the S2, PI, HI amd OI values tend to be low. The organic matter of this units, thus, can be classified as Type III which is mainly of terrestrial origin. This unit contains, therefore, immature Type III kerogen that can only be considered as a possible gas source.

The 492 samples from the Kanguk Formation contain both Type II and Type III organic matter (Figs.6 and 7). Type II is present in all sections and is more abundant than Type II which is only present in 9 of the 14 sections. The Kanguk Formation is an organic-rich unit as indicated by the high TOC values in all sections with a maximum of 9.96 wt.% in the Bay Fiord section. HI values are relatively high, up to 559 mg HC/g TOC, in the lower part of the formation but usually are very variable and commonly low in the upper part. Tmax and PI are relatively low and indicate the presence of only immature kerogen. OI values are usually higher in the upper

part of the section, where Type II kerogen dominates. The Type II kerogen is well represented in the lower organic-rich mudstones and, therefore, this part of the Kanguk Formation constitute a possible oil source. The rest of the formation contains only immature Type kerogen that is only a gas source material.

Pyrolysis data for the lower Iceberg Bay Formation of the Eureka Sound Group are based on only five samples and, thus, these data may not be representative of the organic character of this formation. Also these samples were collected from the organic-rich mudstone and coaly mudstone intervals and no sample from the majoritary sandstones was included in the pyrolysis analysis. The coaly samples have high TOC values, up to 12.94 wt.% but, otherwise the Iceberg Bay samples contain moderate TOC around 2.5 to 3.0 wt.%. The other pyrolysis values are always low, indicative of immature, Type III kerogen. This unit could constitute a small gas source. However, the lower Iceberg Bay sandstones are very porous and permeable in hand specimen and could constitute an exellent reservoir since they are capped by relatively thick mudstone intervals.

CONCLUSIONS

A combination of sedimentological, palynological, and Rock-Eval/TOC pyrolysis analysis permitted the characterization of the Kanguk Formation and of its petroleum potential. The lower Kanguk beds represent a transition from coastal to offshore deposition whereas the upper Kanguk Formation is indicative of the initiation of deltaic sedimentation. Marine palynomorph species and specimens are abundant in the lower part of the Kanguk Formation and decrease rapidly upwards in the sections whereas the number of terrestrial species show an opposite trend.

Despite the high organic content of the Kanguk Formation, only the lower part of this formation may represent a good oil source-rock in some areas, whereas the rest of the formation may be considered only as a gas-prone interval. The distribution of the organic matter type roughly correlates with the palynological assemblage composition.

ACKNOWLEDGMENTS

The author wish to acknnowledge the logistic support of Polar Continental Shelf Project. Financial support was provided by the University of Calgary (Thesis Research Grants) to L.K.Núñez-Betelu and R.A.MacRae. Further economic assistance was provided by the American Association of Petroleum Geologists, American Association of Stratigraphic Palynologists, Geological Society of America, and Northern Scientific Training Program (Department of Indian and Northern Affairs, Govenment of Canada) and Natural Sciences and Engineering Research Council Grants in Aid of Research to Dr. L.V. Hills. Many thanks are extended to Dr.C.Reidiger and Dr.L.Showdon for their guidance. We want to warmly thank also Ms.L.Bloom and Ms.B.Rhoades, who efficiently processed the samples.

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