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CENOZOIC STRATIGRAPHY OF MACKENZIE DELTA, NORTHWEST TERRITORIES

NTS 107B, 107C

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EDITOR'S NOTE

Please note that the stratigraphic nomenclature proposed and used in this open file report is not necessarily as it will appear in the final publication (Bulletin 336, in press).

All new stratigraphic names should be regarded as informal only and this report should not be cited or referenced as the source of any new stratigraphic names. New formation and other names will be designated formally only in the final publication of this bulletin.

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Abstract

Over 10 km of Cenozoic sediments accumulated beneath the modern Mackenzie Delta within the Richards Island Basin which is flanked to the southeast by the northern Interior Platform and to the southwest by the Northern Cordillera. Northward, this basin forms part of the continental terrace wedge of the Beaufort Sea.

Cenozoic deltaic sediments of the Richards Island Basin are divisible into two main facies: mud-dominant and sand-dominant, corresponding generally to prodeltaic and delta-front to delta-plain depositional environments respectively. These two facies, along with major unconformities, form the basis for defining formations within this sequence. In ascending order, the Cenozoic formations (new units italicized) are: Reindeer Formation including the Aklak and sandstone-mudstone members (the latter being the major Cenozoic hydrocarbon reservoir), *Richards Formation*, *Kugmallit Formation* including the *Ivik* and *Amak* members, *Mackenzie Bay Formation*, Beaufort Formation, and *Nuktak Formation*.

The Reindeer Formation, formed by northward progradation of a delta-plain to delta-front facies complex during mid-Paleocene to Early Eocene times, consists of sandstone, silty mudstone and minor amounts of conglomerate and coal. Its major source area was the western tectonic highland, but the uplifted Eskimo Lakes fault zone to the southeast also contributed clastic sediments. Deltaic depocentres at this time developed in the Richards Island and northern Tuktoyaktuk Peninsula areas. The Reindeer Formation is rich in temperate terrestrial palynomorphs and yields sparse brackish-water foraminifers of the **Saccammina-Trochammina** spp. assemblage.

The Reindeer is conformably overlain by the Richards Formation, a northward thickening prodeltaic facies consisting of mudstone and shale deposited after subsidence and transgression in Early to Middle Eocene time. The formation is marked by the **Haplophragmoides** spp. agglutinated foraminiferal assemblage and, in the lower part, by a rich zone of dinoflagellates dominated by **Wetzeliella** spp. The upper part of the Richards Formation probably represents the northeastward-migrating toe of a major upper Paleogene deltaic wedge (Kugmallit Formation) which thickens markedly north and northeastward. The Kugmallit Formation consists of sand, mudstone, gravel, and lignite. It is conformable (north) to probably disconformable (south) over the Richards Formation. A rich terrestrial palynoflora dated latest Eocene to Oligocene occurs in the Kugmallit.

Following deposition of the Kugmallit deltaic wedge, possibly in Middle to Late Oligocene time, the immediate area of the Mackenzie Delta was uplifted; a major unconformity now separates Neogene strata from Paleogene. To the north and northwest, however, deposition seems to have been continuous and the Neogene-Paleogene contact is in a conformable marine mudstone sequence (Mackenzie Bay Formation). A basin in the Richards Island area still existed with the advent of early Neogene deposition. Gravelly fluvial and fan-delta sediments of the Beaufort Formation are intertongued with and replaced seaward in the basin by the marine muds of the Mackenzie Bay Formation which conformably overlies the Kugmallit. The Mackenzie Bay Formation carries cool-temperate to boreal terrestrial palynomorphs and the neritic **Cibicides** spp. foraminiferal assemblage which is rich in calcareous benthonic species.

During the Pliocene, the sea may once again have retreated from the Mackenzie Delta area, with subsequent scouring of the upper surface of the Beaufort-Mackenzie Bay sequence causing a widespread unconformity. The Pliocene-Pleistocene Nuktak Formation records the last off-lapping deltaic sequence prior to final marine transgression over the area and Late Pleistocene complexities caused by advancing and retreating continental ice sheets. The Nuktak consists of nonmarine (lower gravel member) and marine (upper mud member) facies and contains the cool-water, inner-shelf **Elphidium** spp. foraminiferal assemblage and a variety of *in situ* fossils as well as conspicuous reworked foraminifers and palynomorphs.

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INTRODUCTION

Historical perspective

The modern Mackenzie Delta has been the site of deltaic sedimentation for over 65 million years. During this time-interval a series of overlapping deltaic complexes over 10 km thick has accumulated. These deltaic sediments contain great quantities of coal and petroleum, and, like other major deltas of the world, such as the Niger and Mississippi, have become very attractive in man's quest for energy resources.

Drilling in the Mackenzie Delta region began in the mid 1960's, and was greatly stimulated by the discovery of petroleum at nearby Prudhoe Bay, Alaska, in 1968. During the decade since, over 150 exploratory wells have been drilled, about half of which had primarily Tertiary exploration targets. The Tertiary was explored in earnest only after mid 1971, following the discovery of the Taglu gas field by Imperial Oil Limited.

To date, established marketable reserves of gas in the Mackenzie Delta area amount to approximately 186×10^9 m^3 (6 trillion cu ft), and oil only about 30×10^6 m^3 (200×10^6 bbls) (Canadian Petroleum Association, 1979). Most of the gas discovered is trapped in reservoir rocks of Tertiary age, mainly in the Taglu, Niglintgak, Ukalerk, Garry, Adgo, and Ya Ya fields. The second largest gas field in the area, the Parsons field, is located east of the Delta in Lower Cretaceous sandstones (Fig. 1). The number and size of Tertiary oil and gas discoveries have been disappointing to explorationists, and the only promising and active play presently is the Beaufort Sea continental shelf.

Owing to the relatively short time elapsed since the Tertiary section was first drilled, little attempt has yet been made to establish formal stratigraphic nomenclature. Abrupt changes in facies and thicknesses have contributed to complexities in the lithostratigraphy, while provincialism, reworking, and low-diversity populations have caused biostratigraphic difficulties. Aging and fermentation of stratigraphic concepts has been required but sufficient research, debate, and refinement of the ideas of government and industry geologists now have occurred and a series of formations with approximate ages can be reasonably established. Such is the purpose of this report.

The new stratigraphic units proposed complete the formal stratigraphy of the Cenozoic succession in the Mackenzie Delta subsurface. They all overlie the Reindeer Formation and range in age from Eocene to Pleistocene. From base to top the new units are: *Richards, Kugmallit, Mackenzie Bay*, and *Nuktak* formations. The Kugmallit Formation is divided into the *Ivik* and *Amak* members. The previously established Beaufort Formation is extended into the subsurface and a reference section given.

Previous work

Outcrops of Tertiary strata near Mackenzie Delta were recognized by Geological Survey officers during Operation Porcupine in 1962. Mountjoy (1967) erected the Moose Channel and Reindeer Formations based on this reconnaissance mapping, and subsequently Young (1975) modified Mountjoy's definitions of these units, describing reference sections and extending them into the subsurface.

Chamney (1971) made the earliest attempt to establish a biostratigraphic zonation, based on a micropaleontological study of the first borehole in the region, the BA-Shell-IOE Reindeer D-27 well. However, early signs of the controversial nature of micropaleontological datings in this basin appeared with the publications by Petracca (1972) and Langhus and Petracca (1973) of Gulf Canada Limited. Since that time reduction in the dating discrepancies between and among government and industry biostratigraphers has occurred, along with a recognition of the influential role of facies in controlling the development of benthonic foraminifers.

In the Paleogene part of the succession, palynomorphs came to be regarded as more diagnostic than foraminifers for correlations and datings. In a fine example of industrial cooperation, the biostratigraphic concepts of several major operations in the area were summarized by Staplin (1976), establishing marker palynomorphs and important secular trends in microfloral assemblages on which correlations could be based. Similar assemblages were noted also by Doerenkamp et al. (1976) from the Caribou Hills outcrop section of the Tertiary sequence, and correlated to distant well sections on Banks Island. Ioannides and McIntyre (1980) have also reported on the palynology of the Tertiary outcrop sections in the Caribou Hills.

Significant attempts to provide a regional stratigraphic and tectonic setting in which to view the Mackenzie Delta and its Tertiary predecessors were made by Lerand (1973), Norris (1973, 1974), Yorath (1973), Hawkings and Hatleid (1975), Young et al. (1976) and Lane and Jackson (1980). In these reviews most of the surface geological information used was obtained by the Geological Survey of Canada. Gravity data were derived from surveys by the Earth Physics Branch of the Department of Energy, Mines and Resources (Sobczak et al., 1973), and seismic profiles from various industry sources.

Few stratigraphic or sedimentologic analyses of the Tertiary sequence have been published. During the time of intense interest in the basin, a core conference sponsored by the Canadian Society of Petroleum Geologists put on public display many cores of deltaic and shallow-water sediments from several Delta wells (Shawa, 1974). Young (1975) described the sequences, facies and petrography of the Moose Channel and Reindeer Formations from the IOE Ellice O-14 well and nearby surface sections. The petrographic, sedimentologic and geochemical properties of the Taglu reservoir units (upper Reindeer Formation) were described by Bowerman and Coffman (1975) and Dixon (1981). Recently, Shawa (1978) and Nentwich (1980) prepared graduate theses on stratigraphy, sedimentology and petrography of the subsurface Reindeer Formation.

Quaternary sediments have been described primarily in reports of surficial materials. Notable among these are the studies by Mackay (1963), Rampton (1974), Hughes (1972), Naylor et al. (1972) and Johnson et al. (1976). The only subsurface discussion of Quaternary deposits is that based on drill-cores obtained near Inuvik by Johnston and Brown (1965).

Present study and acknowledgments

This report is an outgrowth of a continuing project involving both Mesozoic and Cenozoic deposits of the Mackenzie Delta region, which the senior writer and his associates began in 1969, and which will continue into the future. The present purpose is to complete the establishment of formations in the Cenozoic succession of the outer Mackenzie Delta subsurface, to illustrate well correlations, and to describe lithologic and biostratigraphic attributes of the various recognized stratigraphic units.

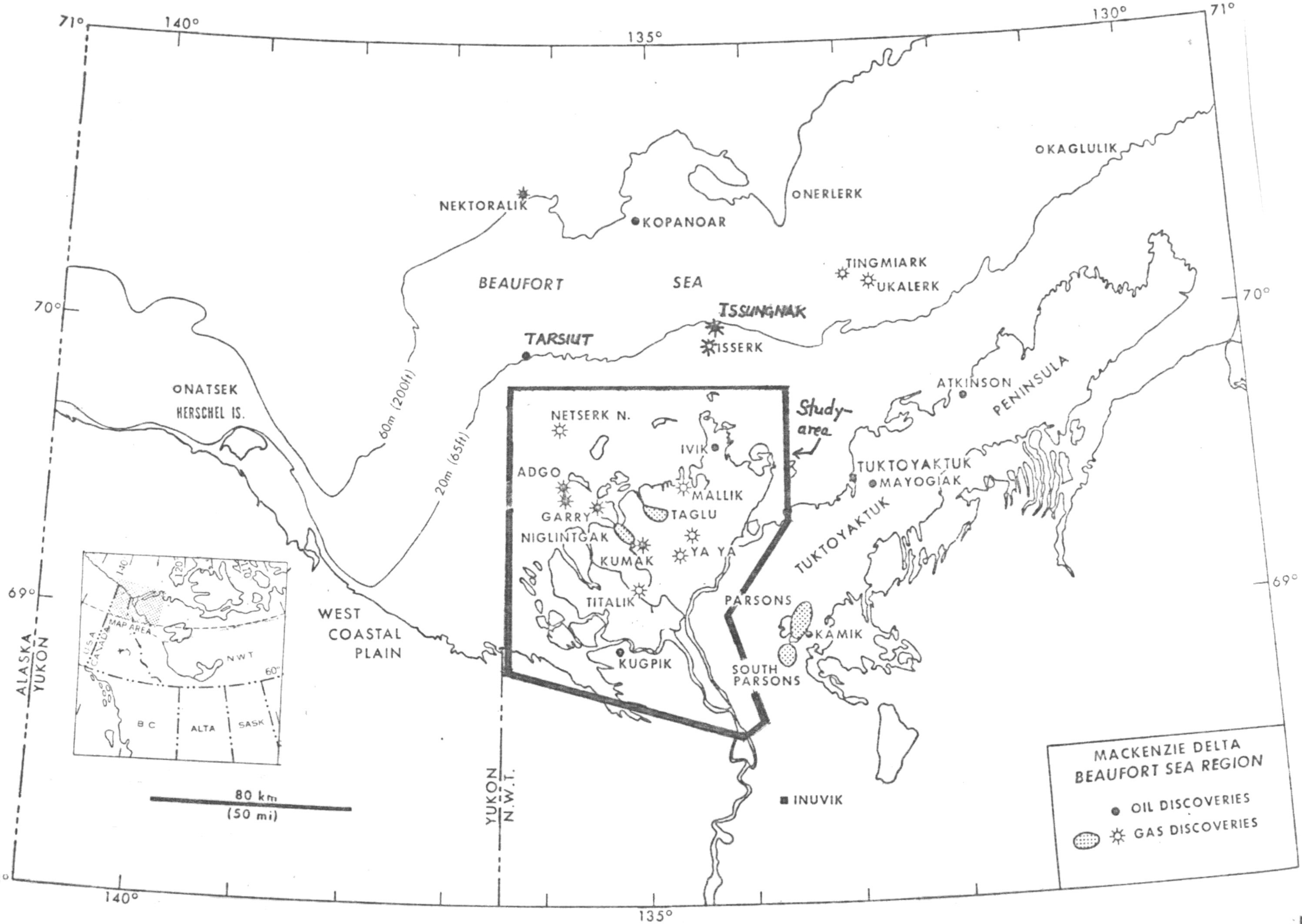

Figure 1. Location map, showing oil and gas discoveries, Mackenzie Delta and Beaufort sea at end of 1980.

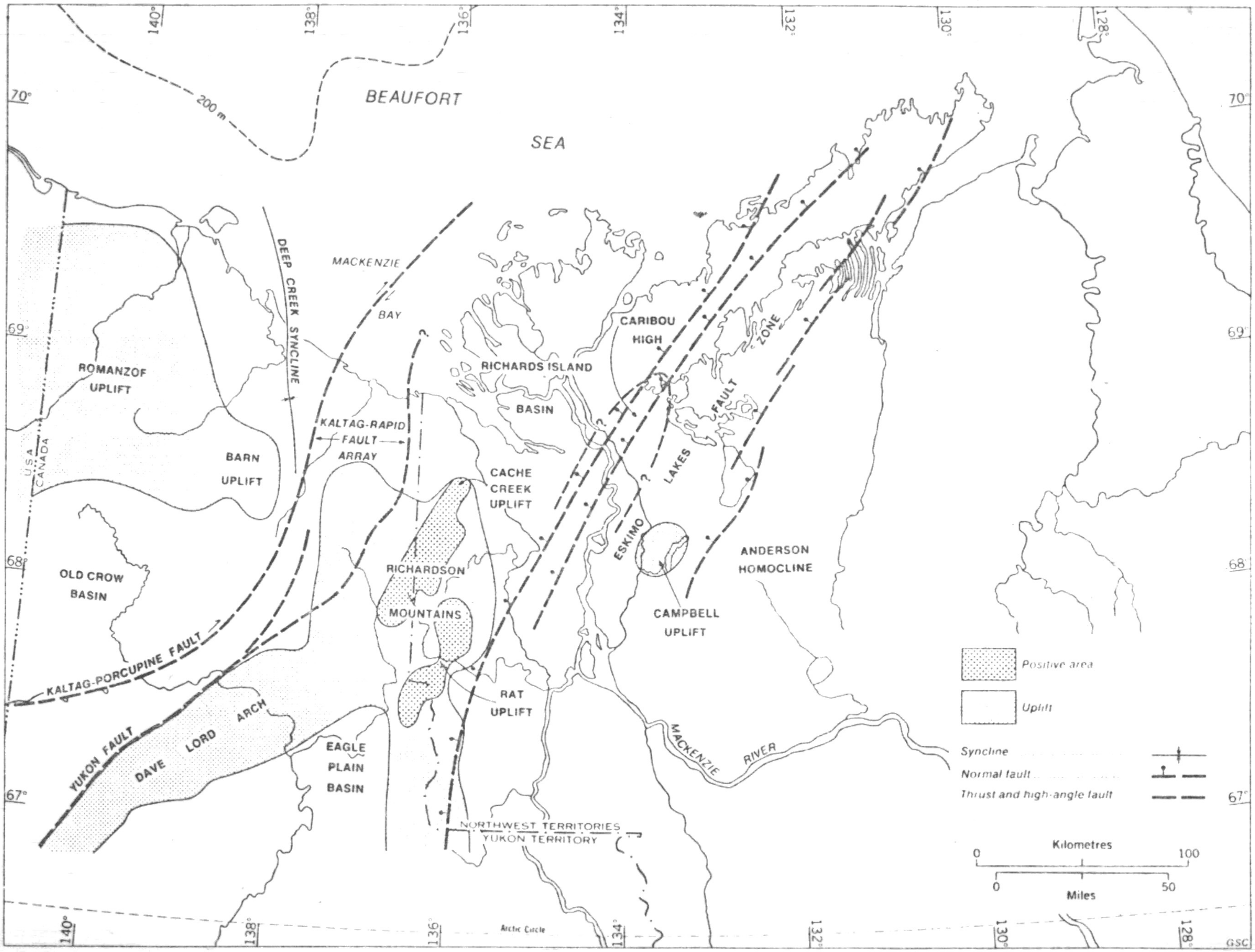

FIGURE 2. Map showing Laramide tectonic elements

Research into the Cenozoic succession was undertaken initially by C.J. Yorath, K.F. Der and D.W. Myhr, and the results of their studies were incorporated largely in the report by Young et al. (1976). The present writers have continued to examine new lithostratigraphic and biostratigraphic data, particularly within the upper part of the succession. No seismic profiles have been used in preparing this synthesis because of the confidential nature of seismic data obtained almost entirely by private industry. Admittedly, this gap in the data-base weakens the areal and structural aspects of the stratigraphic analysis; however, the basic correlations and formation definitions presented here are definable mainly without reference to seismic profiles.

The writers wish to express their appreciation to their colleagues on the Beaufort-Mackenzie Cenozoic project, including J. Dixon, N.G. Koch, R. Baird, N.S. Ioannides, A.R. Sweet, and W.S. Hopkins for many interesting and informative discussions relating to Cenozoic stratigraphy and correlations. J.H. Wall undertook a preliminary study of micropaleontology in several key wells, and greatly assisted the junior author in getting established in the project.

The palynological research of G. Norris, University of Toronto, undertaken for Austin and Cumming Consultants, was condensed and summarized for this report. His cooperation in the process of sorting out indigenous from reworked palynomorphs in the various formations and key wells is greatly appreciated. We thank N.S. Ioannides for his cheerful assistance in this matter also.

Regional geological setting

Cenozoic sediments beneath the Mackenzie Delta accumulated within the Richards Island Basin (Young et al., 1976), termed the Mackenzie Basin by Lerand (1973). Structurally, the Richards Island Basin is flanked by the northern Interior Platform, the Aklavik Arch Complex, and the Richardson Mountains segment of the Northern Cordillera (Fig. 2). Northward it forms part of the continental terrace wedge of the Beaufort Sea, beyond which lies the abyssal plain of the Canada Basin.

The Richards Island Basin is a depression developed as a consequence of Laramide tectonism in the landward margins of the earlier Beaufort-Mackenzie Basin. Yorath (in Yorath and Norris, 1975; Young et al., 1976) has postulated that this depression resulted from downward buckling along the inside corner of a bend in the Kaltag-Rapid fault complex, a major dextral wrench fault. Other factors that may have contributed to its development are its pericratonic location along the southern margin of the Beaufort Sea, and its negative coupling with the generally positive Eskimo Lakes Fault Zone of the Aklavik Arch Complex. Thick accumulations of late Mesozoic and Cenozoic sediments are known along the entire continental shelf of the southern Beaufort Sea (Grantz et al., 1975) and may be an effect of the opening or foundering of the Canada Basin (Yorath and Norris, 1975) accompanied by Laramide Orogeny in the Northern Cordillera.

The Cenozoic succession comprises the upper portion of the Brookian Sequence, the last of four major depositional sequences recognized in the Mackenzie Delta region (Lerand, 1973; Norris and Yorath, 1978). The Brookian Sequence ranges in age from Jurassic to Recent, and consists predominantly of terrigenous clastic rocks, derived from uplifts of the Cordilleran Orogen to the west and south. The sequence displays an evolution in depositional phases of classical geosynclinal character (Young, 1973). An epicontinental phase of Jurassic and Early Cretaceous age at the base is followed by a syntectonic flyschoid phase (largely west of Mackenzie Delta) in the late Early Cretaceous, succeeded in turn by an Late Cretaceous starved basin phase and, finally, a molassic phase throughout the Cenozoic Era.

GENERAL STRATIGRAPHY

Introduction

Cenozoic sediments of the Beaufort Sea continental shelf near Mackenzie Delta form a series of offlapping, sigmoidal wedges, resulting in an overall regressive megasequence spoon (*sensu* Dailly, 1975). Thus in the Delta area younger stratigraphic units tend to become thicker (and more likely to contain hydrocarbons) basinward, then progressively thinner in the distal, deep-water parts of the depositional spoon. This geometry is illustrated in seismic profiles published by Yorath and Norris (1981, Fig. 3) and Hawkings and Hatlelid (1975, Figs. 10, 12).

The off-lapping characteristic also can be appreciated by constructing a simple stratigraphic-structural profile through a series of wells plotted in a landward to basinward sense (Fig. 4). Under the modern Mackenzie Delta plain, Cenozic sediments wedge out southward and plunge northward to depths greater than 4000 m (13 000 ft). In the near offshore the basal Tertiary beds dip below the range of economic drilling, as exemplified by the Imperial Netserk F-40 well, in which the base of the Moose Channel Formation (base of Tertiary) is estimated to be at -5650 m (-18 500 ft) MSL. Lerand (1973) estimated over 10 km (30 000 ft) of Mesozoic and Cenozoic strata in the centre of the megasequence spoon, a high proportion of which is probably Cenozoic.

By way of comparison, the maximum thickness of the Neogene alone in front of the Mississippi Delta is approximately 8 km (26 000 ft) (Jones, 1969).

Formations

The molassic depositional sequence of the Mackenzie Delta subsurface is chiefly Cenozoic and includes, in ascending order (new formations in italics): the Tent Island, Moose Channel, Reindeer, *Richards*, *Kugmallit*, *Mackenzie Bay*, Beaufort, and *Nuktak* formations (Table 1). Thicknesses of formations reported in Table 1 refer to ranges encountered in the study area (Fig. 1).

Ages of these units in all cases are tentative and approximate only, subject to refinements in biostratigraphic correlations to reference sections outside the basin, and to more detailed paleontological studies. For example, the Tent Island, Moose Channel, and Reindeer Formations are revised to younger ages than those previously reported (Young, 1975; Young et al., 1976), largely because of the careful research on latest Cretaceous palynomorphs and megaspores by Sweet (1978 and pers. comm.).

In certain places, angular unconformities grade laterally into disconformities and conformable sequences. As might be expected in an offlapping sequence, disconformities and angular unconformities tend to be more numerous and represent larger hiatuses landward (southward), as indicated on the table of formations.

From the oldest unit in the molassic sequence, the Tent Island Formation, to the youngest alluvium, it can be seen that terrigenous clastic sediments with minor organic

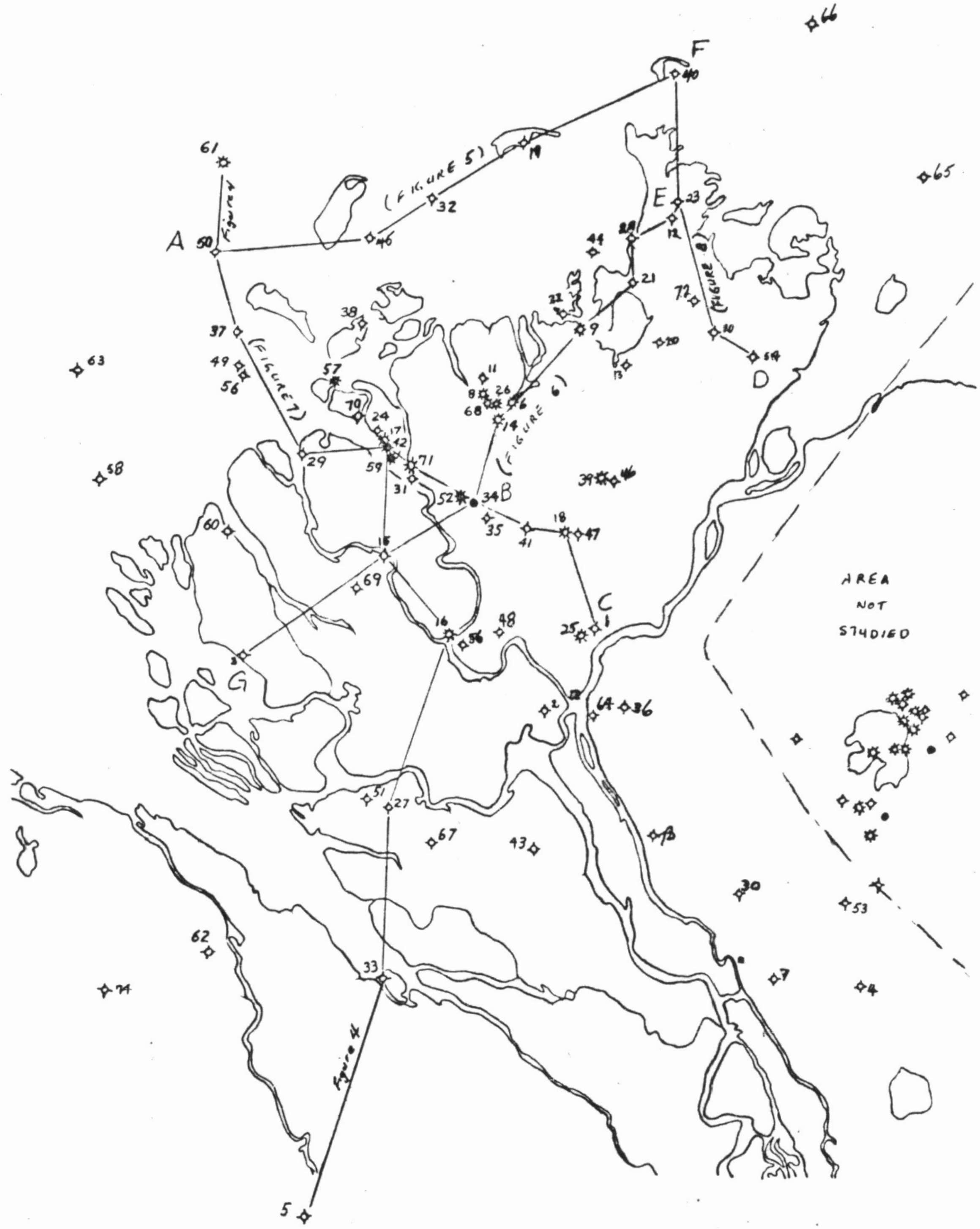

Figure 3. Map of well locations and lines of cross-sections.

Borehole (abandoned)
Borehole (gas)
Borehole (oil)

Line of section A —— B
(Figs. 4-8)

0 12 24 36
KILOMETRES

Note: boreholes numbered in order of spudding date. See appendix for listing of numbered boreholes.

TABLE 1 TABLE OF FORMATIONS

SYSTEM	SERIES (STAGE)	FORMATION	LITHOLOGY, MEMBERS
QUATERNARY	HOLOCENE	Unnamed Mackenzie Delta alluvium	Absent in Richards Island area; mud and sand in uppermost 30 m of modern Mackenzie delta-plain.
	PLEISTOCENE	HERSCHEL ISLAND and other glacial deposits	Silt, thin-bedded, and interbedded sand, quartzose, fine-grained; pebbly till; peat.
		Disconformity	
	PLEISTOCENE / PLIOCENE	NUKTAK *	Mud member: commonly present between 70-200 m depth; mud, light grey, sandy, medium-grained, quartz, chert, coal, shale, mica clasts; shell fragments, ostracods, foraminifers, wood common accessories. Gravel member: gravel, chert granular & pebbly, sandy; sand, med. to coarse-grained, salmon-pink quartz, minor chert & feldspar; interbedded clay-mud, grey, sand and wood fragments common.
		? Disconformity and Paraconformity	
NEOGENE	MIOCENE	BEAUFORT	Gravel, grey chert predominant; gravelly sand, sandy mud, coarse-grained; wood fragments, dark brown, abundant
		Intertonguing relationship, or Conformable	
		MACKENZIE BAY *	Mudstone, light grey or brownish grey, soft, slightly sandy, scattered chert pebbles; rare to common plant fragments; pyritic tubes (burrows?) common. Conformable
	OLIGOCENE	Conformable sequence (north), grading to Disconformity & Angular Unconformity	
		KUGMALLIT *	Arnak Member:* Sand, fine to coarse-grained, grey chert & quartz; some clay and dolomite cement; gravel common southward; lignite abundant as laminae (woody) and beds.
			Local Disconformity (southeast)
PALEOGENE			Iyik Member:* Mudstone, light brownish grey, soft, sandy in part; alternating with sandstone units; sandstone friable, very fine to medium-grained, in part dolomite or calcite cemented; resin grains & coaly wood fragments common; rare sideritic mudstone beds.
		Conformable sequence (north) or Disconformity (south)	
	EOCENE	RICHARDS *	Mudstone, light grey, soft, slightly expandable, variably silty, sandy and carbonaceous; scattered chert pebbles and granules; minor bentonitic beds. Locally mobilized into shale anticlines and diapirs.
		Intertonguing facies or Conformable sequence	
		REINDEER	Sandstone-mudstone member: Alternating units of sandstone and mudstone; sandstone uniform, fine to coarse-grained, friable, some calcite-cemented, chert and quartz composition mainly; mudstone grey, silty; rare bentonite beds. Aklak Member: Sandstone, as in upper member, with interbedded conglomerate, mudstone, coal, marlstone, tuff.
		Conformable sequence or Local disconformity	
	PALEOCENE	MOOSE CHANNEL	Ministicoog Member: Interbedded grey mudstone and siltstone, with minor lenticular sandstone units; fine to coarse-grained litharenite. Basal sandstone member: Alternating sandstone and mudstone units; sandstone, fine- to coarse-grained, pebbly; rich in chert, quartz, feldspar; rare coal.
		Conformable sequence to Unconformity (south)	
CRETACEOUS	UPPER CRETACEOUS (MAASTRICHTIAN)	TENT ISLAND	Mudstone, shale, siltstone, in part calcareous; with minor sandstone units and beds. Cuesta Creek Member: Interbedded sandstone, conglomerate and mudstone; sandstone very rich in grey to black chert.
		Angular unconformity to ?Conformable sequence	
		BOUNDARY CREEK	

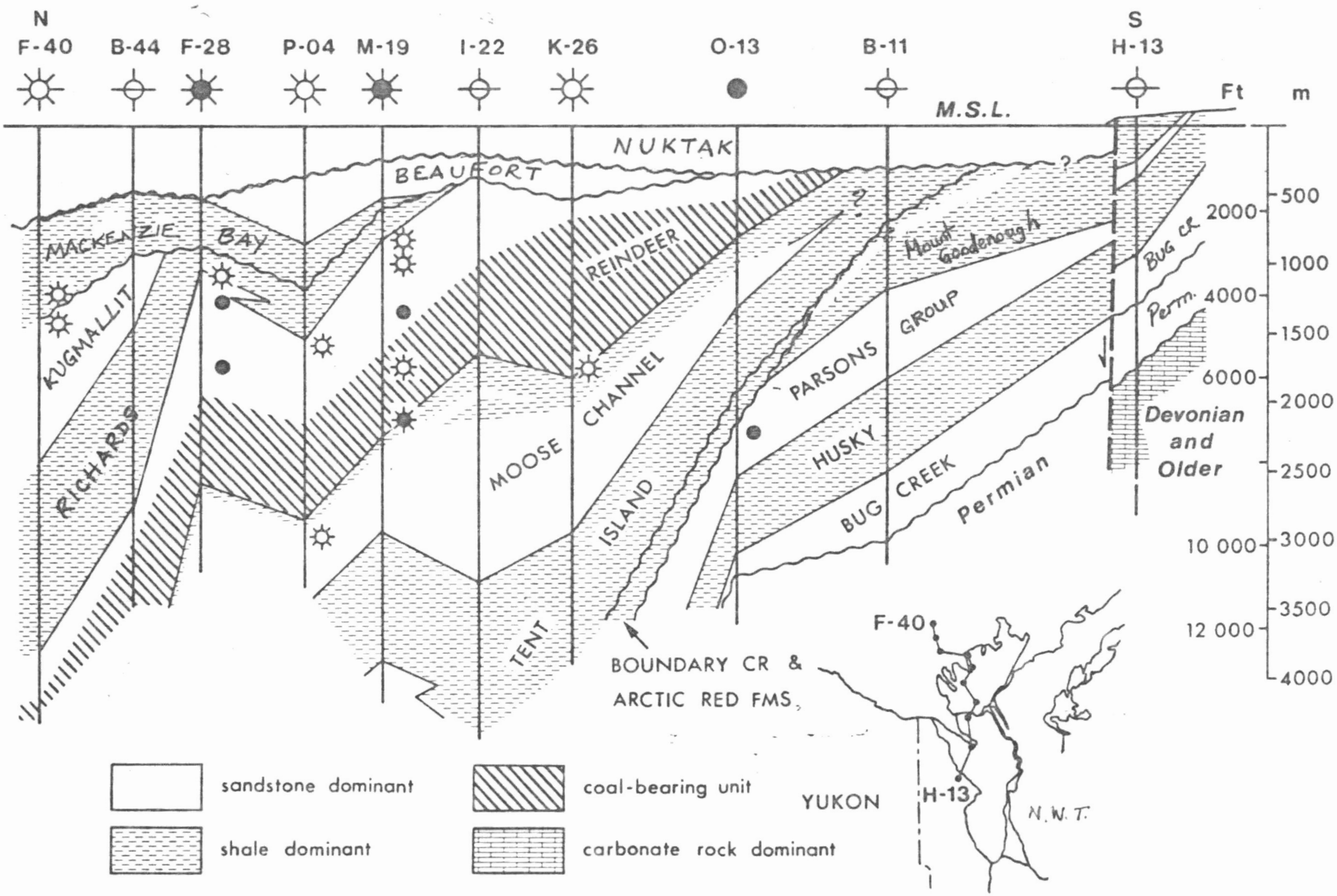

Figure 4. North-south stratigraphic profile through wells of lower Mackenzie Delta. Base of Tertiary corresponds approximately with base of Moose Channel Formation.

Explanation:

contact

structure
contour
(1000 ft sub-sea)

fault

Langley High

Borehole (see
Fig. 3)

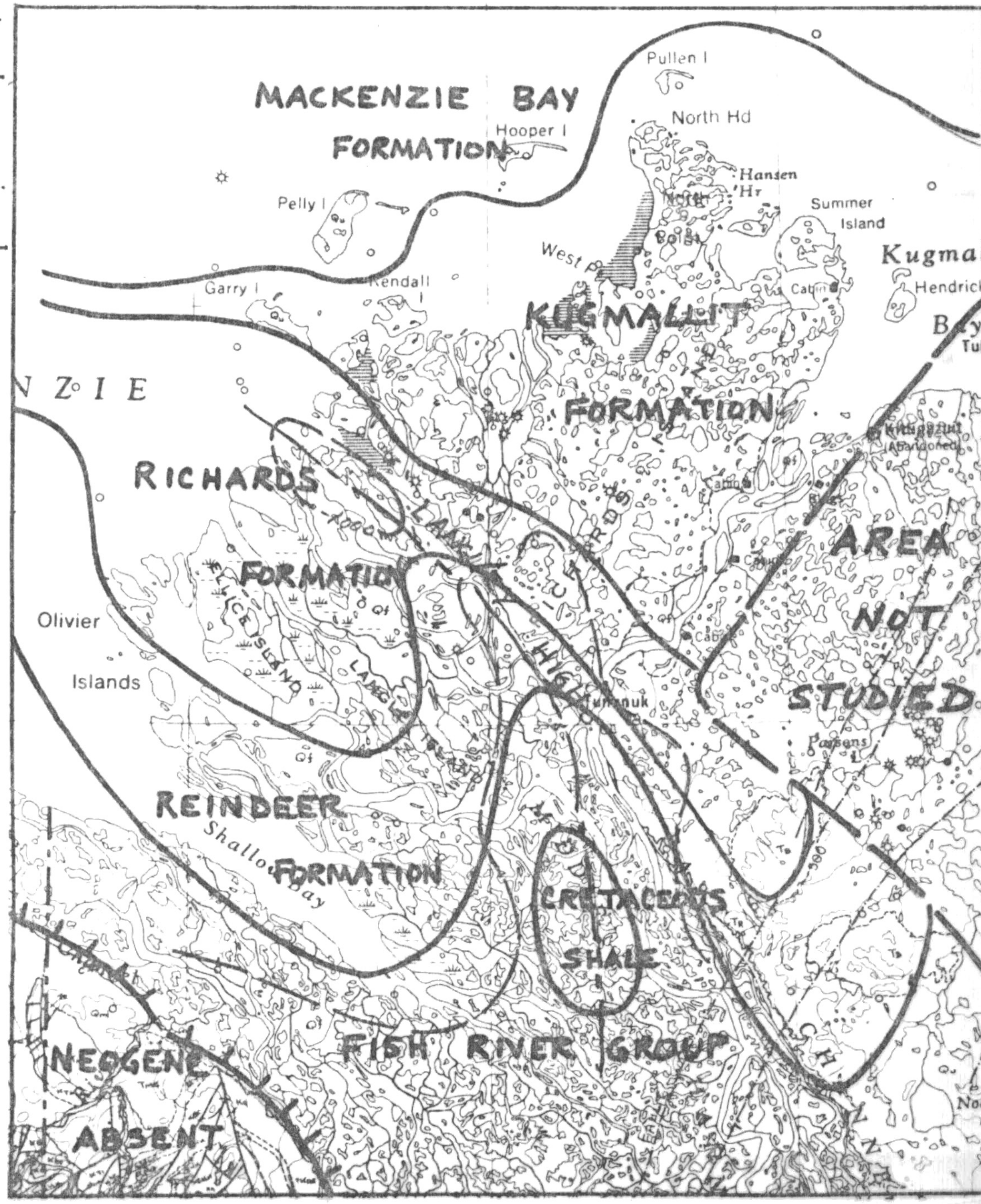

Figure 9. Pre-Late Oligocene Unconformity Subcrop Map and 1000-foot subsea structural contours of unconformity.

deposits are characteristic throughout. Mudstone-dominant formations, such as the Tent Island and Richards formations, are probably the prodeltaic facies of coarser grained delta-plain and delta-front deposits, represented by other formations such as the Moose Channel and Kugmallit Formations.

Correlation framework

Four profile lines were laid out over the study area to establish a correlation network among key well sections (Fig. 3); however, many more wells were used in establishing lithostratigraphic correlation concepts. The cross-sections (Figs. 5-8) are drawn on a vertical scale of 1:2400.

In dealing with dominantly terrigenous clastic sequences, electrical well-logs are used generally; however, E-logs are commonly poor in quality in Mackenzie Delta wells because of saline drilling muds used to control thawing of permafrost. Thus gamma ray-sonic logs were used alternatively for certain wells to delineate lithologic character on the log profiles.

In many boreholes caving or washing out of the soft mudstone intervals and unconsolidated sand and gravel units occurred to a degree detrimental to obtaining good quality well-logs, and this problem must be recognized at the outset of any analysis or discussion of log characteristics. Unfortunately, sidewall caving also adversely affects the quality of sampled cuttings, and mixing of uphole material with newly drilled sediment causes confusion in all stratigraphic studies.

The cross-section grid consists of two subparallel lines running northeast-southwest (Figs. 5, 6), joined by a short north-south connecting line at the northeastern end (Fig. 8), and a long, northwest-southeast trending section (Fig. 7) at the southwestern side. The well-logs are referred in the vertical sense to a sea-level datum, and are uncontrolled in the horizontal sense. Because virtually all wells in the area have been drilled on structurally high features, it must be realized that one is skipping from one "hilltop" to another structurally and stratigraphically on these profiles; seismic profiles are required to help fill in the stratigraphic characteristics of the intervening depressed areas. Despite the limitations of these cross-sections, some general conclusions on overall structural trends can be seen readily on them.

From southwest to northeast (Figs. 6, 10), the Paleogene part of the section expands greatly, with the Kugmallit Formation thickening from zero at Kumak J-06 to over 2 km (6400 ft) in Ivik N-17. Similarly, this part of the section expands northward (Figs. 7, 8), thereby depressing the top of the Reindeer Formation to practically undrillable depths in the near offshore region.

The base of the Neogene part of the section generally drops increasingly lower basinward (south to north), but remains at a relatively constant level beneath much of Richards Island. This is illustrated also on the structure contour map (Fig. 9) and discussed in the chapter on <u>Structural Geology</u>.

The Tertiary succession is divisible into formations by virtue of the presence of persistent mudstone units sandwiched between predominantly coarse clastic formations. In particular, the Richards Formation (mudstone) allows the Paleogene section to be divided into three main formations: the Reindeer, Richards, and Kugmallit. Where the Richards changes facies southwestward into mixed coarse and fine clastics and coals, as in the Ellice O-14 well, little basis remains for subdivision, and the entire Paleogene section is there referred to the Reindeer Formation (Young, 1975).

Once the large-scale formations are identified, they are further divisible into members, based upon vertical facies arrangements. For example, the Kugmallit Formation consists of two members: the coarser, relatively nonmarine facies of the upper one (Arnak) always overlies the lower, mixed arenaceous and pelitic member (Ivik).

Biostratigraphic zonations carried out on many wells also greatly aid in the placement of subtle unconformities, and in establishing the limits of units in both sequences, in particular the Neogene. Some idea of the direction of diachronous stratigraphic contacts also can be obtained from the comparison of biostratigraphic and lithostratigraphic tie-lines.

Marker beds are relatively rare and limited in areal extent in this succession. Resistivity log-markers are formed by bentonitic tuff beds in the Moose Channel, Reindeer, Richards, and Mackenzie Bay formations. These are generally inward deflections (lower resistivity) on well-logs. The problem of identification of individual beds arises due to the large number of these in many units. In several instances, however, these beds comprise relatively thick zones which can be traced over a wide area, such as the bentonitic zone near the top of the Richards Formation. A carbonate unit underlies the Nuktak Formation in the offshore near the Netserk wells. This may be a hardground formed at the top of the sediment column during marine transgression when clastic sediment supply was minimal.

Biostratigraphic markers are also useful in correlating well sections. Some practical examples in the Mackenzie Delta Tertiary succession were given by Staplin et al. (1976), who suggested that the highest occurrences of the fungal spore **Pesavis tagluensis** and the dinoflagellate **Wetzeliella hampdenensis**, among others, were particularly consistent markers. In the present study, the highest occurrences of the foraminifer **Asterigerina guerichi s.l.** and its associates (**Cibicides** spp. assemblage) are used to help distinguish the Beaufort and Mackenzie Bay Formations from the overlying Pliocene-Pleistocene Nuktak Formation.

BIOSTRATIGRAPHY

Previous work

Paleontological work on the Cenozoic sediments of the Mackenzie Delta has involved mostly preliminary work on the microfaunas and microfloras recovered from exploratory wells and from Cenozoic outcrops in areas marginal to the delta, the Yukon Coastal Plain on the west and the Caribou Hills on the east. The work has been accomplished by members of the Geological Survey of Canada, the petroleum industry, and by various researchers reporting through private consulting firms. The last are of particular significance in this study, in that the palynological data are drawn almost exclusively from the reports of Norris (<u>in</u> Austin and Cumming, various reports), and the ostracod data from Braun and Brooke (<u>in</u> *op. cit.*). Additionally, the preliminary descriptions of the Cenozoic foraminiferal assemblages in the delta by Braun and Brooke (<u>in</u> *op. cit.*) formed a significant source of information aiding the present research.

Publications on the foraminifers began with Chamney's (1969) recognition of an anomalously thick Tertiary sequence in the first exploratory well in the Mackenzie Delta — the Reindeer D-27 well drilled by the British American Oil

Company Limited, Shell Canada Limited, and Imperial Oil Enterprises Limited. Chamney (1971, 1973a, b) later attempted a biostratigraphic division of the Reindeer D-27 borehole, assigning 1433 m (4700 ft) of sediments to the Tertiary. Comparable biostratigraphic divisions were discriminated and correlated among wells in the Tuktoyaktuk Peninsula (Chamney, 1973). In contrast to Chamney's (1971) findings, Petracca (1972) and Langhus and Petracca (1973) described an Eocene microfauna consisting of agglutinated foraminifers, notably **Alveolophragmium ["Cyclammina"] arctica** Petracca and **A. borealis** Petracca, in addition to benthonic and planktonic calcareous foraminifers in core of the Reindeer D-27 borehole between 2887 and 2895 m (9473 and 9498 ft); thus, in beds assigned to the Upper Cretaceous by Chamney (1971, addendum). Chamney (1973) considered the Eocene age assignment for those beds to be erroneous and noted that no similar planktonic microfauna had been recovered from the 27 delta wells drilled to that date, thus alluding to a spurious source for the microfauna (such as contamination of microfossil samples in laboratory processing). More recently, in a biostratigraphic study based mainly on palynomorphs and foraminifers, Staplin et al. (1976) used selected marker species of foraminfers and an assemblage zonation based on selected species to correlate strata between boreholes in the delta. The controversial **"Cyclammina arctica-borealis"** microfauna was included in the lower Paleogene by Staplin.

Palynological contributions to the Cenozoic biostratigraphy of the delta include preliminary biostratigraphic determinations by Hopkins (1971), Brideaux (1973, 1974), Brideaux and Sweet (1974), and Brideaux (in Young, 1975). Brideaux and Myhr (1976) recognized four biostratigraphic subdivisions in the Reindeer Formation of the Gulf-Mobil Parsons N-10 well and dated the units as Paleocene to Eocene. In a four-well biostratigraphic study, Staplin (1976) employed quantitative methods to delineate palynomorph assemblages of Paleogene and Neogene age which were used together with foraminifers for correlation and interpretation of Tertiary strata in the delta. Palynological zones T-1 to T-4 including subzones were defined by Staplin using the Imperial Taglu G-33 well as a type well, with zonal correlations to the Imperial Taglu C-42, Gulf-Mobil Ya Ya P-53, and BA-Shell-Imperial Reindeer D-27 wells. In the Caribou Hills, on the southeastern margin of the delta, Doerenkamp et al. (1976) summarized their findings of Paleocene to Eocene palynomorph assemblages overlain by Miocene-Pleistocene assemblages and correlated these assemblages to the northeast with sequences in Banks Island. Also, Ioannides and McIntyre (1980) have described three palynological associations in the Lower Tertiary sediments of the Caribou Hills. A systematic and stratigraphic study of the palynomorphs of the Imperial Nuktak C-22 well by G. Norris is in a final stage of preparation.

Biostratigraphic context

The list of problems cited by paleontologists working in the Mackenzie Delta is substantial. Many are inherent to subsurface study; others are peculiar to the paleogeographic setting. Reworked fossils, complex facies changes in nondescript sand-shale-mudstone sequences, caving and contamination of drill-cuttings are problems common to all biostratigraphic studies based on well-cuttings in the deltaic regime. However, study in the Mackenzie and the boreal realm in general involves, as well, many unique characteristics of the assemblages. As a rule, the assemblages are less diverse, substantially different, and poorly known in comparison to their counterparts of the central latitudes. These distinctions are significant since the standard zonal sequences of international chronostratigraphy have been established mainly from the more southerly latitudes of Europe. Because the assemblages are lacking in most of the standard zonal indices, such as planktonic foraminifers, chronostratigraphic analysis relies more heavily on longer ranging groups of fossils. Age determinations within the Richards Island Basin are thus generalized and tentative.

Regardless, the Cenozoic biostratigraphy of the Mackenzie Delta is becoming increasingly clear in light of data accumulated from many of the more than 150 exploration wells drilled since 1965. The current biostratigraphic framework is constructed primarily by recognition of distinctive assemblages of particular fossil groups, with reliance on the uppermost occurrence of certain species to provide marker horizons. Foraminifers, dinoflagellates, pollen, and spores have been the primary fossil groups employed. They provide information that can be used with varying degrees of confidence to interpret many of the basic characteristics of this important Cenozoic basin and its evolution.

Foraminiferal assemblages

The foraminifers of the Mackenzie Delta Cenozoic are described here in four assemblages (Table 2). They range in age from Paleocene to Pleistocene and collectively indicate marginal-marine to outer-shelf environments of deposition through respective parts of the sequence. Either agglutinated or calcareous benthonic species dominate the assemblages to the total exclusion of planktonic species. In addition to the diagnostic *in situ* elements, assemblages may contain distinctive siliceous foraminifers which are particularly common in the Pliocene and Pleistocene but were reworked from Cretaceous or older sources.

The palynological characteristics of the delta, synthesized from the reports of Norris (in Austin and Cumming, 1978a, b, c; 1979a, b, c, d, e), are outlined later in the general discussions of the paleontology and age for each of the Cenozoic formations, accompanied by complementary details on foraminifers and other fossil groups.

The earliest Tertiary foraminiferal assemblage in the Mackenzie Delta lies in the Moose Channel Formation but is not described here because the lithostratigraphic basis for this study begins with the Reindeer Formation, focusing on the construction of a lithostratigraphic and biostratigraphic framework for the newly named formations in the Mackenzie Delta Cenozoic sequence.

Saccammina-Trochammina spp. assemblage

The **Saccammina-Trochammina** spp. assemblage occurs in the lower Reindeer Formation (Table 2). Extreme low diversity characterizes it, only the two nominal species **Saccammina** sp. and **Trochammina** sp. 1 (Plate 1) are present.

Trochammina sp. 1 has been recorded previously as **Haplophragmoides** 4106 by Staplin (1976, Pl. 2, figs. 27-29) who recognized it as a marker species, low in the Mackenzie Delta Paleogene. As well, Price et al. (1980) have recorded it from the type Reindeer Formation in the Caribou Hills at the eastern margin of the delta. It occurs too in outcrop along the Yukon Coastal Plain. Preliminary study of samples from the type Aklak Member of the Reindeer Formation and from the underlying Ministicoog Member of the Moose Channel Formation has revealed both of the nominal species. A clear distinction can be made between the two members on the basis of foraminifers. **Saccammina** sp. and **Trochammina** sp. 1 are abundant in the Aklak but rare below. In the

TABLE 2 FORAMINIFERAL ASSEMBLAGES IN THE MACKENZIE DELTA CENOZOIC SEDIMENTS

AGES		FORMATIONS	FORAMINIFERAL ASSEMBLAGES	REPRESENTATIVE TAXA NORTH		SOUTH
QUATERNARY	PLEISTOCENE	NUKTAK	Elphidium spp.	Buccella frigida (Cushman), Elphidiella hannai (Cushman and Grant), Elphidium bartletti Cushman, E. clavatum Cushman, E. ustulatum Todd, Islandiella helenae Feyling-Hanssen and Buzas, I. islandica (Norvang), Protelphidium anglicum Murray, P. orbiculare (Brady), P. cf. P. orbiculare (Brady), and Quinqueloculina seminulum (Linne)		non-marine biofacies with charaphytes, plant debris, statoblasts, and ostracods
TERTIARY	PLIOCENE	NUKTAK				
TERTIARY	MIOCENE	BEAUFORT; MACKENZIE BAY	Cibicides spp.	Asterigerina guerichi s.l.	Asterigerina guerichi s.l. (Franke), Cibicides grossa ten Dam and Reinhold, Cibicides perlucidus Nuttall, C. cf. C. tenellus (Reuss) C. sp., Cyclogyra involvens (Reuss), Ehrenbergina variabilis Trunko, Elphidiella(?) brunnescens Todd, Eponides binominatus Subbotina, Globocassidulina subglobosa (Brady), Globulina inaequalis Reuss, Melonis cf. M. affine (Reuss), Miliolinella circularis (Bornemann), Miliolinella sp., Nodosaria spp., Parafissurina sp., Scutuloris sp., Sphaerodina bulloides d'Orbigny Trifarina fluens (Todd), and Turrilina alsatica Andreae	A. guerichi s.l., C. involvens, E.(?) brunnescens, and Miliolinella sp.
TERTIARY	OLIGOCENE	MACKENZIE BAY; KUGMALLIT	Cibicides spp.	Turrilina alsatica		
TERTIARY	EOCENE	KUGMALLIT; RICHARDS	Haplophragmoides sp.	Alveolophragmium sp. 1, Pathysiphon pseudolcculus (Myatliuk), Haplophragmoides sp.		
TERTIARY	EOCENE	RICHARDS	Haplophragmoides sp.	Alveolophragmium sp. 1, A. sp. 2, Bathysiphon pseudolcculus (Myatliuk), Gravellina sp., Haplophragmoides cf. H. carinatus Cushman and Renz, Jadammina sp., Recurvoides sp., Trochammina sp. 2, and Brizalina cf. B. substriatula (Asano)		Jadammina sp.
TERTIARY	EOCENE	REINDEER				
TERTIARY	PALEOCENE	REINDEER	Saccammina-Trochammina spp.	Saccammina sp., Trochammina sp. 1		

PLATE 1

Foraminifera of the **Saccammina-Trochammina** spp. Assemblage

Figures

1\. **Saccammina** sp., X71, GSC 68659 from B.A.-Shell-I.O.E. Reindeer D-27 between 1722 and 1734 m (5650-5690 ft).

2a-c. **Trochammina** sp. 1, X83, GSC 68660 from B.A.-Shell-I.O.E. Reindeer D-27 between 1737 and 1750 m (5700-5740 ft).

3a-c. **Trochammina** sp. 1, X82, GSC 68661 from B.A.-Shell-I.O.E. Reindeer D-27 between 1737 and 1750 m (5700-5740 ft).

PLATE 1

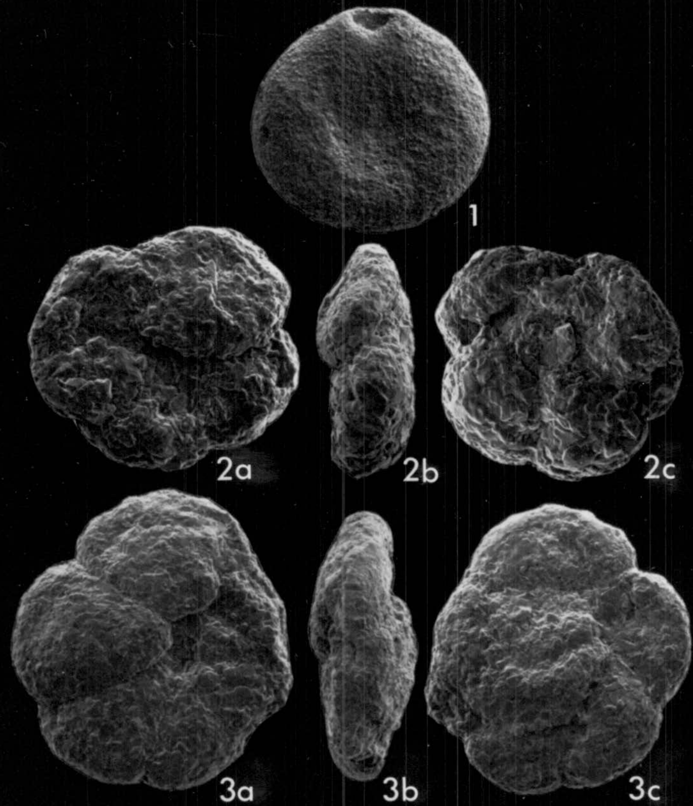

PLATE 2

Foraminifera of the **Haplophragmoides** spp. Assemblage

Figures

1. **Bathysiphon pseudoloculus** (Myatliuk), X39, GSC 68662 from Imperial Netserk B-44 between 1920 and 1950 m (6300-6400 ft).

2. **Bathysiphon pseudoloculus** (Myatliuk), X38, GSC 68663 from Imperial Netserk B-44 between 1920 and 1950 m (6300-6400 ft).

3a, b. **Haplophragmoides** sp., X45, GSC 68664 from Imperial Netserk B-44 between 2865 and 2895 m (9400-9500 ft).

4a, b. **Haplophragmoides** sp., X51, GSC 68665 from Sun BVX et al. Pelly C-35 between 2712 and 2743 m (8900-9000 ft).

5a-c. **Haplophragmoides** cf. **H. carinatus** Cushman and Renz, X59, GSC 68666 from Sun BVX et al. Pelly C-35 between 3048 and 3078 m (10 000-10 000 ft).

6a, b. **Haplophragmoides** cf. **H. cartinatus** Cushman and Renz, X84, GSC 68667 from Sun BVX et al. Pelly C-35 between 3048 and 3978 m (10 000-10 100 ft).

7a-c. **Jadammina** sp., X43, GSC 68668 from Imperial Netserk B-44 between 2895 and 2926 m (9500-9600 ft).

8a-c. **Jadammina** sp., X46, GSC 68669 from Imperial Taglu G-33 core at 2088 m (6851 ft).

9a-c. **Jadammina** sp., X47, GSC 68670 from Imperial Netserk B-44 between 2164 and 2194 m (7100-7200 ft).

10a-c. **Jadammina** sp., X49, GSC 68671 from Imperial Netserk B-44 between 2590 and 2621 m (8500-8600 ft).

11a-c. **Trochammina** sp., X120, GSC 68672 from Imperial Netserk B-44 between 2286 and 2316 m (7500-7600 ft).

12a, b. **Gravellina** sp., X122, GSC 68673 from Sun BVX et al. Pelly C-35 between 2834 and 2865 m (9300-9400 ft).

13a-c. **Gravellina** sp., X91, GSC 68674 from Sun BVX et al. Pelly C-35 between 2834 and 2865 m (9300-9400 ft).

PLATE 2

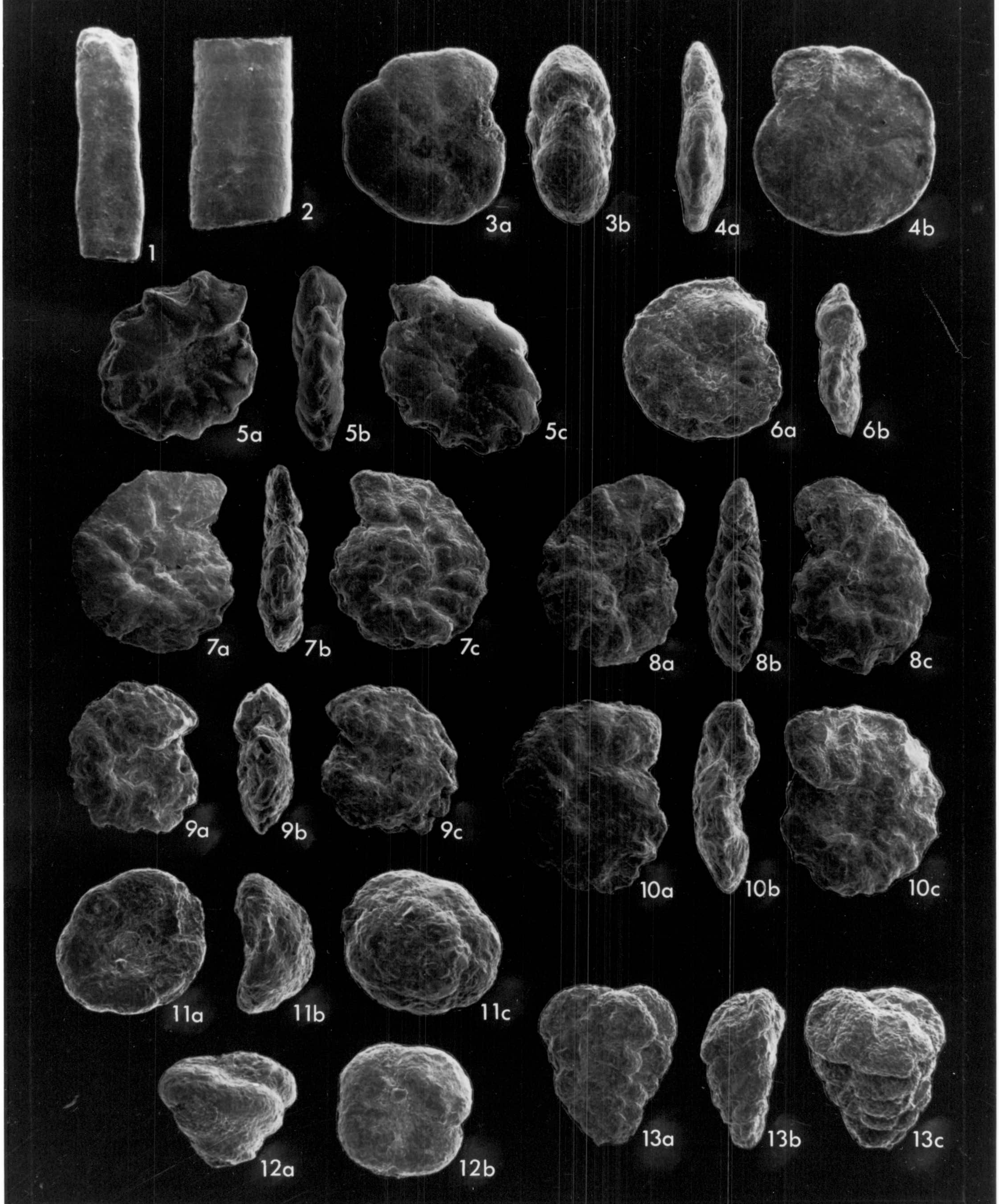
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PLATE 3

Foraminifera of the **Haplophragmoides** spp. Assemblage

Figures

1a, b. **Alveolophragmium** sp. 1, X21, GSC 68675 from Sun BVX et al. Pelly C-35 between 2682 and 2712 m (8800-8900 ft).

2a, b. **Alveolophragmium** sp. 1, X22, GSC 68676 from Sun BVX et al. Pelly C-35 between 3108 and 3139 m (10 200-10 300 ft).

3a, b. **Alveolophragmium** sp. 1, X31, GSC 68677 from Sun BVX et al. Pelly C-35 between 2743 and 2773 m (9000-9100 ft).

4a, b. **Alveolophragmium** sp. 1, X36, GSC 68678 from Imperial Netserk B-44 between 2042 and 2072 m (6700-6800 ft).

5a, b. **Alveolophragmium** sp. 2, X43, GSC 68679 from Imperial Netserk B-44 between 1981 and 2011 m (6500-6600 ft).

6a-c. **Recurvoides** sp., X62, GSC 68680 from Sun BVX et al. Pelly C-35 between 3048 and 3078 m (10 000-10 100 ft).

7a-c. **Recurvoides** sp., X77, GSC 68681 from Imperial Netserk B-44 between 2103 and 2133 m (6900-7000 ft).

8a-c. **Recurvoides** sp., X78, GSC 68682 from Sun BVX et al. Pelly C-35 between 3048 and 3078 m (10 000-10 100 ft).

9a-c. **Ammomarginulina** cf. **A. foliaceus** (Brady), X82, GSC 68683 from Sun BVX et al. Pelly C-35 between 2590 and 2621 m (8500-8600 ft).

10a, b. **Brizalina** cf. **B. substriatula** (Asano), X89, GSC 68684 from Sun BVX et al. Pelly C-35 between 2590 and 2621 m (8500-8600 ft).


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PLATE 4

Foraminifera of the **Cibicides** spp. Assemblage

Figures

1a-c. **Miliolinella** sp., X64, GSC 68685 from Imperial Netserk B-44 between 704 and 722 m (2310-2370 ft).

2a-c. **Scutuloris** sp., X59, GSC 68686 from Imperial Netserk B-44 between 914 and 944 m (3000-3100 ft).

3a-c. **Miliolinella circularis** (Bornemann), X78, GSC 68687 from Imperial Netserk B-44 between 1280 and 1310 m (4200-4300 ft).

4. **Pyrgo** sp., X50, GSC 68688 from Imperial Netserk B-44 between 585 and 606 m (1920-1990 ft).

5. **Nodosaria soluta** (Reuss), X70, GSC 68689 from Sun BVX et al. Pelly C-35 between 749 and 758 m (2460-2490 ft).

6. **Nodosaria** sp., X33, GSC 68690 from Imperial Netserk B-44 between 1219 and 1249 m (4000-4100 ft).

7. **Lagena semilineata** Wright, X88, GSC 68691 from Sun BVX et al. Pelly C-35 between 704 and 749 m (2430-2460 ft).

8. **Saracenaria** sp., X58, GSC 68692 from Sun BVX et al. Pelly C-35 between 740 and 749 m (2430-2460 ft).

9. **Astacolus** cf. **A. hyalacrulis** Loeblich and Tappan, X37, GSC 68693 from Imperial Netserk B-44 between 822 and 850 m (2700-2790 ft).

10. **Oolina**(?) sp., X125, GSC 68694 from Imperial Netserk B-44 between 1005 and 1036 m (3300-3400 ft).

11. **Parafissurina** sp. 2, X70, GSC 68695 from Imperial Netserk B-44 between 1188 and 1219 m (3900-4000 ft).

12. **Parafissurina** sp. 1, X79, GSC 68696 from Sun BVX et al. Pelly C-35 between 704 and 717 m (2310-2340 ft).

13. **Globulina inaequalis** Reuss, X54, GSC 68697 from Imperial Netserk B-44 between 670 and 701 m (2200-2300 ft).

14. **Turrilina alsatica** Andreae, X126, GSC 68698 from Imperial Netserk B-44 between 1920 and 1950 m (6300-6400 ft).

15a, b. **Trifarina fluens** (Todd), X63, GSC 68699 from Sun BVX et al. Pelly C-35 between 813 and 822 m (2670-2700 ft).

16a, b. **Trifarina fluens** (Todd), X70, GSC 68700 from Sun BVX et al. Pelly C-35 between 704 and 717 m (2310-2340 ft).

17a, b. **Sphaeroidina bulloides** d'Orbigny, X76, GSC 68701 from Sun BVX et al. Pelly C-35 between 758 and 768 m (2490-2520 ft).

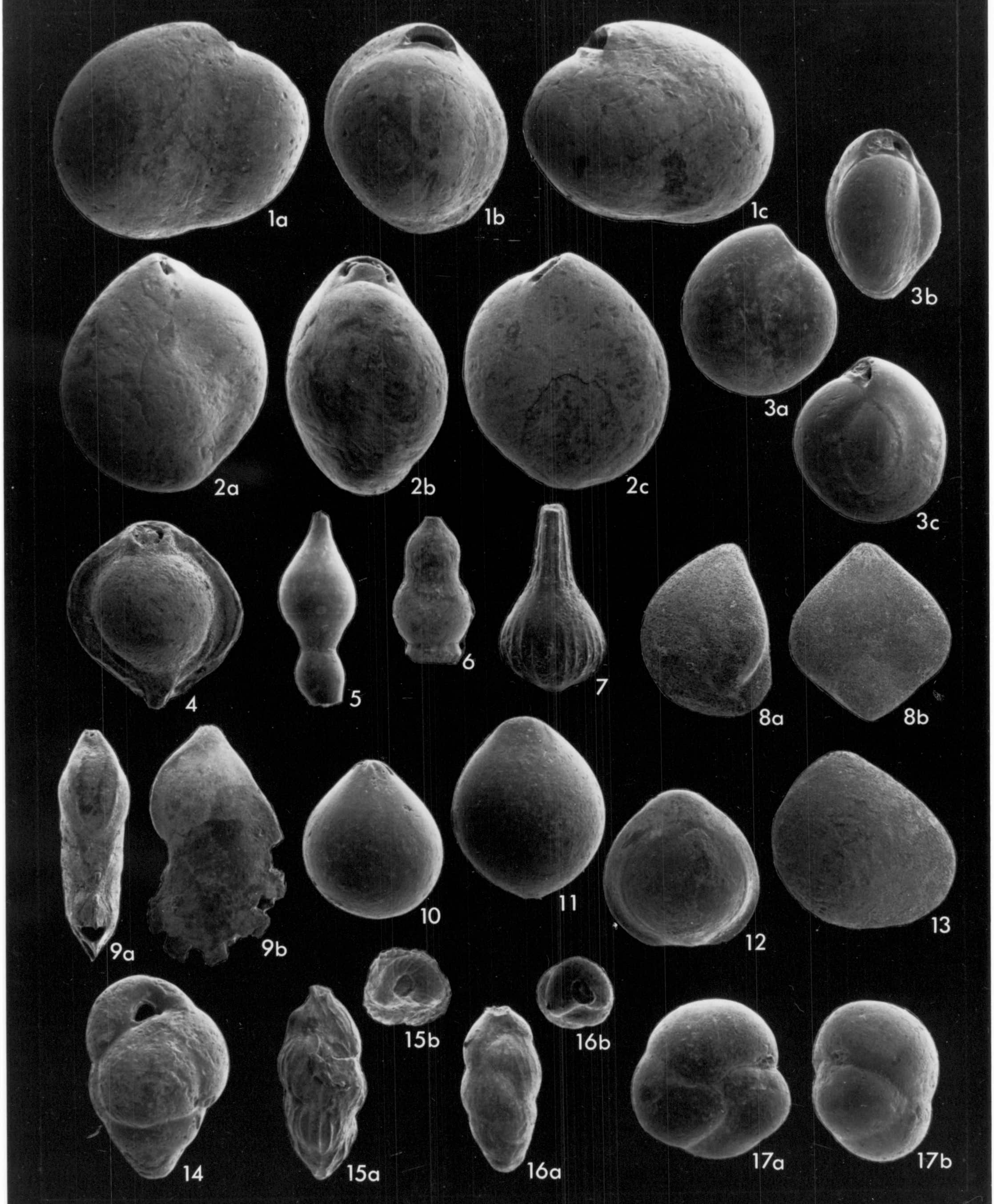
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PLATE 5

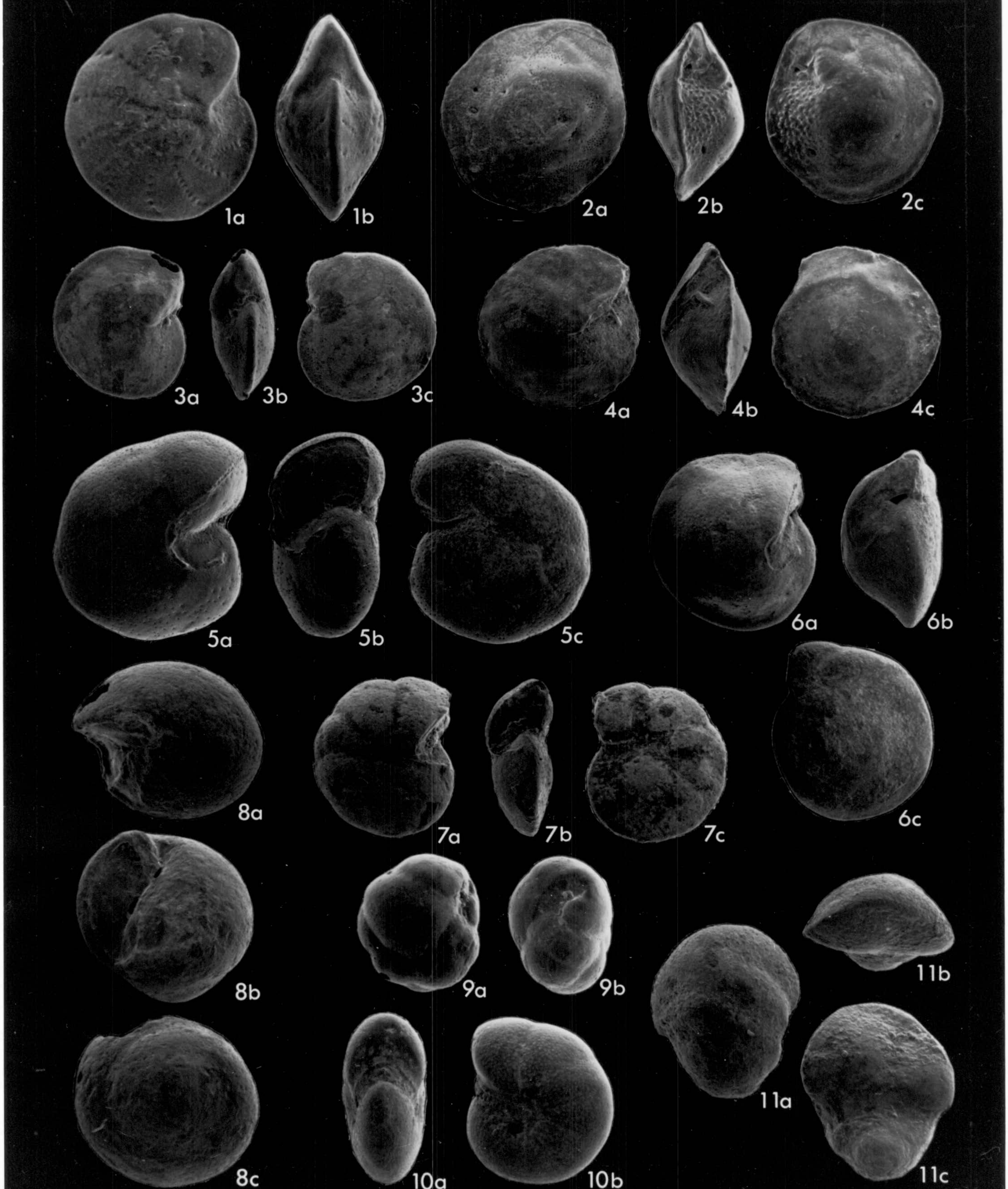
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PLATE 5

Foraminifera of the **Cibicides** spp. Assemblage

Figures

1a, b. **Elphidiella**(?) cf. **E. brunnescens** Todd, X59, GSC 68702 from Sun BVX et al. Pelly C-35 between 749 and 758 m (2460-2490 ft).

2a-c. **Asterigerina guerichi s.l.** (Franke), X72, GSC 68703 from Imperial Netserk B-44 between 585 and 603 m (1920-1980 ft).

3a-c. **Eponides binominatus** Subbotina, X88, GSC 68704 from Sun BVX et al. Pelly C-35 between 701 and 731 m (2300-2400 ft).

4a-c. **Eponides binominatus** Subbotina, X94, GSC 68705 from Imperial Netserk B-44 between 1097 and 1127 m (3600-3700 ft).

5a-c. **Cibicides grossa** ten Dam and Reinhold, X43, GSC 68706 from Imperial Netserk B-44 between 548 and 579 m (1800-1900 ft).

6a-c. **Cibicides perlucidus** Nuttall, X43, GSC 68707 from Imperial Netserk B-44 between 1158 and 1188 m (3800-3900 ft).

7a-c. **Cibicides** cf. **C. tenellus** (Reuss), X70, GSC 68708 from Sun BVX et al. Pelly C-35 between 740 and 749 m (2430-2460 ft).

8a-c. **Rotaliatina** cf. **R. mexicanus** Cushman, X56, GSC 68709 from Imperial Netserk B-44 between 1066 and 1097 m (3500-3600 ft).

9a, b. **Globocassidulina** cf. **G. subglobosa** (Brady), X104, GSC 68710 from Imperial Adgo F-28 between 701 and 822 m (2300-2700 ft).

19a, b. **Melonis** cf. **M. affine** (Reuss), X70, GSC 68711 from Sun BVX et al. Pelly C-35 between 749 and 758 m (2460-2490 ft).

11a, b. **Ehrenbergina variabilis** Trunkó, X79, GSC 68712 from Sun BVX et al. Pelly C-35 between 670 and 701 m (2200-2300 ft).

PLATE 6

Foraminifera of the **Elphidium** spp. Assemblage

Figures

1a-c. **Quinqueloculina seminulum** (Linné), X43, GSC 68713 from Imperial Netserk B-44 between 30 and 60 m (100-200 ft).

2a-c. **Buccella frigida** (Cushman), X104, GSC 68714 from Imperial Netserk B-44 between 124 and 143 m (410-470 ft).

3a, b. **Elphidium bartletti** Cushman, X73, GSC 68715 from Imperial Netserk B-44 between 521 and 539 m (1710-1770 ft).

4a, b. **Elphidium clavatum** Cushman, X82, GSC 68716 from Imperial Netserk B-44 between 124 and 143 m (410-470 ft).

5a, b. **Elphidium clavatum** Cushman, X94, GSC 68717 from Imperial Netserk B-44 between 274 and 301 m (900-990 ft).

6a, b. **Elphidium ustulatum** Todd, X116, GSC 68718 from Imperial Netserk B-44 between 124 and 143 m (410-470 ft).

7a, b. **Elphidium ustulatum** Todd, X100, GSC 68719 from Imperial Netserk B-44 between 219 and 237 m (720-780 ft).

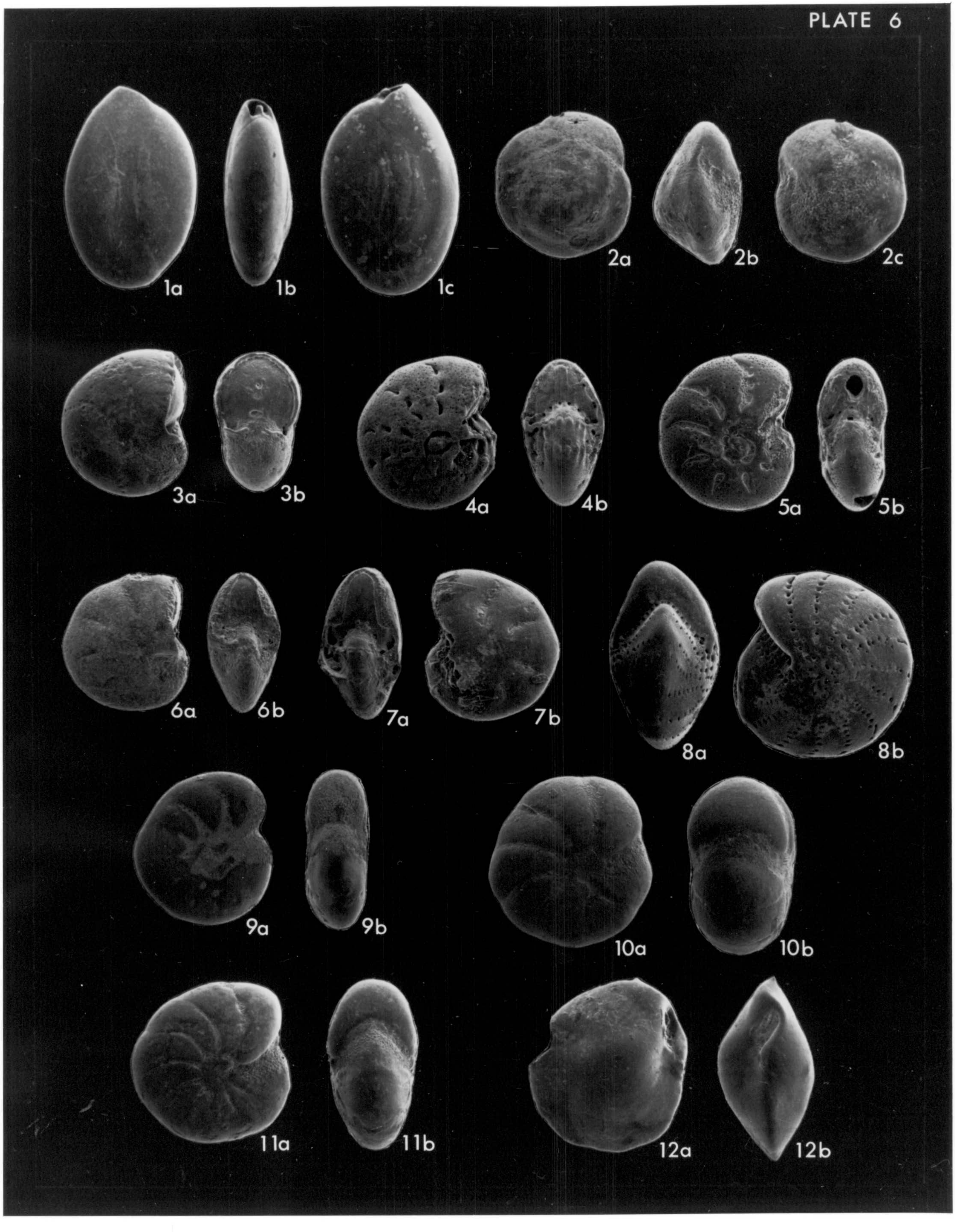
8a, b. **Elphidiella hannai** (Cushman and Grant), X30, GSC 68720 from Imperial Netserk B44 between 457 and 487 m (1500-1600 ft).

9a, b. **Protelphidium anglicum** Murray, X66, GSC 68721 from I.O.E. Ellice O-14 between 57 and 70 m (190-230 ft).

10a, b. **Protelphidium orbiculare** (Brady), X74, GSC 68722 from Imperial Netserk B-44 between 79 and 88 m (260-290 ft).

11a, b. **Protelphidium** cf. **P. orbiculare** (Brady), X70, GSC 68723 from Imperial Netserk B-44 between 124 and 143 m (410-470 ft).

12a, b. **Islandiella helenae** Feyling-Hanssen and Buzas, X63, GSC 68724 from Imperial F-40 between 100 and 118 m (330-390 ft).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Ministicoog, a more varied assemblage is dominated by the poorly preserved (flattened and silicified) **Alveolophragmium coksuvorovae** (Subbotina) in addition to species of **Bathysiphon Saccammina, Ammodiscus, Trochammina, Verneuilinoides,** and internal moulds from two genera of calcareous(?) foraminifers; one of which resembles **Lagena,** the other an indeterminant planispiral rotaliinid.

The foraminiferal sequence that is so clearly developed in the Aklak Creek sections is less readily discerned in the subsurface sections studied. For example, in the Reindeer D-27 well an essentially uniform assemblage of **Saccammina** sp. and **Trochammina** sp. 1 spans the upper Tent Island to the lower Reindeer Formation. The contrast between the outcrop section and the subsurface section is probably strongly environmentally controlled. Detailed taxonomic and foraminiferal distribution studies will be needed to properly assess the biostratigraphy of the Tent Island and Moose Channel, but these are outside the scope of the present study.

Little is known of **Saccammina** sp. or **Trochammina** sp. 1 outside the Mackenzie Delta, and their age and paleogeographic ranges have not been determined. The lower Reindeer, however, has been dated palynologically as Paleocene (pers. comm., A.R. Sweet). Environmentally, the low diversity assemblage consisting of only **Saccammina** and **Trochammina** probably represents brackish-water sedimentation in a sequence that is otherwise dominated by nonmarine, coastal-plain sediments rich in terrestrial floras and coaly sediments. In the Ministicoog Member of the underlying Moose Channel Formation, the more varied assemblage of agglutinated foraminifers with at least some calcareous species probably reflects increased salinity and more stable marine conditions of sedimentation.

Haplophragmoides spp. assemblage

The **Haplophragmoides** spp. assemblage occurs in the Richards Formation from the area of the Ya Ya P-53 well northwards and in the lower part of the Kugmallit Formation from the Ivik K-54 well northwards (Figs. 5, 6, 7). It consists exclusively of agglutinated foraminfers dated approximately as Eocene in the Mackenzie Delta. Several of the species are apparently new and endemic to the Arctic, suggesting relative isolation of the Arctic Ocean from the Pacific and Atlantic Oceans at this time.

Principal elements of the assemblage (Table 2, Plates 2, 3) include **Alveolophragmium** sp. 1, **Bathysiphon pseudoloculus** (Myatliuk), **Haplophragmoides** sp., **Jadammina** sp., and **Recurvoides** sp. Less common are **Alveolophragmium** sp. 2, **Ammomarginulina** cf. **A. foliaceus** (Brady), **Gravellina** sp., **Haplophragmoides** cf. **H. carinatus** Cushman and Renz, **Saccammina** sp., and **Trochammina** sp. 2. The calcareous benthonic foraminifer **Brizalina** cf. **B. substriatula** (Asano) occurs rarely.

The only previous reference to this assemblage in the Mackenzie Delta was that by Staplin (1976, p. 132; Pl. 1, figs. 1, 2) who cited **Haplophragmoides** sp. (= **Jadammina** sp.) as a marker species for biostratigraphic correlation.

The **Haplophragmoides** spp. assemblage probably falls within a Middle to Late Eocene time span. In the lowermost Richards Formation, the assemblage is associated with the dinoflagellates **Wetzeliella (W.) articulata** Eisenach [includes **W. hampdenensis** Wilson and **W. (Apectodinium) hormomorpha** Deflandre and Cookson]. Staplin (1976) noted that these species indicate a late Early to early Middle Eocene age. This conclusion is comparable with that provided by Costa and Downie (1976) for **Wetzeliella** in northwestern Europe and numerous other regions on a near world-wide basis. They record a Paleocene to Eocene range for **W. (A.) hormomorpha** and an Eocene to Oligocene range for **W. (W.) articulata.** Elements of the **Haplophragmoides** spp. assemblage have not been found to range higher into sections containing the Oligocene-Miocene **Cibicides** spp. assemblage. Northward under the Beaufort Sea, however, the assemblage may be found to span a greater part of the section due to proportionately greater amounts of marine beds which no doubt dominate the offshore section.

The **Haplophragmoides** spp. assemblage is distinctive in its generic and specific composition, a fact no doubt reflecting pronounced environmental and geographic controls, i.e. variable influences of deltaic sedimentation and relative isolation of the Arctic Ocean basin. For example, through most of Richards Island, **Jadammina** sp., is the dominant or only foraminiferal species in the Richards Formation. In the lower Kugmallit Formation at the northern margin of the delta, the assemblage consists of only **Bathysiphon pseudoloculus** (Myatliuk), **Haplophragmoides** sp., and **Alveolophragmium** sp. 1 (Table 2). Its endemic nature is also pronounced; many of the species are unknown outside of the Arctic Ocean area.

The assemblage apparently developed in a prodeltaic, shelf environment extending over much of the Richards Island area. Its agglutinated composition suggests a low salinity marine environment which may have been locally induced (i.e. deltaic) or of widespread extent (i.e. Arctic Ocean basin), although many other ecological factors may have been effective in limiting the diversity of the assemblage, such as low oxygen levels, high carbon dioxide levels, or high turbidity. Proximity to shorelines and terrestrial influences are well shown by an abundance of fungal spores in the Richards Island Formation. Nearshore conditions of sedimentation are also suggested, at least for the lower part of the Richards Formation, by the occurrence of the dinoflagellate **Wetzeliella** which has, in the Paleogene of England, been interpreted as an estuarine indicator (Downie et al., 1971). The assemblage attains its greatest diversity in the Richards Formation in the offshore wells (Fig. 5). A fairly sharp increase there in species diversity and introduction of rare calcareous foraminifers, such as **Brizalina,** suggest increasing distance from shoreline and deltaic or terrestrial influences and possibly deposition in the outer shelf or uppermost slope.

Cibicides spp. assemblage

The **Cibicides** spp. assemblage, which is composed almost entirely of calcareous benthonic taxa, is rich in both species and specimens (see Plates 4, 5). It occurs in the Mackenzie Bay and Kugmallit Formations and is best developed in the Mackenzie Bay Formation in the northern part of the area studied (Fig. 5). The assemblage disappears rapidly southeastward where the facies change from the shallow marine mud of the Mackenzie Bay to the nonmarine gravels of the Beaufort Formation.

Principal elements of the assemblage include **Asterigerina guerichi s. l.** (Franke), **Cibicides grossa** ten Dam and Reinhold, **C. perlucidus** Nuttall, **C.** cf. **C. tenellus** (Reuss), **C.** sp., **Cyclogyra involvens** (Reuss), **Elphidiella** (?) **brunnescens** Todd, **Eponides binominatus** Subbotina, **Globocassidulina subglobosa** (Brady), **Globulina inaequalis** Reuss, **Melonis** cf. **M. affine** (Reuss), **Miliolinella** sp., **Scutuloris** sp., **Trifarina fluens** (Todd), and **Turrilina alsatica** Andreae. Less common are **Ehrenbergina variabilis** Trunkô, **Lagena semilineata** Wright, **Miliolinella circularis**

(Bornemann), **Nodosaria** spp., **Oolina**(?) sp., **Parafissurina** sp., **Pullenia** sp., **Pyrgo** cf. **P. rotalarius** Loeblich and Tappan, **Quinqueloculina** sp., **Rotaliatina** cf. **R. mexicanus** Cushman, **Saracenaria** sp., and **Sphaerodina bulloides** d'Orbigny.

The **Cibicides** spp. assemblage is dated Oligocene to Miocene. **T. alsatica** indicates an Oligocene age for its lower part. Above **T. alsatica**, the assemblage is Miocene, characterized by common to abundant **A. guerichi s. l.** which is not known to range above the Middle Miocene. The extreme upper beds of the **Cibicides** spp. assemblage contain **C.** cf. **C. grossa**, a species known from the Miocene and Pliocene (Feyling-Hanssen, 1980). In Netserk B-44, for example, **C.** cf. **C. grossa** ranges 60 m above **A. guerichi s.l.**, suggesting a Late Miocene or possibly younger age for this uppermost extension of the assemblage. In general, age assignments are drawn from comparisons with Tertiary assemblages of northwestern Europe (Batjes, 1958; Hansen, 1972; Doppert, 1980) and the Labrador Shelf of eastern Canada (Gradstein and Williams, 1976; Dufaure et al., 1976). The concept of **A. guerichi**, a critical species in this biostratigraphic correlation, warrants a note of explanation. A variety of **A. guerichi**, var. **staeschei** ten Dam and Reinhold, was differentiated in 1942. The variety has been considered by some workers to be a subspecies or a distinct species and to be an index of the Early to Middle Miocene (ten Dam and Reinhold, 1942; Doppert, 1975, 1980; and Meuter and Laga, 1976). Batjes (1958, p. 159) and Gradstein and Williams (1976, p. 17), however, recognized only one species, **A. guerichi**, and doubted the validity of variety **staeschei** as an index of the Miocene. Tentatively, **A. guerichi s.l.** is adopted here, but a systematic and chronostratigraphic study of the species may prove to be of value in refining the biostratigraphic division of the Oligocene-Miocene succession in the Mackenzie Delta.

In Alaska, an assemblage comparable to that of **Cibicides** spp. has been described from the Nuwok Member of the Sagavanirktok Formation on Carter Creek by Todd (1957) and by Bergquist (in Detterman et al., 1975). Todd considered the assemblage to be of Miocene or Pliocene age; Bergquist suggested a Pliocene age. To the contrary, the Carter Creek assemblage may be older. A direct comparison of the Mackenzie Delta foraminifers with original Carter Creek material (now in the American National Museum of Natural History at Washington, D.C.) indicated that the Alaskan assemblage is virtually identical to the lower part (Late Oligocene) of the **Cibicides** spp. assemblage. The most important species in common include **Cibicides perlucidus**, **Elphidiella**(?) **brunnescens**, **Eponides binominatus** (=Todd's microspheric generation of **Cibicides perlucidus**), **Globocassidulina subglobosa**, **Melonis** cf. **M. affine** (=Todd's **Nonion erucopsis**, **Miliolinella circularis**, **Trifarina fluens**, and **Turrilina alsatica** (=Todd's **Buliminella curta** Cushman). Notably, **A. guerichi s. l.** is not present in the Carter Creek assemblage; but if the above correlation is correct, then **A. guerichi s.l.** which is dominant only in the upper part of the **Cibicides** spp. assemblage would reasonably be absent in the Carter Creek section.

By comparison with the ecology of Recent foraminifers as summarized by Murray (1973) and Boltovskoy and Wright (1976), the **Cibicides** spp. assemblage is typical of the inner shelf (less than 100 m). Two biofacies of the assemblage have been recognized (Table 2). One consists of a sparse microfauna including **Elphidiella**(?) **brunnescens**, **Miliolinella** sp., and more rarely **Asterigerina guerichi s.l.** and **Cyclogyra involvens**. This microfauna occurs in the Arnak Member of the Kugmallit Formation and in the Beaufort Formation and suggests a nearshore environment of deposition. The other, a more diverse, prolific microfauna, consists of the above elements with common to abundant occurrences of **Cibicides perlucidus**, **C.** sp., **Asterigerina guerichi s.l.**, **Turrilina alsatica**, **Trifarina fluens**, and numerous other rare to common elements. This biofacies is also characterized by many inner-shelf elements, but its increased diversity suggests a paleoenvironmental position nearer to middle shelf. It is most characteristic of the Mackenzie Bay Formation but occurs rarely in the upper part of the Kugmallit Formation.

Elphidium spp. assemblage

The **Elphidium** spp. assemblage is the youngest foraminiferal assemblage distinguished here in the Mackenzie Delta Cenozoic and its distribution is confined to the Nuktak Formation (Table 2). The assemblage consists almost entirely of calcareous benthonic foraminifers dominated by **Elphidium** and related genera (see Plate 6). Planktonic species are absent and *in situ* agglutinated foraminifers are rare.

The **Elphidium** spp. assemblage distinguishes the shallow-water, marine facies of the Nuktak Formation. Its individuals are generally recovered in greatest abundance and diversity in the most northern and northwestern portions of the delta and in the upper part of the formation. Part of the Nuktak, particularly the middle and lower, are marked by a dominance or exclusive occurrence of freshwater ostracods, suggesting a tenuous balance between marine and nonmarine conditions of sedimentation. The **E.** spp. assemblage is largely absent in the southern area of the delta where it is replaced by a nonmarine biofacies distinguished by ostracods, charaphytes, seed casings and woody or lignitic debris.

Principal elements of the assemblage include **Elphidiella hannai** (Cushman and Grant), **Elphidium bartletti** Cushman, **E. clavatum** Cushman, **Protelphidium anglicum** Murray, **P. orbiculare** (Brady), and **P.** cf. **P. orbiculare** (Brady). Less common elements include **Buccella frigida** (Cushman), **Elphidium ustulatum** Todd, **Islandiella helenae** Feyling-Hanssen and Buzas, **I. islandica** (Norvang), **Quinqueloculina seminulum** (Linné), and rare agglutinated species of the genera **Haplophragmoides**, **Ammodiscus**, and **Miliammina**(?). Comparable assemblages are well known in the boreal realm (Feyling-Hanssen et al., 1971; and Gudina, 1976) and all but one of the species range through the Pliocene, Pleistocene, and Holocene. **Elphidium ustulatum** Todd is the exception, found only in the pre-Holocene, and thus is an important index (Gregory and Bridge, 1979). The other elements of the assemblage are extant and their ecological significance has been well assessed. For example, Vilks et al. (1979) have reported virtually all of the species from Holocene sediments of the Beaufort Shelf. They recognized an **Elphidium clavatum** - dominant assemblage developed in low-salinity waters that contained large amounts of suspended matter from the Mackenzie River outflow. Seaward, the assemblage changed to one dominated by stenohaline **Cassidulina teretis** Tappan. They concluded that salinity was the primary control on the foraminiferal distributions; a conclusion also arrived at by Cronin (1979) for similar biofacies variations in the Upper Pleistocene sediments of the St. Lawrence Lowlands.

The **Elphidium** spp. assemblage distinguished in the Richards Island area no doubt compares with the nearshore, low-salinity biofacies recognized by Vilks et al. and by Cronin; the occurrence of rare **I. helenae**, **Stainforthia concava**, and a general increase in diversity in the northermost wells, e.g. Netserk F-40, signify biofacies change towards normal-marine, shelf-type paleoenvironments.

In addition to *in situ* foraminiferal and ostracod assemblages, the Nuktak Formation is marked both in its marine and nonmarine facies by reworked, siliceous foraminifers of Cretaceous or possibly Jurassic age. The reworked assemblage is particularly rich in Albian foraminifers, some of which are identifiable to species level, such as **Gaudryina nanushukensis** Tappan.

DESCRIPTIONS OF FORMATIONS

Introduction

The only formally defined formations in the Mackenzie Delta Tertiary succession are those established from surface studies. They include the Moose Channel, Reindeer, and Beaufort formations. With the completion of over 75 wells drilled in the outer delta area, considerable information on the lithology and stratigraphy of these and several units which occur only in the subsurface is presently available. With the passage of several years during which stratigraphers in both private industry and government have mulled over the intricacies of the Delta's geology, several conventions and informal names have become established. These are followed here as far as possible; the only departures from certain informal names are due to prior usage elsewhere in North America.

An important redefinition and restriction of the Reindeer Formation by Price et al. (1980) at its type section is adopted here, and extended into the subsurface. A more detailed account of the thickness, facies, and contact relationships of the restricted Reindeer than those offered in previous publications is included in this report.

The Moose Channel and Tent Island formations (Fish River Group) are not treated here because they are already defined and their surface and subsurface stratigraphy discussed in earlier publications (Young, 1975; Young et al., 1976). It should be kept in mind, however, that these lower units (Table 1) form the basal part of the molassic wedge of which the following formations are medial and upper components.

Reindeer Formation

Introduction

The Reindeer Formation is the main hydrocarbon reservoir unit in the Mackenzie Delta area. Natural gas in pools at the Taglu, Niglintgak, Garry, and Adgo fields are located primarily within the Reindeer Formation. Because of its importance to the petroleum industry, this formation has been subjected to more paleontological, geochemical and sedimentological research than all other Tertiary units in the basin. Some of this work is summarized in papers by Wai (1975), Holmes and Oliver (1973), Hawkings and Hatlelid (1975), Bowerman and Coffman (1975), Young (1975), Young et al. (1976), and Doerenkamp et al. (1976). Shawa (1978) completed a doctoral thesis concerned largely with stratigraphy and sedimentology of the Reindeer Formation, and Nentwich (1980) studied its petrographic characteristics in a Master's thesis project. Also recently studied by the Geological Survey was the Caribou Hills section (Price et al., 1980), the type section of the Reindeer Formation as designated by Mountjoy (1967), but incompletely described by him and subsequent workers. Dixon (1981) discussed and interpreted the upper Reindeer deltaic sequence in the Taglu area.

The Caribou Hills section (partially shown in Fig. 14) was tentatively assigned a Paleogene age by Mountjoy (1967). The biostratigraphic attributes of this section were later found to include Neogene as well as Paleogene sediments Doerenkamp et al. (1976). Meanwhile, subsurface stratigraphers had become accustomed to restricting the Reindeer Formation to the lower Paleogene deltaic wedge, commonly gas-bearing, and fairly distinctive in the Delta subsurface. Careful field studies and measurements of the Caribou Hills section by Price et al. in 1978 led to documentation of at least one intra-Tertiary unconformity in this section. The need for revising the nomenclature and contacts, which had been established in a reconnaissance fashion by Mountjoy, had become clear, and Price et al. (1980) have proposed such a revision.

Strict adherence to the letter of the American Code of Stratigraphic Nomenclature requires either raising the name Reindeer to group status to embrace all new units defined within the Caribou Hills section, or complete abandonment of the term. However, because of common usage and acceptance of the name Reindeer Formation for the lower Paleogene deltaic wedge in the subsurface, Price et al. (1980) considered it desirable to retain the term and to propose a modified type section for it. A reference subsurface section is here also selected in the Shell Kumak J-06 well in the depth interval 1136 to 2485 m (3750-8200 ft) in order to aid the subsurface stratigrapher. The lithology and log-character of this interval are portrayed on Canadian Stratigraphic Service Ltd. log number D-NWT-554.

One formal member in the Reindeer Formation has been proposed: the Aklak Member at the base, originally described from the southwestern landward areas (Young, 1975). The Aklak Member includes the lower part of the formation in which bedded coal is common (predominantly a delta-plain facies). Its type section is on Aklak Creek which drains into Coal Mine Lake on the west side of the modern delta. The rarely coal-bearing, upper part of the Reindeer Formation is here referred to as the sandstone-mudstone member, which thickens northward and northeastward at the expense of the underlying, coal-bearing Aklak Member (Fig. 10).

Distribution and thickness

The Reindeer Formation occurs throughout the study area, but is eroded beneath the pre-Beaufort unconformity (Figs. 4, 9) to a feather-edge near the southern margin of the area. The limit of erosion runs approximately east-west along a line lying just north of the Reindeer D-27 and Ellice O-14 boreholes. Its distribution and thickness are incompletely known from well information in the northern and northeastern parts of the outer Delta because the formation dips to great depths in these areas.

In the limited remaining area in which the formation is complete and penetrated by boreholes, its thickness ranges mainly between 1350 and 1675 m (4500 and 5500 ft). Its greatest thickness in a borehole is in the North Ellice J-23 well, where it is 2160 m (7073 ft) thick, and its minimum is in the Ya Ya A-28 well, where only 485 m (1590 ft) are present. The Reindeer Formation is somewhat atypical in all the Ya Ya wells, where a medial mudstone unit up to 455 m (1500 ft) thick appears above the Aklak Member.

Contact relationships

The basal contact of the Reindeer Formation with the underlying Ministicoog Member of the Moose Channel Formation varies from interbedded and gradational in some wells (e.g. Ellice O-14) to abrupt and erosional in others (e.g. Kumak K-16). Owing to the variable thickness of the underlying Ministicoog mudstone, and the thinning of the interval between the base of the Reindeer and the Langley tuff marker in the Moose Channel Formation, a local disconformity is suggested, especially in the Niglintgak-Kumak (Langley High, Fig. 10) area.

The upper contact with the Richards Formation is a conformable vertical facies change, which may vary in stratigraphic level from one well to another. Without internal markers or precise biostratigraphic control in the basal part of the Richards, it is difficult to know the degree of stratigraphic shift at this contact between various wells. The marine dinoflagellate zone, characterized by species of **Wetzeliella**, which straddles the Richards-Reindeer contact in the south, is found higher in the section farther north. This biostratigraphic evidence and regional considerations suggest the upper contact becomes younger toward the west and southwest. Similarly, the contact between the Aklak and sandstone-mudstone members shifts upsection to the southwest, such that ultimately the entire formation can be considered Aklak Member in the Ellice O-14 well (Fig. 6).

Lithology

The lithology of the Reindeer Formation has been the subject of many studies, several of which have been published, such as Holmes and Oliver (1973), Young (1975), Bowerman and Coffman (1975), Young et al. (1976), and some are still unpublished. Thus, a brief summary only is given here, as the present study did not involve any new petrographic research of this unit.

The Reindeer consists primarily of sandstone and grey silty mudstone. These rocks are present as thin alternating beds, or as relatively thick uniform units of the one, followed by similarly thick units of the other. The latter format is more typical of the delta-front cycles (e.g. Fig. 20B in Young et al., 1976) found mainly in the sandstone-mudstone member. Channel-fill sandstones of the fluviodeltaic facies tend to be relatively thin but plentiful (e.g. Fig. 20A in op. cit.). The proportion of sandstone in the formation decreases from 39 per cent at Ellice O-14 to 29 per cent at Langley E-29 and 26 per cent at Taglu C-42 in an overall northeastward sense.

Minor rock types of the Reindeer Formation include conglomerate, siltstone, coal, marlstone, and tuff. Bentonitic tuff beds are fairly common in the upper part of the formation, but are almost too numerous to be useful as correlation markers.

Sandstones are typically fine to coarse grained, friable except where cemented by calcite, and speckled grey ("salt-and-pepper"), owing to abundant light grey to black chert grains mixed with quartz (Young, 1975). Clay minerals such as kaolinite and illite are commonly present as cements.

Cores of the sandstone (Fig. 11) display a great variety of sedimentary structures, including homogeneous texture, cross-stratification, parallel lamination, coal laminae, sideritic mudstone pebbles, shale chips, and vertical and horizontal burrows.

Mudstones of the Reindeer range from dark grey claystone to thinly interbedded claystone and siltstone (Fig. 12), exhibiting lenticular bedding, bioturbation structures, and flow convolutions. Finely divided mica and carbonaceous matter are common in these pelites.

Paleontology and age

The Reindeer Formation is dominated by terrestrial palynomorphs, but low diversity dinoflagellate and foraminiferal assemblages do occur. Based on data from Norris (in Austin and Cumming, 1978a, c and 1979d) for the Titalik K-26, Niglintgak H-30, and Netserk B-44 wells, the terrestrial palynomorph assemblages are characterized by abundant and varied fungal spores, various species of angiosperm pollen, including those of the deciduous hardwoods, gymnospermous pollen, and spores of ferns including **Azolla**, lycopods, and mosses. In general, the microflora is suggestive of a temperate climate. In Niglintgak H-30 and Titalik K-26, the palynomorphs indicated a terrestrial succession through the entire Reindeer. Brackish-water foraminifers, however, occur in the lower part of the Reindeer in these wells. Farther north, several well-defined marine palynomorph assemblages are conspicuous in the Reindeer. In Netserk B-44, for example, the uppermost 150 m of the formation yields marine palynomorphs in association with the **Haplophragmoides** spp. foraminiferal assemblage. Caved well-cuttings may obscure the true microfossil distribution of the uppermost Reindeer but most of the species occurrences seem indigenous and some have their uppermost occurrences within the Reindeer such as **Cannosphaeropsis** cf. **C. reticulensis** Pastiels. Lower in the formation, marine sequences are again marked by dinoflagellates. For example, in the Adgo F-28 well, Norris reports species of **Deflandrea, Horologinella,** and **Cannosphaeropsis** cf. **C. reticulensis** at 1395 to 1485 m (4600 to 4900 ft) and **Wetzeliella homomorpha quinquelata** Williams and Downie at 1600 to 1700 m (5300 to 5600 ft).

Two foraminiferal assemblages occur in the Reindeer Formation. They are the **Saccammina-Trochammina** spp. and **Haplophragmoides** spp. assemblages (see Table 2). The **Saccammina-Trochammina** spp. assemblage is of brackish-water origin, contains only the two nominal species, and occurs in the lower part of the formation. Both **S.** sp. and **T.** sp. 1 range into the Ministicoog Member of the Moose Channel Formation as well. Little is known of the geographic or temporal ranges of the elements of this assemblage, but it is clear from a palynological basis that the age is approximately Paleocene.

The other foraminiferal assemblage of the Reindeer Formation is that of **Haplophragmoides** spp. which occurs in the upper part of the formation in the Netserk B-44 well. The assemblage is also well developed in the overlying Richards Formation and its distribution and composition are described in a following section on the Richards Formation.

Palynological evidence indicates a Paleocene-Eocene age for the Reindeer Formation. Norris (*op. cit.*) has reported **Pistillipollenites mcgregorii** Rouse, **Diphyes colligerum** (Deflandre and Cookson), **Ctenosporites eskerensis** Elsik and Jansonius, **C. wolfei** Elsik and Jansonius, and **Wetzeliella homomorpha homomorpha** Deflandre and Cookson. To the southeast of the present study area, Brideaux and Myhr (1976) cited a Paleocene to Middle Eocene age for the Reindeer Formation in the Parsons N-10 well. From outcrop sections of the type Reindeer Formation in the Caribou Hills on the east margin of the Mackenzie Delta, Doerenkamp et al. (1976) assigned a generalized Paleocene-Eocene age. The Miocene-Recent uppermost part of the Caribou Hills Reindeer Formation of Doerenkamp et al. is now tentatively assigned largely to the Beaufort Formation, following the revision of the type Reindeer Formation by Price et al. (1980). Ioannides and McIntyre (1980) have also assigned a Paleocene-Eocene age to the type Reindeer Formation.

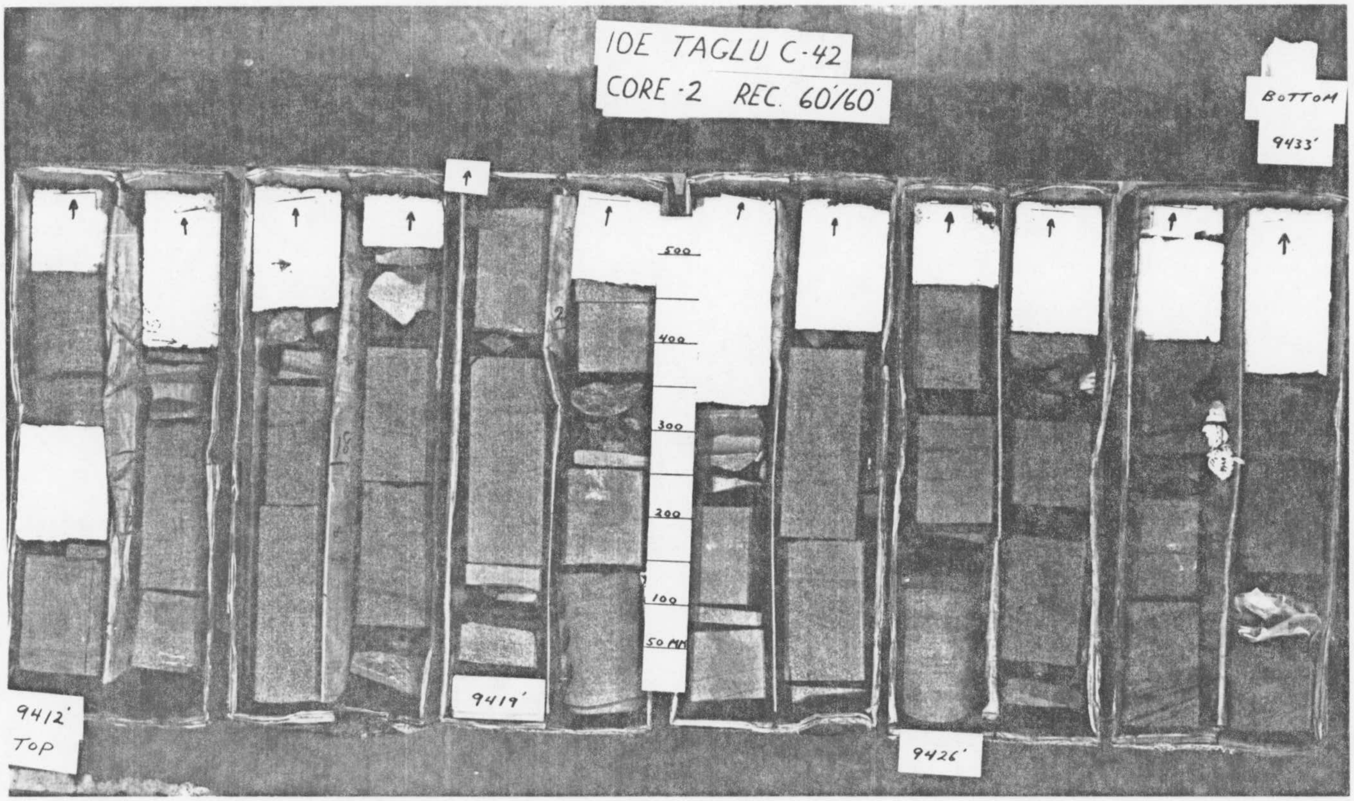

Figure 11. Slabbed core of typical sandstone of the Reindeer Formation; Core #2, Imperial Taglu C-42, 2869-2875 m (9412-9433 ft). ISPG 875-3.

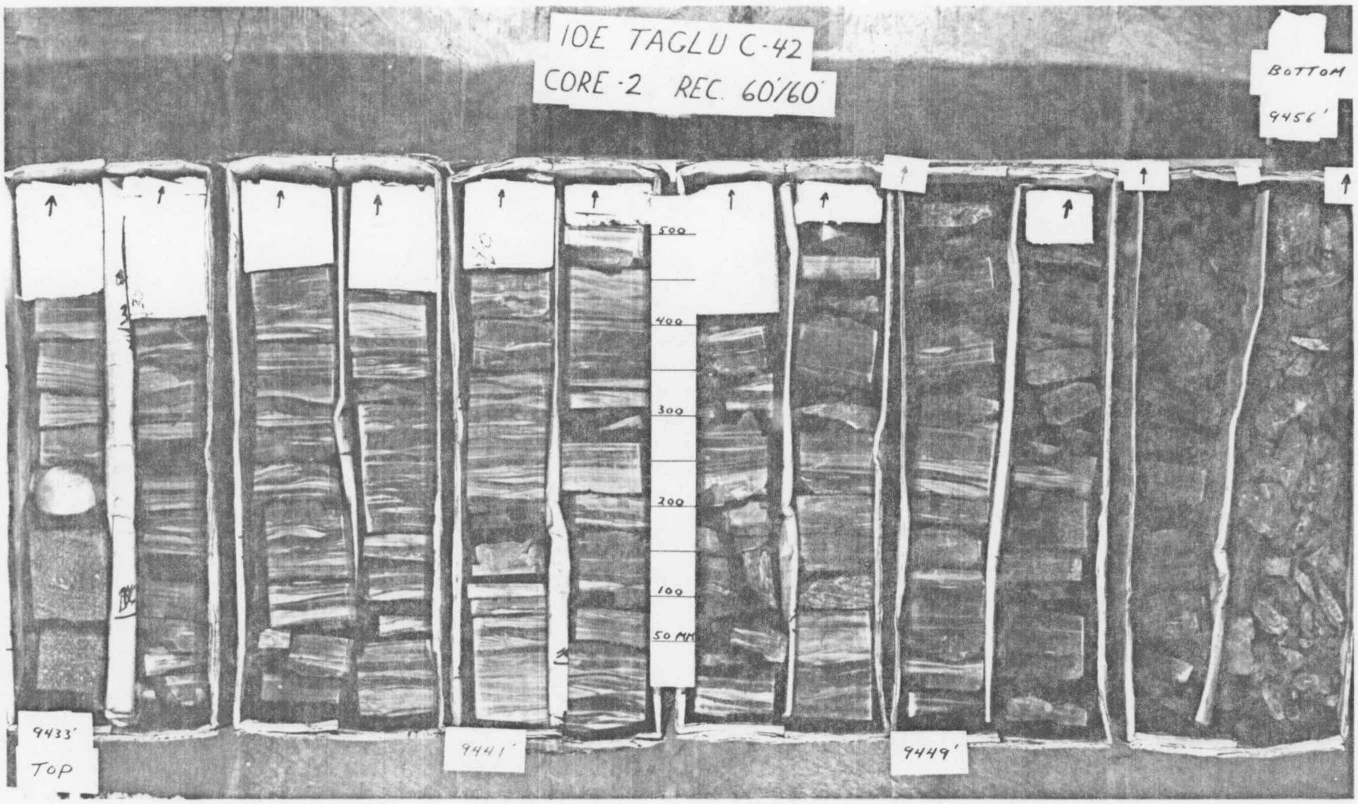

Figure 12. Slabbed core of typical pelites of the Reindeer Formation; Core #2, Imperial Taglu C-42, 2875-2882 m (9433-9456 ft). ISPG 875-4.

Depositional environments

The coal-bearing Aklak Member is probably a delta-plain complex, dominated by distributary channels, shallow swamps, and brackish-water bays (Young, 1975). The latter are indicated by the presence of agglutinated foraminifers (the **Saccammina-Trochammina** spp. assemblage) and are represented presumably by mudstone-siltstone units up to 30 m (100 ft) thick, as in the lower half of the Reindeer Formation in the Kumak J-06 well.

The sandstone-mudstone member, without coal and containing the **Haplophragmoides** spp. foraminiferal assemblage, represents sedimentation in the marine-dominant portion of the delta complex. Coarsening-upward cycles and relatively thick mudstone units describe an interfingering array of delta-front sand-sheets, distributary-mouth bars, and prodeltaic muds. Detailed descriptions and interpretations of these facies in the Taglu field are given by Bowerman and Coffman (1975), Shawa (1978), and Dixon (1981).

Richards Formation

Introduction

A thick mudstone unit of probable prodeltaic origin overlies the Reindeer Formation under most of the outer Mackenzie Delta area. Previously, this unit was called informally the "unnamed Eocene shale unit" (Young et al., 1976; Young, 1978; Schedule of Wells, var. eds., Dept. of Indian and Northern Affairs; Hea et al., 1980). It is here named the Richards Formation after Richards Island, under which it is best preserved and known. The subsurface section of the Imperial Taglu West P-03 well (1609-2585 m; 5280-8480 ft) is designated the type section (see summary description in Appendix), having the best quality well logs and cuttings samples of all the Taglu wells, although poor by usual standards. The Taglu gas field may be considered the type area of the formation so that cores and geochemical or paleontological data obtained from the different Taglu wells can be used as reference material on the Richards Formation.

Distribution and thickness

The Richards Formation underlies all of Richards Island, the adjacent offshore area, and the outer fringe of deltaic islands to the southwest. In the latter area the Richards is eroded beneath the pre-Mackenzie Bay - Beaufort unconformity (Fig. 10), and also changes facies southwesterly into coarser clastics and coals assigned to the Reindeer Formation. A pelitic unit in the subsurface of Tuktoyaktuk Peninsula may be a landward tongue of the Richards Formation (see Fig. 14 of Young et al., 1976). More well control and paleontological information are desirable before making a positive correlation of the mudstone from Richards Island to Tuktoyaktuk Peninsula.

Besides the six Taglu wells, only five other wells in the study area completely penetrate a fully preserved sequence of the Richards Formation. Three further wells were drilled into shale diapirs or pillows formed by the Richards, and were completed before reaching the base of the unit after drilling over 1500 m (4920 ft) into it.

The thickness of the Richards varies even within a relatively small area like that of the Taglu field. Here its thickness ranges from 758 to 1158 m (2486-3780 ft) and averages 950 m (3100 ft); to the northwest it is 1342 m (4400 ft) thick in the Netserk F-40 well.

Some of the thickness variation can be explained by listric growth faults which were active before, during, and after Richards deposition (see Fig. 14 of Bowerman and Coffman, 1975). Overpressure is a common characteristic of this mudstone (Hawkings and Hatlelid, 1975), and undoubtedly contributed to lutokinetic diapirism (Yorath and Norris, 1975) in the basin.

Contact relationships

The basal contact of the Richards mudstone with the Reindeer Formation is locally abrupt (e.g., Netserk F-40), but is most commonly transitional in character. Sandstone units interfinger with the mudstone at the base of the Richards in the Taglu area, thus the stratigraphic level of the contact varies slightly from one well to another. It is fairly sharp in the Langley-Niglintgak-Kumak area, but even here the contact probably is slightly variable in stratigraphic level.

The upper contact with the Kugmallit Formation is typically abrupt, but mainly conformable. A possible exception exists in the Kilagmiotak wells, in which the Richards seems to have been eroded beneath the Kugmallit Formation (Fig. 7). The contact is characterized on well logs by abrupt upward decreases in gamma ray intensity, self-potential, and sonic velocities (left-hand shifts), reflecting greater silt and sand content in the overlying formation. Where the Richards is overlain unconformably by the lithologically similar Mackenzie Bay Formation, the contact is difficult to pick from logs alone, and biostratigraphic information is necessary.

Lithology and depositional environments

The Richards Formation consists mainly of marine mudstone and shale, which is typically light grey, soft, and mildy expandable when wetted because of its minor smectite content. Its softness and wettability render sample-collecting difficult, because the mudstone tends to break down and mix with the drilling mud during transit from the bit to the sampling screens. The mudstones are variably silty, sandy, and carbonaceous. Floating granules and pebbles, composed mainly of chert, are also common.

Minor rock types in the formation are bentonite, argillaceous sandstone and conglomerate, siltstone, and marlstone.

Bentonite seams and smectitic mudstone form two units near the top of the formation that are very useful as local correlation markers. The bentonite beds are recognized easily on electrical logs as abrupt decreases in resistivity (left-hand deflections of recording traces) (see Figs. 5, 6). Where they have been sampled, they appear as massive, pale greyish white mudstone, and instantly disintegrate when wetted. The upper marker becomes limy and well defined under northeastern Richards Island, where it is approximately 31 m (100 ft) thick.

Scattered thin beds of siltstone and sandstone are typically argillaceous and grade locally into arenaceous mudstone. In places these beds are calcareous or dolomitic, and therefore quite hard relative to the uncemented varieties. Argillaceous limestone forms rare thin beds or nodules within the mudstone.

A core in Taglu G-33 and one in Adgo C-15 penetrated pebbly mudstone to very argillaceous pebble-conglomerate (Fig. 13). The former was described by Glaister and Hopkins

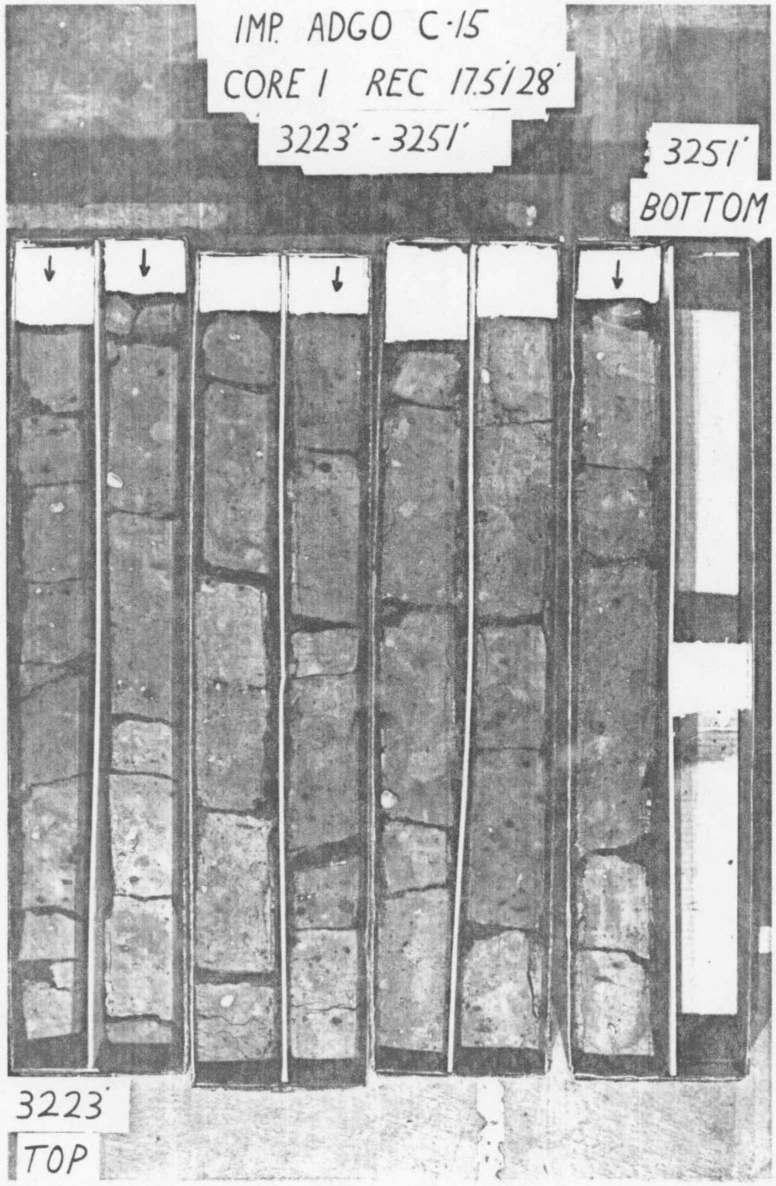

Figure 13. Slabbed core of pebbly mudstone from Richards Formation; Core #1, Imperial Adgo C-15, 982-991 m (3223-3251 ft). ISPG 910-1.

(1974), and interpreted by them as a subaqueous debris-flow deposit. The conglomerate is very poorly sorted, poorly stratified, and interbedded with pebbly, sandy mudstone and bentonitic mudstone. Such mixed component deposits indicate slurry-type flow and give evidence of a sloping depositional surface, as would be expected in a prodeltaic setting.

More of the Richards Formation may consist of pebbly mudstones of flow origin than can be appreciated from cuttings samples or well-logs, as neither of them provide distinct evidence for this lithology. Insofar as two 7.5 m (25 ft) cores cut at random in two distantly separated boreholes are composed entirely of this rock-type, a strong case can be made for claiming an abundance of it in the formation.

The basal part of the formation is commonly grey marine shale, without much silt, sand or pebbles. This unit is distinctive on well logs in the Netserk wells where it is 186 m (610 ft) and 202 m (660 ft) thick in B-44 and F-40 respectively. Its richer content of marine dinoflagellates and foraminifers as compared to higher parts of the formation, and its clay-rich nature suggest it represents quiet, shallow marine deposition following a transgression of the Reindeer delta-plain.

Paleontology and age

The paleontology of the Richards Formation is characterized by rich terrestrial palynomorph assemblages, two marine palynomorph assemblages in the lower part of the formation, and the **Haplophragmoides** spp. foraminiferal assemblage that spans the formation in much of the area studied.

The **Haplophragmoides** spp. assemblage consists almost entirely of agglutinated species (see Plates 2, 3) and occurs as plotted in Figures 5 to 8. It extends commonly but with reduced diversity, into the overlying Kugmallit Formation and rarely into the uppermost Reindeer Formation as in Netserk B-44. In the wells of the shallow Beaufort Sea (Fig. 4) the assemblage attains its greatest diversity -- ten or so species of the genera **Alveolophragmium, Bathysiphon, Gravellina, Haplophragmoides, Jadammina, Recurvoides,** and **Trochammina,** as well as a rare calcareous benthonic foraminifer, **Brizalina** cf. **B. substriatula** (Table 2). South of cross-section A-F (Fig. 5), the assemblage is close to monospecific, for example, in the Taglu area and south to its disappearance probably by erosional truncation beyond the area of the Ya Ya P-53 well (*fide* Staplin, 1976, Fig. 5) where only **Jadammina** sp. (= **Haplophragmoides** sp. 504 of Staplin, 1976) has been recovered. The assemblage is elaborated on more fully in a preceding chapter on the foraminiferal assemblages of the Mackenzie Delta Cenozoic.

Based on Norris's reports (<u>in</u> Austin and Cumming, 1979b, c, 1979b, d, and 1980) on the palynomorphs in the Netserk B-44, Nuktak C-22, Taglu C-42, Adgo F-28, and Niglintgak H-30 wells, the Richards Formation contains a rich assemblage of angiosperm pollen, including numerous species of the deciduous hardwood complex, less common elements of gymnospermous pollen and a variety of spores including many ferns, sphagnum, club moss, and the freshwater fern **Azolla.**

The lowest Richards is marked by a distinctive dinoflagellate assemblage. Staplin (1976, p. 136) first noted the distribution of this assemblage, characterized by species of **Wetzeliella,** and stressed its importance as a marker above the gas-producing Taglu sand. The assemblage, described by Norris (*op. cit.*) consists of **Astrocysta** sp., **Cannosphaeropsis** cf. **C. reticulensis** Pastiels, **Ceratiopsis** sp., **Samlandia** sp., **Wetzeliella** cf. **W. hampdenensis** Wilson, and less commonly **Hystrichosphaeridium** cf. **H. radiculatum.** Of these, **W.** cf. **W. hampdenensis** occurs most consistently. The assemblage forms a zone (plotted in Figs. 5, 6, 7) that extends up from 15 to 365 m above the base of the Richards and down to a maximum of 120 m below the contact of the Richards and Reindeer Formations. In general, the zone occurs higher in the section in the northern wells. It should be noted too that the fungal spore, **Pesavis tagluensis** Elsik and Jansonius, has a distribution closely allied to that of the dinoflagellates and thus also serves as a marker in the lowermost Richards or the highest Reindeer.

The lower part of the Richards also contains a diverse assemblage of terrestrial palynomorphs, some of which have upper range limits or "tops" above the **Wetzeliella** zone, but still within the lower part of the formation. **Granatisporites cotalis** and **Granatitricolpites-1** of Norris (*op. cit.*) are examples. Higher, but still in the lower half of the Richards in the Netserk B-44, Nuktak C-22, and Taglu C-42 wells, another marine assemblage occurs, marked by dinoflagellates **Astrocysta** sp., and **Lejeunia** sp. and the acritarch **Mychristridium stellatum** and other less common dinoflagellates. The combined distributions of these palynomorph assemblages provide evidence to substantiate that only the lower part of the Richards Formation is present in the southwestern wells of Niglintgak and Adgo where the Richards is anomalously thin (Fig. 7). For example, where the formation is thick, the assemblages mark the lower part of the formation, as in Taglu C-42 where they occupy a zone between 2455 and 2575 m (8100 and 8500 ft), about 300 m (1000 ft) above the base of the 1200 m (4000 ft) thick formation. Where the formation is thin, the assemblages span the entire formation, as in Niglintgak H-30 and Adgo F-28. There the Mackenzie Bay Formation rests with unconformity on the lower Richards Formation.

As interpreted, the upper part of the Richards is absent in much of the study area (see Figs. 6, 7). But where developed, it contains the marine foraminiferal assemblage of **Haplophragmoides** spp. and a diverse terrestrial palynoflora that varies between wells. One trend in the palynomorph distribution, a decrease in the abundance of fungal spores, is apparent from Norris's distribution charts, but further interpretation of the palynomorph distributions will have to await more detailed study.

Age determinations for the palynomorphs found in the Richards Formation have ranged from Early to Late Eocene, and it is presently considered to be approximately Middle to Late Eocene in age. Staplin (1976, p. 127) interpreted the **Wetzeliella** assemblage to be of Early to Middle Eocene age. Norris (*op. cit.*) considered that the palynomorphs of the Richards in Niglintgak H-30 (his zone 3 and uppermost 4) showed closest comparison to the Middle to Late Eocene Kitsilano Formation of British Columbia as described by Hopkins (1969). The foraminiferal assemblage of **Haplophragmoides** spp. has been assigned a generalized Eocene age.

Kugmallit Formation

Introduction

A seaward-prograding, thick deltaic complex overlies the Richards Formation under Richards Island and peripheral offshore areas. Formerly referred to as the "upper Paleogene clastic unit" (Young et al., 1976), it is here named *Kugmallit*

Formation after Kugmallit Bay. The informal name "Pullen Sand" has been applied to this formation by Hea et al. (1980) and some oil company geologists, but the name Pullen has already been used in North American stratigraphic nomenclature, and is therefore unsuitable. Typically, it consists of two distinct members, one above the other. The lower one is transitional in facies character between the Richards mudstone below, and the coarse-grained delta-plain deposits above. This mixed sandstone and mudstone unit is termed here the *Ivik Member*; the upper, nonmarine member is called the *Arnak Member*.

The top of the formation in much of the area is marked by an unconformity, above which are nonmarine deposits of the Beaufort Formation that are very similar to those of the Kugmallit. The two together were called informally the "upper fluviodeltaic unit" (e.g. Schedule of Wells, var. eds., Dept. of Indian and Northern Affairs), before biostratigraphic studies (Staplin, 1976) defined the unconformity in several keys wells.

The Kugmallit Formation may outcrop in the Caribou Hills (Fig. 14) near Reindeer Depot. This outcrop, tentatively referred to as the "white-clay unit" by Price et al. (1980), was originally assigned to the upper partial section of the type Reindeer Formation (Mountjoy, 1967) and was reassigned to the Beaufort Formation by Young (1978). Because of the uncertain identification of these beds and their relative thinness, a subsurface section was selected as a type section. Owing to the typically unlithified nature of these sediments, cuttings samples are generally poor. Thus, the Imperial Nuktak C-22 well (the depth-interval 955 to 2366 m; i.e. 3150-7810 ft) was selected as a type section (see description in Appendix) partly because detailed palynological research on this well is in progress by G. Norris of University of Toronto. This well is selected also as the type section of the Arnak Member (depth-interval 955-1518 m; 3150-5010 ft), named after the Arnak L-30 well. The formation is well developed and known also in the Ivik and Umiak wells which penetrate part of its type area. The type section of the Ivik Member is the depth-interval 2040 to 2894 m (6735-9550 ft) of the Imperial Ivik J-26 well.

Onshore, several small hydrocarbon pools have been discovered in the Kugmallit Formation, including oil in the Ivik J-26 well and gas in the Mallik L-38 well. However, follow-up wells were dry, as were other wildcat holes in the area, resulting in a disappointing success ratio to date. Offshore potential may be better.

Distribution and thickness

The Kugmallit Formation is a roughly spoon-shaped deposit whose outline is shown approximately on the map of Figure 9. It thickens abruptly under Kugmallit Bay and Richards Island from a zero-edge near the shore of Tuktoyaktuk Peninsula, as illustrated in Figure 18 of Young et al. (1976). It becomes severely truncated northeast of and parallel to the Niglintgak-Kumak trend (Langley High, Fig. 10), northwest of which the zero line swings westward. It is uncertain whether or not the Kugmallit ever existed very far southwest of its present zero edge, but internal trends (e.g. thickness of the Ivik Member) suggest this line closely approximates an original depositional edge. Seismic profiles show the formation extends seaward beneath the continental shelf (Figs. 9 and 12 of Hawkings and Hatlelid, 1975).

Correlated well sections (Figs. 6, 10) show that the Kugmallit Formation - and its two component members - thicken gradually northeastward from zero at Kumak J-06 to over 2.6 km (8780 ft) in Pullen E-17.

In the Taglu field the Kugmallit averages 658 m (2157 ft) thick, and 33 km (20 mi) to the north at its type section on Hooper Island it is 1458 m (4780 ft) thick. In the northwestern corner of the study area the formation thickens northward from zero in the Adgo wells to 507 m (1662 ft) in Netserk B-44 and 942 m (3460 ft) in Netserk F-40. Its absence in some wells like Immerk B-48 (Fig. 5) can be attributed to mud diapirism of the Richards Formation, which caused either non-deposition of the Kugmallit or upward displacement of it and erosion after intrusion.

The variation in thickness of the Ivik Member approximates that of the overall formation, except where erosion at the pre-Mackenzie Bay - Beaufort unconformity has cut deeply into the Arnak Member. This, however, appears to have occurred primarily over diapiric structures, such as the one into which the Mallik A-06 well was drilled. The thickest drilled section of the Ivik Member is in the Ivik K-54 well, in which 912 m (2990 ft) were penetrated. At its type section in the Ivik J-26 well, the Ivik Member is 889 m (2915 ft) thick. It is poorly developed and thinnest in the Netserk B-44 well where only 100 m (330 ft) are assigned to it.

The nonmarine Arnak Member is thickest in the Ivik N-17 well (1102 m or 3613 ft), which is also the thickest drilled section of the entire formation. When considered together with the Beaufort Formation in the Pullen E-17 well, the predominantly nonmarine sequence there totals 1873 m (6140 ft) thick.

Contact relationships

The Richards Formation becomes increasingly arenaceous upward near its contact with the Kugmallit Formation beneath Richards Island, however the contact between the two units is generally abrupt by virtue of the presence of a basal sandstone bed in the Kugmallit. In the absence of the sandstone bed, the well-log character typically shows a marked change to siltier and sandier sediments in the Kugmallit.

Price et al. (1980) identified an unconformity with an associated paleosol at the base of the possibly equivalent "white clay unit" in the Caribou Hills section. This contact may represent a brief shoaling or tectonic event in the basin, which was followed by renewed deltaic progradation throughout Kugmallit deposition.

In the Richards Island subsurface, the Kugmallit Formation is overlain conformably to disconformably by the Beaufort Formation, a nonmarine gravel and sand unit very similar in character to the upper part of the Kugmallit. Hence, this contact is difficult to pick in some wells by means of well-logs alone; however, the base of the Beaufort consists typically of a massive gravel unit which forms a distinct outward (decrease) deflection of the gamma ray logs. The structural level of this contact, which is the pre-Beaufort unconformity, is reasonably predictable, as shown on the contour map (Fig. 9).

Toward the northwest corner of the study-area, the Beaufort Formation changes facies into the Mackenzie Bay Formation, which is predominantly mudstone. Here the upper contact of the Kugmallit is placed readily at the abrupt contact between the sand-dominant sequence below and the mud-dominant unit above.

The contact between the Ivik and Arnak members is gradational to abrupt and generally conformable. Only in the Kilagmiotak wells is there a suspected unconformity between

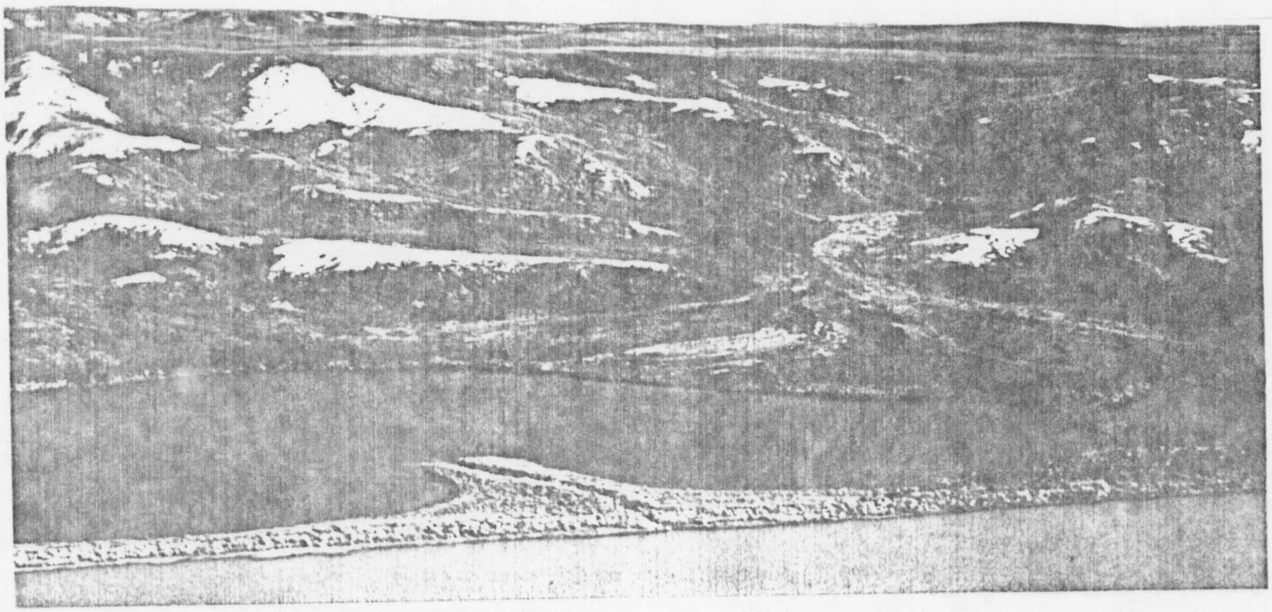

Figure 14. West-facing scarp of Caribou Hills on eastern margin of Mackenzie Delta, exposing the upper part of the Reindeer Formation (lower bare ridge), the "white-clay unit" of Price et al. (1980) (upper bare spurs), and basal gravel beds of the Beaufort Formation. ISPG 420-12.

the two (Fig. 8), because of thinning of the Ivik Member in the M-16 well and the very sharp contact of overlying sand in the Arnak Member.

The base of the Arnak Member is chosen at the lowest level of channel-fill gravels and sands with interbedded lignite. In some wells the Arnak sands are noticeably richer in yellow and red grains near the contact than those of the underlying Ivik Member.

Lithology and depositional environments

The Kugmallit Formation consists mainly of sand, mudstone, gravel and lignite. Sideritic mudstone beds or nodules are rare.

The sands grade into friable sandstones and, rarely, cemented sandstones, especially toward the base of the formation. Argillaceous, carbonaceous, and calcareous varieties are present, although most of the sand is apparently fairly clean. Sand composition is mainly colourless quartz and light to dark grey chert, resulting in a medium to dark grey, speckled sediment. Most of the sand is fine to coarse grained, with very fine-grained sand common in the Ivik Member (Fig. 15), and grains are mainly subangular to subrounded. Some rounded to well rounded quartz grains are also present, indicating a mixture of first and multiple cycle detritus.

The formation is notable for its abundant lignite and coalified wood fragments throughout. Pale yellow to dark amber resin grains are also prevalent in both outcrop and cuttings samples. This land-derived, woody material was deposited in discrete laminae and beds (Fig. 16), or as a dispersed component in both sands and muds of the unit. Some of the lignite is sulphurous, and occurs with pyritic sandstones and thick sand beds.

Mudstone and siltstone are more common in the Ivik Member than in the Arnak Member. The siltstone is in part calcareous, sandy, and medium brown in colour, and in part dark grey and carbonaceous. Similarly, the mudstone is partly dark grey and carbonaceous or coaly, and partly light brown-grey, soft, and silty or sandy. Core samples of the light grey mudstone beds of the Ivik Member, display silt and sand streaks and burrow-fillings (Fig. 17), as well as expandable clay-rich beds. The soft, semi-consolidated character of the Kugmallit sediments is evident in the core taken at 1850 m depth (6000 ft) in the Netserk F-40 well (Fig. 18).

Various types of vertical lithologic sequences are present in the Kugmallit Formation, most of which are typical of deltaic and alluvial sedimentary environments. The E-log characteristics and significance of these were illustrated in Figure 19 of Young et al. (1976).

The Ivik Member consists typically of rhythmic alternations of mudstone and sandstone, commonly in coarsening-upward trends typical of progradational deltas (Scruton, 1960; Coleman and Wright, 1975). Under northeastern Richards Island, these rhythms are approximately 75 to 150 m (250-500 ft) thick, and exhibit sufficient regularity among closely spaced wells to suggest they may be correlatable. In other areas much less order is displayed, as sand units appear haphazardly within mudstones of the member.

Fining-upward rhythms in which sand or gravel grade upward into siltstone and coal are common in the Arnak Member. These were formed probably by meandering stream-channels (Visher, 1965) on an alluvial or deltaic plain. Also typical are stacked and isolated channel sands and gravels (Fig. 19), which have sharp basal and upper contacts and form a blocky gamma ray and SP log character in well section. Mudstone, marl or coal form minor interbeds in this facies, which is also mainly fluvial in origin.

Paleontology and age

The Kugmallit Formation yields rich terrestrial palynomorph assemblages throughout, agglutinated foraminifers in the lower part, and calcareous foraminifers in the upper part in the northwest.

The palynomorph distributions recorded by Norris (in Austin and Cumming, 1978b, 1979a, b, c, and d) for the Netserk B-44, Pelly B-35, Nuktak C-22, Ivik K-54, and Taglu C-42 wells indicate that a great variety of terrestrial palynomorphs occurs in the formation. Unfortunately, most of the taxa are long-ranging or occur only rarely, and their biostratigraphic significance is difficult to assess. In places, part of the sequence is barren, as in the Ivik Member of the Pelly B-35 well. Certain species, which may prove to be significant in biostratigraphic correlations, have upper range limits within the Kugmallit. Species of the genera **Osmundacidites, Parviprojectus, Leptolepidites, Tricolpites, Corylus,** and tetrad-type pollen are examples. Similarly, Staplin (1976) considered **Parviprojectus** PJ-1 to be an important marker in the delta; it occurs in the Kugmallit Formation in the Taglu G-33 and C-42 wells. Marine palynomorphs are absent or rare in the Kugmallit Formation. The dominance of the terrestrial flora and the common occurrence of coaly fragments in the well-cuttings, especially of the Arnak Member, leave little doubt that much of the formation is nonmarine.

Norris's age determinations, although tentative, indicate a Late Eocene to Oligocene age for the Kugmallit. Staplin (1976) recounted evidence suggesting a comparable age for the "upper part of the Paleogene interval" which corresponds at least in part to the Kugmallit Formation.

Agglutinated foraminifers of the **Haplophragmoides** spp. assemblage are common in the lower part of the Kugmallit and calcareous benthonic foraminifers of the **Cibicides** spp. assemblage have been recovered from various parts of the formation (Table 2), but some of these occurrences may be from caved well-cuttings. Elements of the **Haplophragmoides** spp. assemblage range into the Ivik Member from the underlying Richards Formation in several wells. Only three species of the assemblage have been found in the member -- **Bathysiphon** sp., **Haplophragmoides** sp., and **Alveolophragmium** sp. 1. The extension of this microfauna into the Ivik is a record of transition between the underlying prodeltaic Richards and the overlying coastal-plain sediments of the Arnak Member.

Through much of the delta, the Arnak and upper Ivik are barren of foraminifers (Fig. 5). Coals and related sedimentary features substantiate terrestrial conditions of sedimentation in these areas. However, in the peripheral offshore area (Fig. 5), calcareous foraminifers of the **Cibicides** spp. assemblage occur in the formation. In Netserk B-44, in particular, the **Turrilina alsatica** and other elements of the **C.** spp. assemblage, signifying marine beds of Oligocene age, occur commonly in the upper half of the undifferentiated Kugmallit. Rare occurrences of some of the longer ranging elements of the **C.** spp. assemblage, including **C. perlucidus, Cyclogyra involvens, Melonis** cf. **M. affine** and **Miliolinella** sp., in the Arnak and Ivik intervals in the Pelly B-35 and Nuktak C-22 wells may be *in situ* occurrences, but the possibility of caved well-cuttings exists.

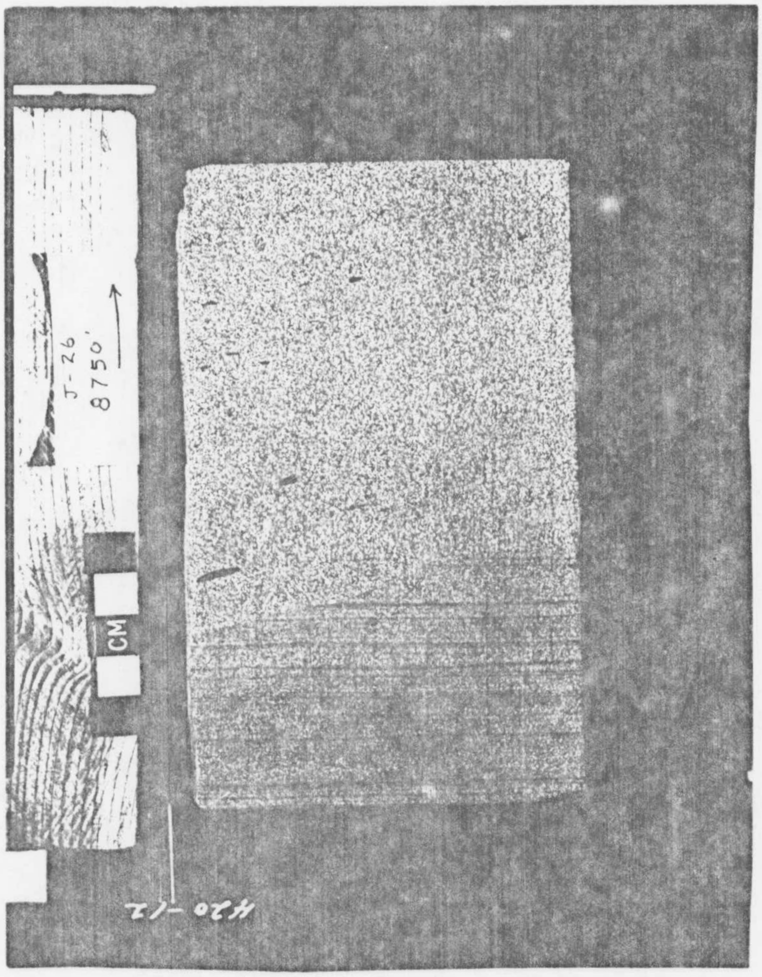

Figure 15. Laminated, very fine grained sandstone, scoured and overlain by homogeneous sandstone with mud-clasts, Kugmallit Formation, Imperial Ivik J-26 well, core no. 5 2667 m (8750 ft). ISPG 420-12.

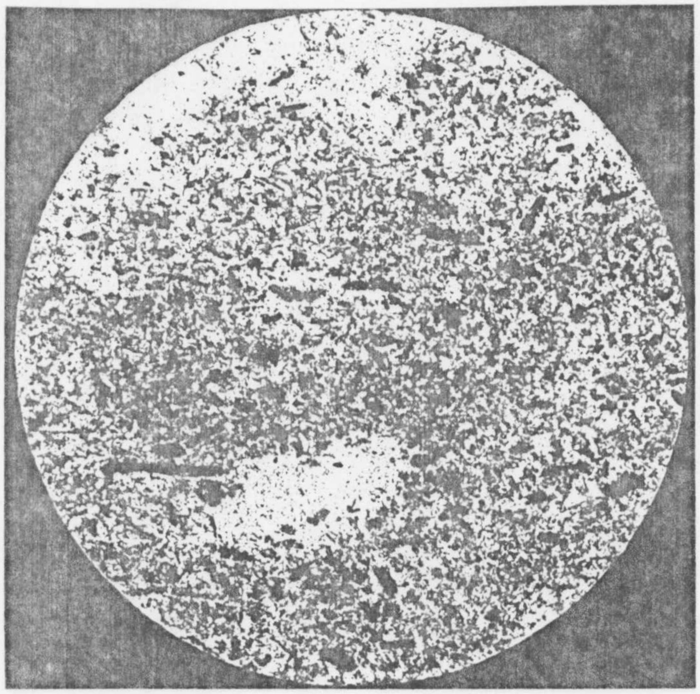

Figure 16. Carbonized plant debris on bedding plane in Ivik Member, Kugmallit Formation, from core plug at 2497 m (8191 ft), Imperial Ivik J-26 well. Core diameter: 10 cm. ISPG 681-5.

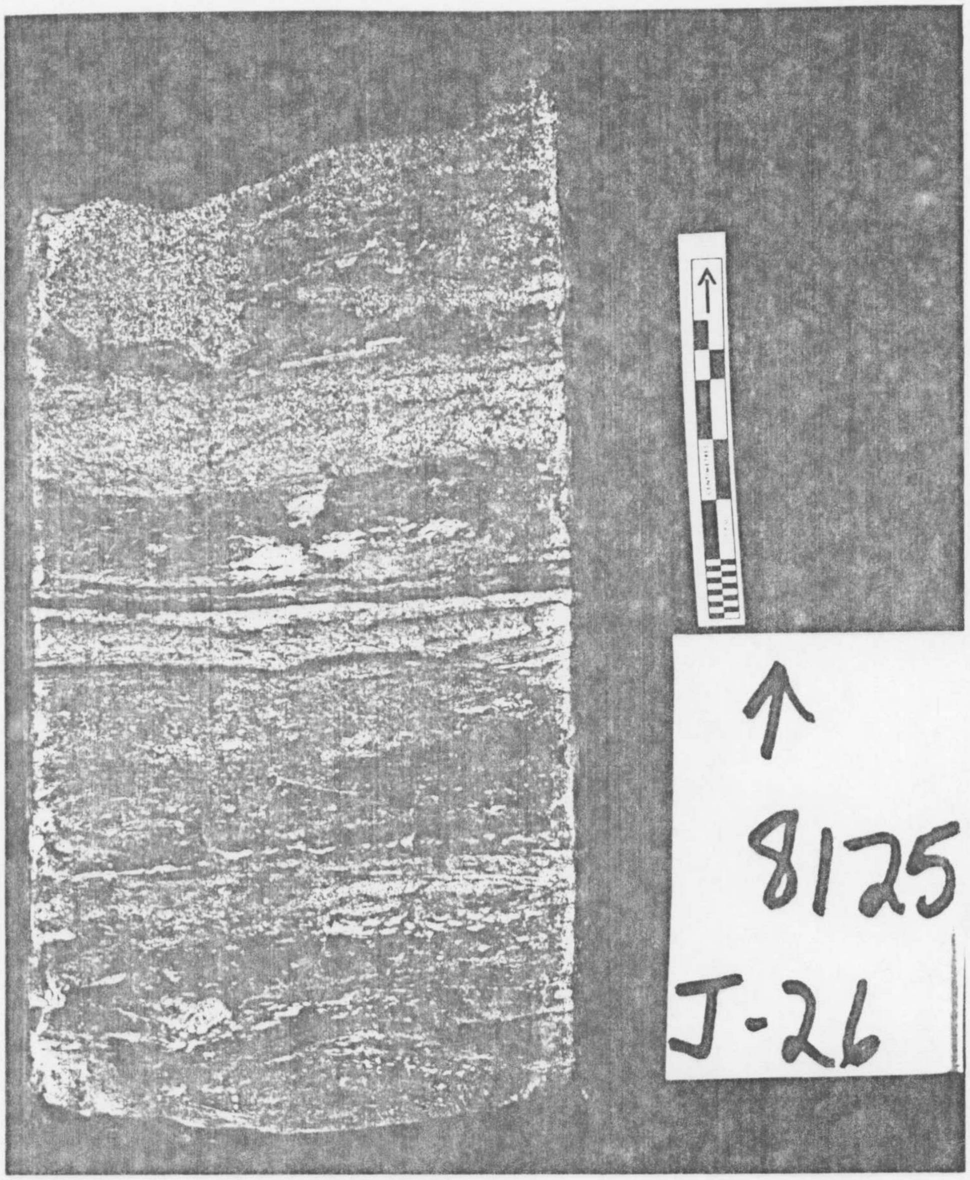

Figure 17. Mudstone containing silt and sand laminae, streaks and mottles in bioturbated fabric, Ivik Member, Kugmallit Formation, Imperial Ivik J-26 well, Core no. 2, 2476 m (1125 ft). ISPG 681-8.

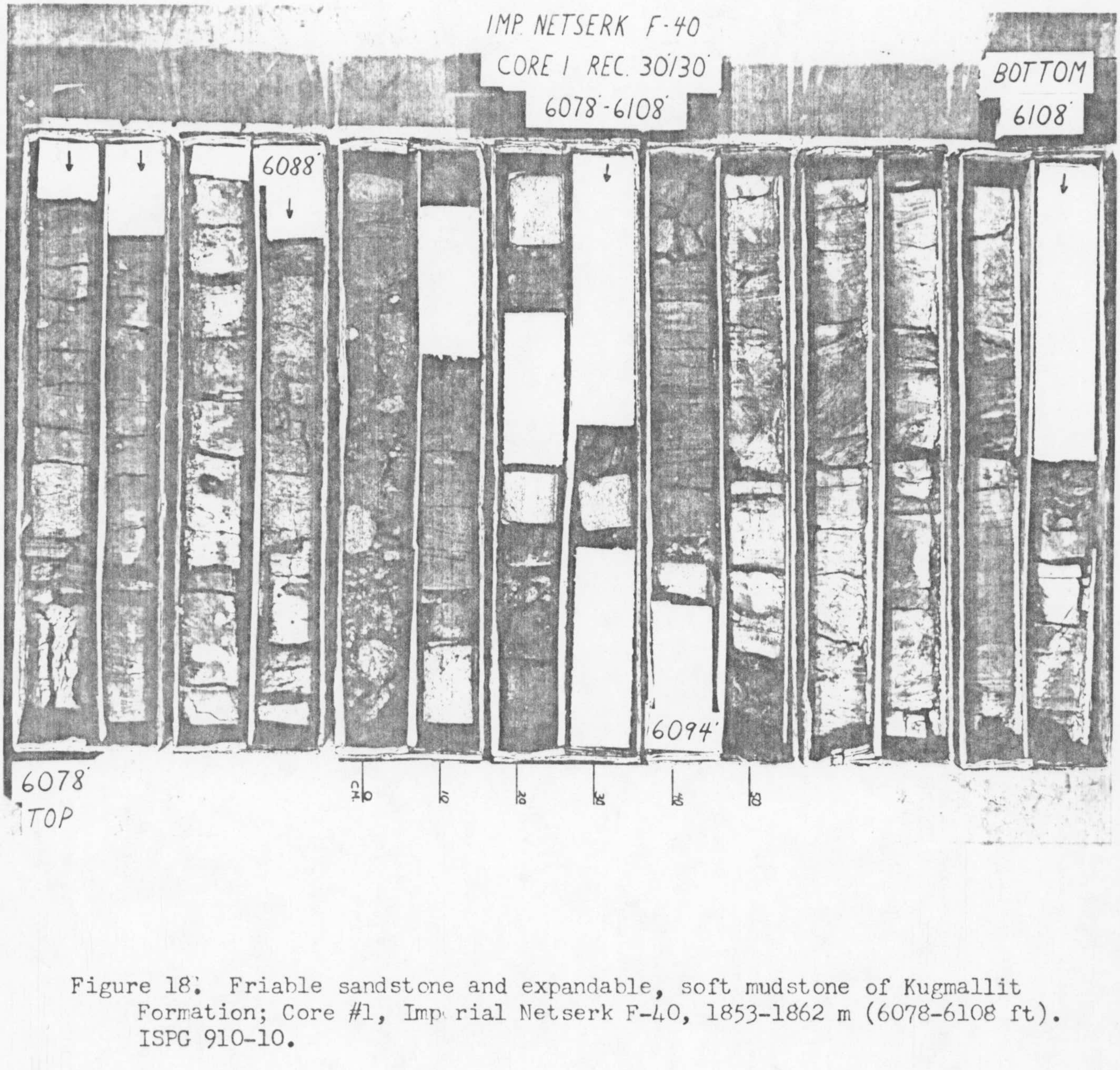

Figure 18. Friable sandstone and expandable, soft mudstone of Kugmallit Formation; Core #1, Imperial Netserk F-40, 1853-1862 m (6078-6108 ft). ISPG 910-10.

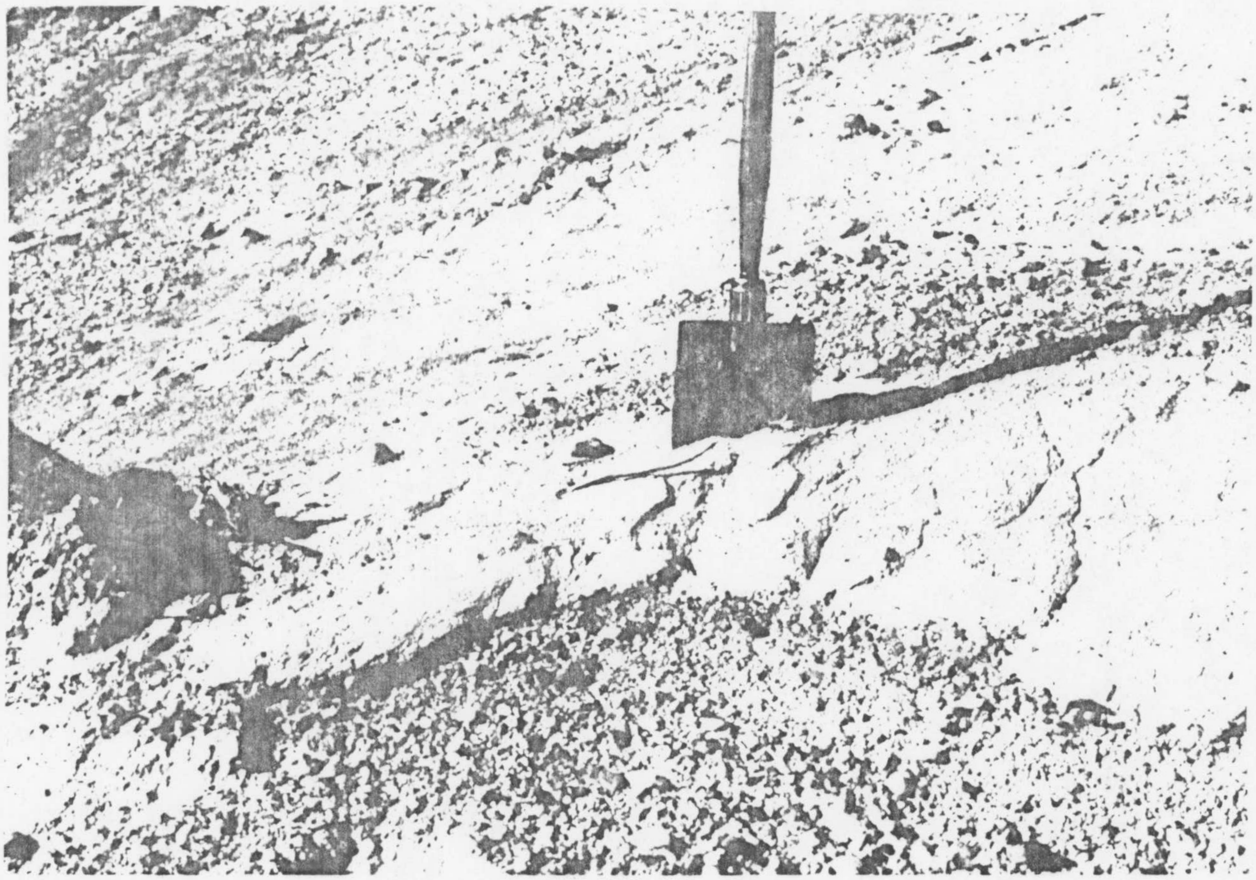

Figure 19. Gravel lenses in unconsolidated, laminated sand of possible Kugmallit Formation equivalent, Caribou Hills section (Fig. 13). ISPG 1015-19.

Mackenzie Bay Formation

Introduction

North and northwest of Richards Island, the Beaufort Formation intertongues with and is overstepped by a mudstone unit, here named the *Mackenzie Bay Formation* after Mackenzie Bay, which lies immediately west of the outer part of Mackenzie Delta. The formation contains abundant indigenous Foraminifera, discussed below, indicating its marine origin.

The Mackenzie Bay Formation is known only in the subsurface, hence requires a representative well section with good samples and geophysical logs for its type section. For these reasons the Shell Kumak E-58 (Lat. 69°17'29"N., Long. 135°14'55"W.) well was chosen for a type section, in the depth-interval 253 to 794 m (830-2600 ft). Because of the increasing off-vertical angle of drilling with depth in this borehole, the true thickness of this interval is calculated to be 396 m (1300 ft).

A significant gas flow was achieved on a drill-stem test of an isolated sand unit within the Mackenzie Bay Formation in the Netserk F-40 well.

Distribution and thickness

The Mackenzie Bay Formation overlies directly the Kugmallit Formation (e.g. Netserk B-44 and F-40 wells) or older units in northwestern and western parts of the study area, and overlaps the partly equivalent Beaufort Formation in the northern and northeastern parts (e.g. Pullen E-17 well), and on the northeastern flank of the Langley High (Fig. 9). Tongues of Mackenzie Bay mudstone are present within the Beaufort Formation under Richards Island (e.g. Taglu field).

Between Kumak J-06 and Netserk B-44, the Mackenzie Bay Formation maintains a relatively uniform thickness of 335 to 430 m (1100-1400 ft), unless truncated severely at its top because of a local structural high, such as at Langley E-29. It seems to thicken northward, attaining a thickness of 627 m (2055 ft) in the Netserk F-40 well. In the Pullen E-17 well it is 370 m (1210 ft) thick, thickening slightly northeastward to 400 m (1314 ft) in Arnak L-30.

Tongues of the Mackenzie Bay mudstone in the Beaufort Formation in the Nuktak C-22 well and the Taglu wells are in the order of 100 m thick (330 ft).

Contact relationships

The basal contact of the Mackenzie Bay Formation on the Kugmallit or older formations in the western part of the area is always abrupt, and, in most cases, unconformable. It may be conformable with the Kugmallit Formation in Netserk F-40, because the same foraminiferal assemblage is present below the contact as above.

Where the Mackenzie Bay Formation overlaps, or is overlain by, coarse clastics of the Beaufort Formation, the contact is conformable and is either gradational or abrupt.

The upper contact with the Nuktak Formation is everywhere abrupt, and is unconformable in most well sections. Erosion of the Mackenzie Bay mudstones may have occurred in structurally high locations, but basinward, only a nonerosional hiatus seems to be present, as indicated by the presence of a limy hardground at the contact.

Lithology

The Mackenzie Bay Formation is predominantly light grey to brown grey, soft, silty to sandy (dispersed grains and sand laminae) mudstone. It contains scattered chert pebbles, carbonized plant fragments, and, characteristically, pyrite tubes and rods. The latter are probably pyritized burrow-walls and -fillings, as some are preserved as Y-junctions in cuttings.

Thin sections cut from sidewall cores of the Netserk F-40 well show the mudstones are typically silty, organic rich, and commonly contain microshards of quartz and other light minerals. One slide from an indicated bentonite bed on resistivity logs consists of abundant microshards and needles with quartz silt, having a felt-like fabric. This is most likely a water-laid, volcanic ash-fall deposit.

Fine-grained sand, composed of quartz and chert with very minor limestone grains, is a minor component of the formation. Coarser sands also are present, especially near or at the base of the formation. Lenses of pea-gravel containing abundant chert and quartzite clasts are also present near the base.

The thick section in the Netserk F-40 well can be divided readily into two units: a lower one containing numerous bentonite and sand beds, about 345 m (1130 ft) thick, and an upper unit, 282 m (925 ft) thick, consisting of uniform, silty, micromicaceous mudstone. The boundary between the **Asterigerina guerichi s.l.**-dominated microfauna above and **Turrilina alsatica**-dominant one below (Table 2) also corresponds closely with the lithological boundary. These lithologic divisions may provide a basis for establishing members in the offshore subsurface as more wells become available for study.

The bentonite seams of the lower part of the formation are recognized on resistivity logs in many of the wells which penetrate the formation, but they are too numerous to be useful as marker beds.

Paleontology and age

The Mackenzie Bay Formation contains fairly diverse assemblages of terrestrial palynomorphs and benthonic foraminifers. Marine microplankton are unknown, except for reworked Cretaceous dinoflagellates.

Calcareous benthonic foraminifers of the **Cibicides** spp. assemblage occur through the Mackenzie Bay Formation in the Netserk B-44, Pelly B-35, and Adgo F-28 wells (Figs. 5, 7). **Cibicides grossa, C. perlucidus, C.** sp., **Asterigerina guerichi s.l., Elphidiella**(?) **brunnescens, Miliolinella** sp., **Scutuloris** sp., and **Turrilina alsatica** are the most common elements of the assemblage (see Plates 4, 5). Other elements are cited in the description of the **C.** spp. assemblage in a preceding chapter. The foraminifers date the Mackenzie Bay as Oligocene to Miocene. The Oligocene-Miocene boundary is drawn at the uppermost range limit of **T. alsatica,** a point that occurs in the Netserk B-44 and Pelly B-35 wells at about the middle of the Mackenzie Bay Formation. In Netserk B-44 and Pelly B-35, the **C.** spp. assemblage spans the Mackenzie Bay-Kugmallit boundary, suggesting a conformable contact (although not necessarily so), but in Adgo F-28, the contact is unconformable, and the assemblage disappears abruptly at the Mackenzie Bay-Richards Island contact. The upper contact of the Mackenzie Bay Formation is unconformable and marks the uppermost limit of the assemblage. A specimen of **C. perlucidus** in the lower Nuktak Formation of the Adgo F-28 well is interpreted as reworked.

As the Mackenzie Bay Formation is traced eastwards and southwards from Netserk B-44, the **C.** spp. assemblage is modified considerably. To the east, the assemblage is absent in Nuktak C-22 where the Mackenzie Bay possibly intertongues with the Beaufort Formation, but rare elements apparently occur in the underlying Kugmallit Formation (assumed not to be contaminated by caved well-cuttings). In the area of the Ivik K-54 and J-26 wells, the Mackenzie Bay Formation is absent by facies change to the coarser sediments of the Beaufort Formation. Facies equivalence is supported by the occurrence of sparse elements of the **C.** spp. assemblage in the Beaufort Formation together with the occurrence of many of the palynomorphs characteristic of the Mackenzie Bay.

Norris's palynological data for the Netserk B-44, Adgo F-28, and Pelly B-35 wells reveal a fairly distinctive cool-temperate to boreal terrestrial assemblage in the Mackenzie Bay Formation. The most common elements of the assemblage include species of the angiosperms **Alnipollenites, Betulaceoipollenites, Castanae, Ulmus,** and ericoid pollen; the gymnosperms, **Picea, Tsuga** and **Abies**; club moss and sphagnum. **Tsuga** is particularly characteristic of the formation. Fungal spores are greatly reduced in abundance and variety in the Mackenzie Bay, relative to the underlying Paleogene sequences. **Tsuga,** along with species of **Abies, Castanae, Ulmus,** and ericoid pollen, consistently have their uppermost local range-limits in the Mackenzie Bay Formation according to Norris's distribution data.

Reworked palynomorphs of Paleozoic, Mesozoic, and Cenozoic age occur in the Mackenzie Bay, but not to the extent that they mark the overlying Nuktak Formation. Rare occurrences of **Pistilipollenites mcgregori** among others in the Mackenzie Bay certainly are reworked from the underlying Paleogene sequences.

Staplin (1976) assigned a generalized Neogene age to the section including the Mackenzie Bay (at that time unnamed) and considered the foraminifer, **Asterigerina** sp., which occurs in the Mackenzie Bay in the Taglu C-42 well, to be a marker of Miocene age. Norris assigned an Oligocene age to the palynomorphs of the Mackenzie Bay Formation, but the foraminiferal evidence, as outlined in the discussion of the **C.** spp. assemblage, indicates an Oligocene to Miocene age.

Depositional environment

The mud-dominant lithologic character of the Mackenzie Bay Formation together with its contained assemblage of calcareous benthonic foraminifers indicate deposition occurred on a shallow marine shelf. Gradual shoaling and freshening of the water from northwest to southeast is indicated by microfaunal evidence and intertonguing relationships with the gravelly, nonmarine Beaufort Formation. Sand bodies near the base of the Mackenzie Bay Formation may be offshore sand bars, developed by storm- or tide-generated bottom currents.

Beaufort Formation

Introduction

The Beaufort Formation was the name assigned by Tozer (1956) to surficial sand and gravel outcropping on Prince Patrick Island in the western Canadian Arctic Islands. This formation was recognized subsequently as mantling much of the western Arctic Coastal Plain (Tozer, 1960; Thorsteinsson and Tozer, 1962; Hills, 1970), and was tentatively assigned to surficial gravel and sand in the northern mainland east of Mackenzie Delta by Yorath et al. (1975). Research on plant megafossils and palynomorphs (Hills and Fyles, 1973 and Hills et al., 1974) dated the Beaufort Formation as Miocene. Similar deposits outcrop in the northern Caribou Hills (Fig. 14), and were assigned to an upper member of the Reindeer Formation by Doerenkamp et al. (1976), who recognized their similarity to the Beaufort Formation of Banks Island. Young (1978) and Price et al. (1980) chose to refer this outcrop section to the Beaufort Formation, and this practice leads to a similar assignment to subsurface Neogene sand and gravel beneath Tuktoyaktuk Peninsula and Richards Island.

The Imperial Ivik J-26 well is selected as a subsurface reference section of the Beaufort Formation for the Mackenzie Delta area. The depth-interval assigned to the Beaufort Formation is from 400 to 1030 m (1311-3380 ft). A good lithologic description of this interval is available from Canadian Stratigraphic Service Ltd. (Can. Strat. log no. D-NWT-495).

On northwestern Banks Island, the Beaufort Formation is divisible into three members, each separated by an unconformity (Hills and Fyles, 1973). The lowest unit consists of medium-grained sandstone, clay and woody peat; the medial unit light-coloured sand; and the upper unit coarse gravels with lenses of wood debris. Similarly, the subsurface Beaufort Formation beneath northeastern Richards Island consists of three units, although here there is no evidence to indicate unconformities between them. The lowest unit is interbedded sand, gravel and mud; the medial unit is mainly sand and mud; and the upper unit is gravel with minor sand and mud. Woody peat is common throughout the formation. The upper gravel unit thins northwestward by facies change from the base upwards.

Distribution and thickness

The Beaufort Formation in the study area is best developed and thickest under the northeastern part of Richards Island and adjacent offshore area to the east. In this region it is 600 to 950 m (2000-3200 ft) thick. To the north and northwest it thins and changes facies to a marine mudstone unit, here named the Mackenzie Bay Formation. The latter is recognizable as a mud member or tongue in the lower third of the Beaufort Formation in the Taglu field and the Nuktak C-22 well (Figs. 4, 5). West and northwest of the Taglu field, the Beaufort abruptly thins, as does the entire lower Neogene interval, and forms only the basal part of the Neogene interval in the Niglintgak-Kumak area. It disappears altogether by facies change into mudstone northwest of a line running through Pelly B-35, Garry P-04 and Langley E-29. In the south part of the study-area it forms a thin basal Neogene sand unit.

At its type section on Prince Patrick Island, the Beaufort Formation is about 76 m (250 ft) thick. The thickness of the Caribou Hills outcrop section assigned to the Beaufort is approximately 500 m (1700 ft) (Doerenkamp et al., 1976). North of Caribou Hills in the subsurface, the formation is absent by erosion below the Pliocene-Pleistocene Nuktak Formation (Reindeer D-27, Ya Ya P-53, Fig. 6), but attains its maximum drilled thickness within a structural depression (Fig. 8) in the Kilagmiotak wells where the Beaufort is approximately 1000 m (3280 ft) thick. The formation is also very rich in gravel and sand in this area, indicating that it may have been some type of alluvial depocentre. At its reference section in the Ivik J-26 well, the Beaufort is 631 m (2069 ft) thick, a typical thickness for the northeastern Richards Island area.

Contact relationships

The basal contact of the Beaufort Formation is the regional unconformity, which is clearly exhibited on seismic profiles (Hawkings and Hatlelid, 1975) and biostratigraphic profiles (Staplin et al., 1976), but is less distinct on well logs and lithologic records. This surface is less erratic in structural elevation (Fig. 10) than underlying stratigraphic horizons, and represents a hiatus in southern parts of the study area. (An extreme case is illustrated by the Shell Kipnik O-20 well, in which the thin Beaufort Formation rests upon Lower Cretaceous shale). In general, however, the Beaufort overlies the similar Kugmallit Formation of late Paleogene age, and the hiatus at the unconformity is probably not large.

To the north, northwest and west of Richards Island where the Beaufort is overlain by the Mackenzie Bay Formation the contact is gradational or interbedded, as would be expected in a lateral facies change. Tongues of one facies alternate with the other in certain well sections, such as Nuktak C-22 (Fig. 5); in such cases the mud tongues are arbitrarily considered members of the Beaufort Formation.

The upper contact of the Beaufort with the Nuktak Formation is mainly unconformable, and in many wells is difficult to pick because of the dominance of gravels above and below the contact. However, the Nuktak gravels typically form very "blocky", or uninterrupted and low-radioactive gamma ray logs in contrast to the more irregular log character through the Beaufort Formation. Lithologic differences have been noted also between the two: the Beaufort sand and gravel in its upper unit is typically medium to dark grey, owing to the abundance of grey chert clasts; the overlying Nuktak sands and gravels are much richer in quartz and possibly feldspar, exhibiting pink, salmon and orange colours.

Lithology

The Beaufort Formation is dominated by sand, generally medium to coarse-grained, and composed mainly of grey chert and quartz. Chert comprises nearly all granules and pebbles dispersed in the sands and forms many gravel beds. Some beds of sand contain over 80 per cent chert, and accordingly are dark grey. Rarely the sand is loosely consolidated into sandstone because of minor amounts of clay and pyrite.

An important minor component is mudstone, which forms interbeds and small- to large-scale tongues within the formation. The mudstone is commonly light brownish grey, sandy, and contains lignitic wood fragments. Expanding clays comprise large parts of some mudstone units.

The ever-present woody debris is practically a hallmark of the Beaufort Formation, which, in Arctic coastal plain outcrops is noted for its retinue of logs, uncompressed wood, spruce cones, and walnuts (Hills and Fyles, 1973). The organic detritus settled out into numerous lenses and beds of detrital woody peat or lignite, particularly in the lower part of the formation.

The northern end of the Caribou Hills escarpment is underlain by pebbly to cobbly gravels, interpreted as the Neogene section by Doerenkamp et al. (1976) and as the Beaufort(?) Formation by Price et al. (1980). The gravel contains pebbles of various types of chert and quartzitic sandstone and siltstone, a few of which contain pelecypod fossils of Mesozoic age. This coarse detritus was derived probably from the west and south, from tectonically uplifted highlands associated with the Cache Creek, Caribou (Young, et al., 1976, Fig. 13), and Campbell Lake highs.

Paleontology and age

Terrestrial palynomorphs characterize the paleontology of the Beaufort Formation. Foraminifers occur only rarely. To the east of the delta, in the western Arctic Coastal Plain, Hills and Fyles (1973) and Hills et al. (1974) have recorded plant megafossils from outcrops of the formation. In Banks Island, Hills et al. (1974, p. 67) assigned a Miocene age to the formation.

Norris's data (in Austin and Cumming, 1978b, c, 1979a, b) for the Nuktak C-22, Niglintgak H-30, Ivik K-54, and Taglu C-42 wells indicate that the palynomorph assemblage of the Beaufort is substantially the same as that of the Mackenzie Bay Formation, although less diverse. **Alnus, Castanae, Corylus, Alnipollenites,** ericoid pollen, **Pices, Tsuga,** and **Lycopodiumsporites** are dominant. Similarly, the foraminiferal assemblage of the Beaufort is essentially that of the Mackenzie Bay, but with a much reduced diversity. Species of the **Cibicides** spp. assemblage in the Beaufort (Ivik K-54 and J-26 wells) include only **Asterigerina guerichi s.l.** and **Elphidiella(?) brunnescens.**

Following an outcrop study of the Beaufort Formation in the western coastal plain of Banks and Prince Patrick Islands, Hills and Fyles (1973) identified plant megafossils belonging to the genera **Picea, Pinus, Larix, Metaseqoia, Alnus,** and **Juglans,** as well as bryophites and abundant pollen. They dated the flora as Middle to Late Miocene and interpreted a cool-temperate paleoclimate, comparable to the Great Lakes region of present North America. In the Mackenzie Delta, Staplin (1976) reported palynomorphs from several wells that indicated a comparable age and climate for the section now included in the Beaufort Formation. Doerenkamp et al. (1976), using outcrop data from the Caribou Hills on the eastern margin of the delta, assigned a Miocene-Recent age to sands and gravels of the upper part of the Reindeer Formation (now included in the Beaufort Formation). Norris's (in Austin and Cumming, 1979a) age determinations for the relevant section in the Ivik K-54 well were as follows: the lower part, characterized by ericoid pollen -- Oligocene in age; a medial section characterized by **Tsuga** -- Middle Miocene in age; and an upper part, above the highest occurrence of **Tsuga** -- Early Pliocene in age. In the Taglu C-42 well, Norris's (in Austin and Cumming, 1979b) assignment of a Late Eocene age to the section spanning 550 to 972 m (1800-3190 ft) (now interpreted as Mackenzie Bay intertongued with Beaufort), is anomalous, perhaps a reflection of reworked palynomorphs because the palynomorphs recorded by Norris are in fact more characteristic of the Paleogene sequence in the delta. The occurrence of **Asterigerina** sp. (Staplin, 1976, Fig. 5) over much of this section justifies a much younger age, probably Miocene. The foraminifers of the Beaufort Formation (Ivik K-54 and J-26 wells) mark the medial part of the formation and indicate a probable Miocene age but have a potential range of Oligocene to Miocene.

Depositional environment

The Beaufort Formation in the Mackenzie Delta area is an abruptly thickening, wedge-shaped unit, consisting of thin to thick gravel units mixed with sand and minor mud and silt interbeds. The irregular character of vertical sequences, as expressed either by well-logs or outcrop sections, together with common terrestrial plant remains, suggest a depositional environment dominated by shallow, probably braided, gravel streams. The sheer bulk of these deposits and their maximum known thickness of 1000 m (3280 ft) signify the development of coalescent alluvial fans.

Gravels nearest the southeastern edge of preservation (e.g., the Caribou Hills outcrops) contain abundant cobble-size clasts, suggesting that rapid physical weathering and erosion of a highland occurred nearby. This was presumably in part a tectonic uplift along the Eskimo Lakes Arch, now a very subdued terrain along the length of Tuktoyaktuk Peninsula.

The intertonguing northwestward along a narrow zone with the Mackenzie Bay marine mudstones implies that the alluvial fan complex encroached upon a marine shoreline, hence by definition the Beaufort gravels represent a fan-delta complex.

Nuktak Formation

Introduction

A widespread clay-mud unit underlies the surface of most of the modern Mackenzie Delta and its outer islands. In the latter area, the mud is in turn underlain by a gravel and sand unit. Together they form a continuous depositional sequence and contain a common microfauna and microflora, and are here named the *Nuktak Formation*. Because of its position near or at the top of the stratigraphic column, it lies generally within the permafrost zone, hence samples and well-logs are typically poor. However, a reasonable type section is available in the Imperial Nuktak C-22 well on Hooper Island (Lat. 69°41'07"N., Long. 134°51'30"W.).

Distribution and thickness

A gravel member at the base of the Nuktak Formation is best developed under Richards Island and adjacent offshore areas. It thickens gradually seaward in a wedge that is about 155 m (500 ft) thick in the Kilagmiotak wells, and 460 m (1500 ft) thick in Pullen E-17. East of Richards Island, this member grades into mostly sand, and thins to zero locally. West of Richards Island, it thickens from practically zero in the Langley High area to over 460 m (1500 ft) in the Netserk F-40 well.

The mud member is found at or near the top of all wells drilled in the modern delta plain and to the northeast on Richards Island and surrounding offshore area. Boreholes drilled 8 km (5 mi) southwest of Inuvik (Johnston and Brown, 1965) encountered a clay unit at a depth of 55 m (180 ft) which they ascribed to an estuarine origin. Between depths of 63 m (206 ft) and bedrock at 70 m (230 ft) the clay becomes pebbly, and may be a glacial till deposit. This clay unit may be a southern thin extension of the Nuktak Formation.

In most wells, the mud member extends from approximately the 50 m depth (165 ft) to depths between 150 and 245 m (500-800 ft) (Figs. 5 to 8). The deepest known elevation of its lower contact is at approximately 245 m (800 ft) below sea level in the Shell Tullugak K-31 and Shell Kipnik O-23 wells along the southern margin of the study area. No seaward thickening trend of the mud member is apparent from well data in the study area.

The geometrical effect of having a slab-like member superimposed upon a wedge-shaped one is an over-all, seaward-thickening wedge. The Nuktak Formation is thinnest in the headward region of the modern Mackenzie Delta, is also thin over the Langley High (approximately 155 m or 500 ft), and thickens seaward to approximately 650 m (2150 ft) in the Netserk F-40 well. It is 500 m (1650 ft) thick at its type section.

Contact relationships

The Nuktak Formation nearly everywhere lies disconformably on the Mackenzie Bay or Beaufort Formations. The contact is abrupt, and probably only mildly erosional in a few places. Basal beds of the Nuktak are generally sand or gravel, providing a contrast in well-log character with underlying units. This is particularly true for the gamma ray log, which shows typically a left-hand deflection (reduced radioactivity) upward into the Nuktak Formation. This deflection in some wells is caused by greater caving of borehole walls in the Nuktak interval than immediately below. In the absence of good well-logs, an examination of drill-cuttings shows a richer quartz content in Nuktak sands than in sands of the Beaufort Formation.

The upper contact of the Nuktak is poorly known due to poor or unavailable well-logs, caving of sidewalls in the permafrost zone, and poor or inadequate sampling in the top hundred metres or so. Nevertheless, a few wells and the boreholes drilled near Inuvik indicate an abrupt, probably unconformable contact with late Pleistocene and Holocene sand, gravel, till, and mud, here assigned tentatively to the Herschel Island Formation (Johnson et al., 1976). This formation is known from surface exposures along the northern Yukon coast, and consists of a mixture of glacial and shallow marine sediments, similar to those on outer Mackenzie Delta, to a maximum depth of about 100 m (330 ft). The Herschel Island Formation is not present everywhere, however, as the Nuktak Formation at its type section extends practically to the surface.

The contact of the mud member with the gravel member is typically fairly abrupt, although a few wells show a thin zone of interbedded lithologies at the contact.

Lithology

The Nuktak Formation exhibits lithologic characteristics which help to differentiate it from underlying formations of similar facies.

As mentioned above, sands are dominated by quartz grains, with chert and shale clasts in the minority. The shale clasts are typically dark brown-grey, fairly hard, and are probably from Lower Cretaceous pelitic units in the region, as great amounts of recycled Albian palynomorphs and foraminifers are recovered.

Another important characteristic is the salmon colours displayed by various quartz, chert, and feldspar granules and pebbles. This pink to orange colouration is formed by thin hematitic films and crusts on the clastic particles.

The mud member consists of light grey mud containing abundant wood-fibre, cuticular debris, ostracods, foraminifers and molluscan shell fragments. Sand grains and lenses, peat beds, chert pebbles, and large flakes of white or colourless mica are also present. Rare carapaces of beetles and other insects and resin grains have been found in the mud.

Thin sections of pelitic sediments of this formation in the Netserk F-40 well show several lithologies, including laminated sandy siltstone, argillaceous siltstone, sandy and non-sandy mudstone. Sand grains consist of quartz, chert, feldspar, carbonate rock, muscovite, slate, tuff, and microschist. Clots of kerogen and glauconite, authigenic clays, and coaly to cuticular organic detritus are also visible.

The gravel member also contains much woody debris and minor amounts of the other accessories noted in the mud member. Sands are pale brown, yellow, and grey, medium- to very coarse-grained, quartz-dominant, and may be interbedded with claystone, silty mudstone, seat earth, gravel or peat. Some sands contain, by visual estimation, over 95 per cent quartz, and less than 5 per cent dark grey chert.

Paleontology and age

The Nuktak Formation contains a variety of fossil material — palynomorphs, charaphytes, seed casings, wood, peat, cuticular debris, foraminifers, gastropod and bivalve fragments, ostracods, and insects. The formation also yields a reworked assemblage consisting largely of agglutinated Early Cretaceous foraminifers and palynomorphs of Paleozoic, Mesozoic, and Cenozoic age. So conspicuous is this reworked component that it may be used as a guide to the formation. Three of the above fossil groups have received study; the following assemblages have been recognized: a cool-temperate to boreal terrestrial palynomorph assemblage; a shallow-marine, mixed foraminifer-ostracod assemblage, and a fresh-water ostracod assemblage.

Norris's data for the Netserk B-44, Pelly C-35, Nuktak C-22, Ivik K-54, and Taglu C-42 wells indicates that the Nuktak is fairly uniform palynologically. It yields a low-diversity, cool-temperate to boreal flora; the common constituents being **Betulaceoipollenites, Pinus, Laevigatosporites, Stereisporites,** and **Sigmopolis hispidus** Hedlund, all of which also occur in the underlying Mackenzie Bay Formation. The lower part of the formation contains palynomorphs and foraminifers that may be reworked from the Mackenzie Bay Formation. A pronounced example is in the Adgo F-38 well where characteristic Mackenzie Bay species are found in the lower 90 m (300 ft) of the Nuktak. They include **Corylus** sp., **Stereisporites** sp., and the foraminifer **Cibicides perlucidus.**

Although the Nuktak is fairly uniform palynologically, the foraminifers combined with data on ostracod distributions interpreted by Braun and Brooke (in Austin and Cumming, 1978b, c; 1979b, c, d) show a well-marked marine biofacies in the northern area of the delta flanked to the south by a nonmarine biofacies. The nonmarine biofacies is developed from Ivik C-52 to Unipkat I-22 on Figure 6 and from Kumak J-06 south on Figure 7. North of the latter, elements of the shallow-water marine **Elphidium** spp. assemblage are common through much of the Nuktak. An exception is the Nuktak C-22 well from which Braun and Brooke recorded a fresh water ostracod unit (in the lower Nuktak) overlain by a marine foraminifer-ostracod unit.

The marine, shallow-water biofacies of the Nuktak Formation is marked by the calcareous foraminifers of the **Elphidium** spp. assemblage. **Elphidium clavatum, E. bartletti, Elphidiella hannai, Protelphidium orbiculare** and **P.** cf. **P. orbiculare** (Brady) are particularly common (see Plate 6). Other elements of the assemblage are outlined in a previous chapter devoted to foraminiferal assemblages.

Based on the palynomorph recovery, Norris (in Austin and Cumming, 1979a, c) assigned a Pliocene age to the flora in Ivik K-54 and Pelly C-35; in other wells he assigned a generalized Neogene age to the flora that span the formation. The foraminifers of the **Elphidium** spp. assemblage indicate a Pliocene to Pleistocene age for the formation.

Depositional environments

The poor quality of lithologic and vertical sequence data on the Nuktak Formation restricts paleoenvironmental interpretations to general conclusions based primarily on fossil remains. As discussed above, both marine and nonmarine microfauna are present in the formation, and in general, more seaward wells contain more marine-dominant assemblages. Also, the higher parts of Nuktak well-sections are more marine in aspect than lower parts. This biofacies sequence, characteristic of onlapping marine conditions, corresponds with the observed lithofacies sequences, consisting of gravel, sand, and peat at the base, overlain by mud at the top.

The gravel member is interpreted to be a fluvial and delta-plain complex, similar to, but perhaps possessing lower stream gradients than those of the Beaufort Formation. Because the development of this gravel-rich, delta plain is best in the present-day Richards Island area and northward thereof, it would seem likely that sedimentation was focused in the same area as that in Beaufort Formation time, only somewhat offset basinward.

The occurrence of well-sorted, nearly pure quartz sands near the base of the Nuktak, followed upward by a widespread, reasonably thick mud unit, containing marine shells and microfauna, indicates that a marine embayment existed over the Mackenzie Delta area during much of the Pleistocene. This circumstance leads to the conclusion that deltaic sedimentation was absent in the study area after the gravel member was deposited, and to the question of where the Pleistocene Mackenzie River debouched. To answer adequately this question is beyond the scope of this paper, however, given the absence of Pleistocene deltaic sediments along the northern Yukon coast and under Mackenzie Delta, we infer that the proto-Mackenzie River emptied into the Arctic Ocean northeast of the present delta.

STRUCTURAL GEOLOGY

Summary accounts of the regional tectonic features and structural elements are available in previous reports (e.g., Lerand, 1973; Young et al., 1976). Nevertheless, important new inferences about the structure of Richards Island Basin can be made simply from the stratigraphy outlined in this report, and the structural elevations and bedding attitudes recorded in various wells. Seismic profiles would be a great benefit to this review, but unfortunately they were not available to the writers.

The main tectonic element of the study area is Richards Island Basin in which the molassic Tertiary sediments discussed in this report accumulated (Fig. 2). Certain long-lived positive elements, such as the Cache Creek High and Eskimo Lakes Fault Zone (Young et al., 1976) probably were intermittently active during Tertiary time, as suggested by local facies and thickness changes. Episodic tectonic disturbances may have triggered movements on listric, normal faults in the Paleogene sequence. Shale diapirs and shale anticlines are commonly associated with these faults, which may be in part sedimentary growth faults (see Fig. 12 of Lerand, 1973). Hydrocarbon accumulations occur in the crests of domical and anticlinal structures related to these listric faults, as for example, the Taglu gas field (Bowerman and Coffman, 1975).

Paleogene strata, possibly as young as the Richards Formation (A.R. Sweet, pers. comm.) are faulted and moderately to severely tilted in the outcrop area immediately west of Mackenzie Delta (Young, 1975). The oldest, undeformed sediments overlying the Paleogene rocks unconformably are probably Pleistocene, thus, a precise dating of the tectonic activity in this area is not possible. However, the general lack of disruption of Neogene strata in the Delta subsurface (see below) suggests that deformation occurred during late Paleogene time. It is quite possible that faulting, tilting and uplift took place in the late Eocene, and that the western area became a source of clastic detritus for the Kugmallit Formation. This hypothesis is supported by the abundance of recycled Paleogene and older palynomorphs and clastic coal in the Kugmallit Formation.

The pre-Mackenzie Bay - Beaufort unconformity is a convenient stratigraphic marker in the examination of subsurface structural complexities. This marker is identified on the basis of low-angle seismic reflectors within the Paleogene sequence which appear to be truncated beneath the base of the younger units (Young et al., 1976). Progressively older formations subcrop beneath this unconformity from northeast to southwest in the area (Fig. 9). Its elevation remains fairly constant at approximately 1000 m (3300 ft) beneath Richards Island (Figs. 6, 9), but southwest of Taglu Field, it rises abruptly to less than -300 m (-1000 ft) (e.g. Langley E-29), forming an asymmetric arch, here called the Langley High, trending northwest-southeast. This appears to be an erosional paleotopographic high relict after uplift and mild tectonism during mid-Tertiary time.

The oldest unit known to subcrop beneath Neogene sediments in the study area is the Lower Cretaceous (Albian) Arctic Red Formation in the Kipnik O-20 borehole. A considerable thickness of section is truncated between this well and the Caribou Hills, only 13 km (8 mi) to the east, below the unconformity.

Facies and thickness characteristics of the Beaufort and Mackenzie Bay Formations with respect to the structural configuration of the underlying unconformity are also informative. The Beaufort Formation is thickest and exhibits its coarsest nonmarine facies precisely where the unconformity surface forms a large basin-like depression. These features together strongly suggest that early Neogene clastic transport was directed into this topographic depression where rapid aggradation occurred in gravelly fluvial channels and deltaic distributaries, and less abundant floodplain and estuarine muds. This fluvio-deltaic complex filled up the Richards Island depression while little or no coarse clastics were deposited west of the Langley High. There, estuarine mud of the Mackenzie Bay Formation was deposited from the transgressing sea, and only a thin sand unit was deposited over crestal parts of the high.

It is also interesting to note the relationship of the pre-Mackenzie Bay - Beaufort unconformity to underlying diapiric structures. In the few wells drilled into or close to shale diapirs, such as Immerk B-48 and Mallik A-06, the unconformity surface is scarcely domed, despite large amounts of missing section and moderate to high bedding angles below it. This relationship suggests that diapiric movements occurred mainly before the Neogene sequence was deposited. Indeed, much of the folding and diapirism observed within the study area seems to have taken place toward the end of Paleogene deposition (coincident with the Eurekan Orogeny of the eastern Arctic), and very little tectonism is evident from Neogene stratigraphic relationships.

Neogene tectonism is evident, however, in tilted and uplifted Beaufort and younger sediments underlying Caribou Hills. The poorly dated, thin Neogene mud unit underlying surficial sediments of the modern delta-plain is quite thinner and different in facies from Neogene gravels and nonmarine sediments exposed in gullies on the flanking eastern scarp of the delta. These differences suggest that the modern delta-plain and Caribou Hills plateau are separated by a fault, with the plateau block once depressed relative to the modern delta.

HISTORICAL SUMMARY

Introduction

Molassic sedimentation, initiated during latest Cretaceous time, continued in the Mackenzie Delta area throughout the Tertiary Period. Distinct tectono-sedimentary pulses are reflected by large-scale, regressive, deltaic or alluvial cycles which gradually built seaward and outward to form the southern continental shelf of the Beaufort Sea. In landward areas, tectonic uplifts brought previously deposited molassic wedges and older rocks to the surface where they were eroded and recycled into the next younger clastic complex. This cannibalism complicates the palynological and micropaleontological records preserved in all cycles of the Cenozoic sequence.

Paleogene history

Laramide deformation and uplift are reflected by the Moose Channel Formation which prograded basinward in early Paleocene time as a result of increased sediment supply on a coastal plain flanking tectonic uplands west and south of the Beaufort-Mackenzie Basin. The Moose Channel wedge consists of clastic rocks and coal deposited in fluvial, delta-plain, littoral, and shallow-marine environments (Young, 1975).

Sandstone and conglomerate of the Moose Channel Formation are rich in chert, volcanic and metamorphic lithic fragments and, together with paleocurrent and dispersal trends, indicate source areas lying west and south of the present coastal plain (*ibid.*; Holmes and Oliver, 1973). Deltaic depocentres appear to be concentrated in the outer Yukon coastal plain and in the subsurface of the northwestern margin of the modern Mackenzie Delta.

Toward the end of Moose Channel time, the Caribou High north of Inuvik, together with parts of northern Richardson Mountains, were tectonically uplifted and eroded. A widespread marine transgression is indicated by the Ministicoog shale member, which is a useful marker in subsurface correlations.

A second major arenaceous wedge, the Reindeer Formation, prograded seaward from uplands ringing the western and southern margins of the basin in late Paleocene and early Eocene times. The major source area was still the western tectonic highland, but uplifts along the Eskimo Lakes Fault Zone also shed coarse debris into Richards Island Basin. Thus, a wide, fringing coastal plain was formed, consisting of paludal, fluvial, and alluvial-fan facies. Deltaic depocentres developed in the Richards Island and northern Tuktoyaktuk Peninsula areas.

Continued subsidence is recorded by the Richards Formation, a thick shale unit that overlies the Reindeer Formation under Richards Island and which probably forms shale tongues southward under Tuktoyaktuk Peninsula.

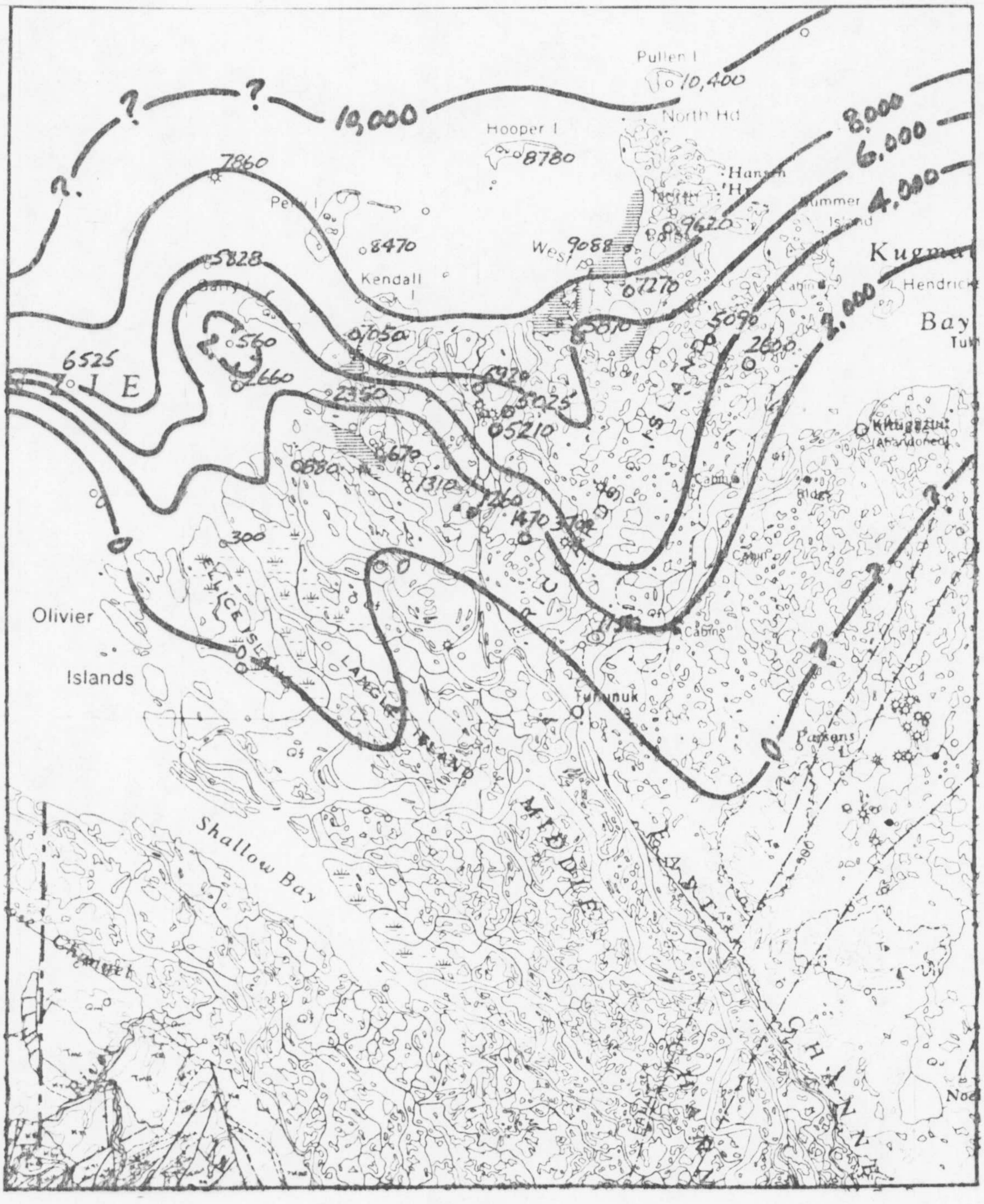

Figure 20. Isopach map of Richards and Kugmallit formations. [Contour interval: 2,000 feet]

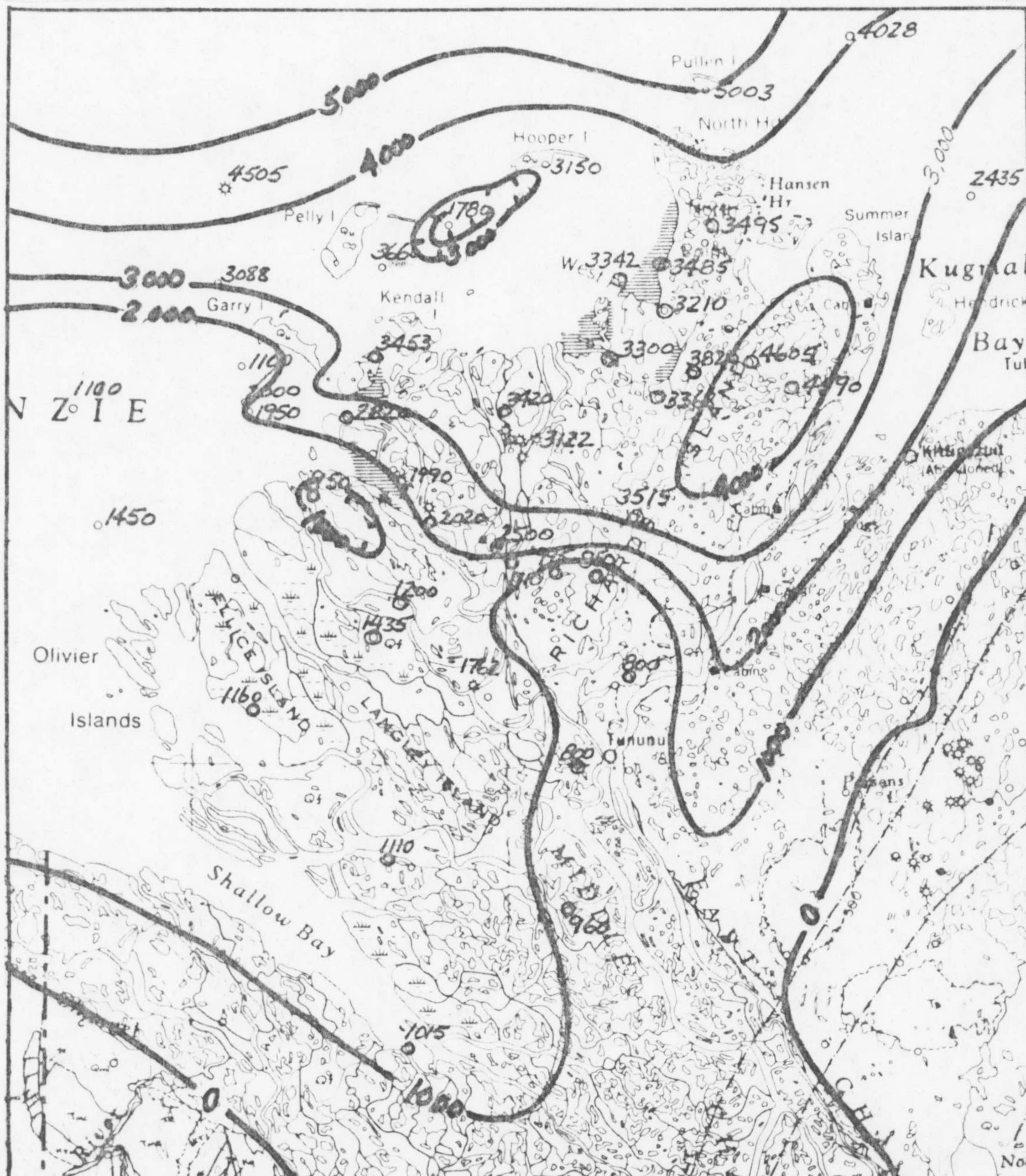

Figure 21. Isopach map of Mackenzie Bay, Beaufort, and Nuktak formations. [Contours in feet]

Complex thickness variations in the Ya Ya and Kilagmiotak wells indicate tectonic activity, probably along faults associated with Cache Creek High or Donna River Fault, during deposition of the Richards Formation.

The upper part of the Richards Formation probably is prodeltaic in origin, comprising the northeastward-migrating toe of the upper Paleogene deltaic wedge, the Kugmallit Formation.

The Kugmallit Formation thickens markedly north- and northeastward in the subsurface of Richards Island and the adjacent offshore area. Recycled palynomorphs and clastic coal fragments indicate a local derivation of much of the detritus in the Kugmallit Formation. Indigenous palynomorphs and microfaunal elements are very scarce and non-diagnostic. Older portions of the molassic deposits west of Mackenzie Delta and on Tuktoyaktuk Peninsula may have been uplifted tectonically at this time, providing an easily eroded upland adjacent to the depositional basin. The absence of this unit in wells drilled southwest of Richards Island may be due to structural elevation beneath the pre-Mackenzie Bay - Beaufort unconformity at these well locations, rather than non-deposition. On the other hand, gradual thinning of the Ivik Member from northeast to southwest under Richards Island suggests an overall thinning trend, and probably wedging out of the entire formation under modern Mackenzie Delta.

The isopach map (Fig. 20) of the combined Richards and Kugmallit Formation shows thinning along the northwest-trending Langley High, part of which may have been uplifted during this depositional interval. Rapid northward thickening across the entire Mackenzie Delta area is evident from the map.

Neogene and Quaternary history

Following deposition of the Kugmallit deltaic wedge, possibly in Middle to Late Oligocene time, the sea appears to have retreated from the immediate area of Mackenzie Delta and was accompanied by mild tectonic and lutokinetic upwarping in this area. These processes account for the relative thinness of the Neogene deposits over the Langley High and the western part of the Mackenzie Delta (Fig. 21). There is little indication of uplift and erosion in the vicinity of Richards Island, where, despite a disconformity at the top of the Kugmallit Formation, a relatively thick sequence of gravels and sands of the Beaufort Formation is preserved (Fig. 21). Deposition seems to have been continuous offshore to the north and northwest.

A basin in the Richards Island area still existed with the advent of early Neogene deposition, marked by thick gravelly fluvial and fan-delta sediments of the Beaufort Formation and marine muds of the Mackenzie Bay Formation. This widespread depositional sequence appears to have filled in pre-existing topographic depressions and prograded several kilometres. During the Pliocene the sea may have once again retreated from the study area, allowing the even upper surface of the Beaufort-Mackenzie Bay sequence to be scoured locally.

The Pliocene-Pleistocene Nuktak Formation records the last offlapping deltaic sequence prior to a final marine transgression over the area and late Pleistocene complexities caused by advancing and retreating continental ice sheets. No significant tectonic deformation is evident within Neogene and Quaternary formations of the area.

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APPENDIX

Description of Type Sections

Schedule of Wells

Section 1. Description of type section of *Richards Formation*, in the Imperial Taglu West P-03 well, located at Lat. 69°22'59"N, Long. 135°00'07"W. Cuttings samples are generally of poor quality, and descriptions are tempered by well-log characteristics. Logged by F.G. Young, June 1978. Samples stored at Institute of Sedimentary and Petroleum Geology, Calgary. Spud date: Dec. 12, 1971. Rig release date: Mar. 29, 1972. K.B. elv.: 8.5 m (28 ft).

Unit	Lithology	Top of depth interval m	(ft)	Thickness m	(ft)
	Sand, very fine to fine grained, quartz-chert-coal fragment composition, poorly sampled (*Kugmallit Formation*)	1600.2	(5250+)	9+	(30+)
	Abrupt contact				
	Richards Formation (type section) 976 m (3200 ft)				
30	Mudstone, light grey, silty, slightly sandy, containing expandable clay, soft	1609.3	(5280)	29	(95)
29	Lignite, brown-black, shaly	1638.3	(5375)	1.5	(5)
28	Mudstone, light grey, silty, soft; minor calcareous and carbonaceous siltstone and sandy mudstone; very small residues and poor samples; logs indicate presence of bentonitic beds (first resistivity marker)	1639.8	(5380)	61	(200)
27	Mudstone, light brown-grey, silty, soft, in part sandy, fine to coarse grained, with laminae of argillaceous, fine grained sandstone; in part bentonitic	1700.7	(5580)	49	(160)
26	Mudstone, sandy, soft, slightly bentonitic; very poor small samples, sandy residues only	1749.5	(5740)	61	(200)
25	Shale, light to dark grey, montmorillonitic, slightly sandy, in part carbonaceous	1810.5	(5940)	6	(20)
24	Siltstone, grey to medium brown, very fine grained sand, carbonaceous in part; minor calcite cement, bentonitic mud interbeds; pyritic tubes (burrows?)	1816.6	(5960)	27	(90)
23	Mudstone, brown-grey, bentonitic, sandy; minor siltstone	1844.0	(6050)	14	(45)
22	Siltstone, calcareous, sandy, carbonaceous in part; minor sandstone, very fine grained, slightly porous	1857.7	(6095)	6	(20)
21	Mudstone, medium grey, fine grained sand, bentonitic, in part carbonaceous; interbedded minor siltstone	1863.8	(6115)	20	(65)
20	Sandstone, fine to medium grained, very argillaceous; interbedded mudstone, as above	1883.6	(6180)	6	(20)
19	Mudstone, light grey-brown slightly bentonitic, sandy, fine grained; minor siltstone, calcareous, hard, sandy	1889.7	(6200)	73	(240)
18	Mudstone, as above, with siltstone, brown, calcareous, plant fragmental, and sand laminae, fine to medium grained, chert and quartz	1962.9	(6440)	37	(120)
17	Mudstone, light grey-brown, silty, slightly sandy, contains floating pebbles and granules of chert; minor carbonaceous, dark grey mudstone	1999.4	(6560)	50	(165)
16	Mudstone, as above, chert pebbles common; minor calcareous siltstone; poor samples	2049.7	(6725)	53	(175)
15	Mudstone, pale brownish grey, sandy; sandstone, very fine grained, light brown, argillaceous, plant fragments; rare ferruginous nodules	2103.1	(6900)	31	(100)
14	Mudstone, light brown-grey, soft, sandy, slightly bentonitic with trace of white bentonite; minor ironstone nodules	2133.6	(7000)	31	(100)
13	Mudstone, as above, with fine grained sandstone stringers, argillaceous, expandable clay	2164.0	(7100)	4	(12)

Unit	Lithology	Top of depth interval m	(ft)	Thickness m	(ft)
12	Mudstone, light brown-grey, sandy, in part carbonaceous; minor hard ironstone and sandstone, fine grained, calcareous, poorly sorted, tight	2167.7	(7112)	60	(198)
11	Mudstone, light grey-brown, slightly sandy and silty, soft, expandable clays; minor coaly wood fragments and calcareous siltstone	2228.0	(7310)	24	(80)
10	Mudstone, as above, with siltstone, yellow-brown, calcareous, and minor sandstone, fine grained, calcareous, poorly sorted	2252.4	(7390)	40	(130)
9	Mudstone, light brown-grey, silty, in part shaly; rare argillaceous limestone, medium brown, and calcareous mudstone; mainly small, poor samples	2292.0	(7520)	96	(315)
8	Mudstone, light brown-grey, soft, slightly sandy, with minor sandstone, very fine-grained, calcareous, slightly porous, poorly sorted, resin and coaly fragments, chert, minor kaolinite cement	2388.1	(7835)	23	(75)
7	Mudstone, light brown-grey, sandy, fine grained; chert, ironstone and shale clasts common; minor very fine to medium grained sandstone, clayey, with scattered chert pebbles and granules	2410.9	(7910)	21	(70)
6	Sandstone, friable, very fine to medium grained, chert and quartz predominant, clayey matrix; mudstone interbeds, as above, and minor siltstone, pyritic, bituminous	2432.3	(7980)	12	(40)
5	Sandstone, fine grained, moderately sorted, quartz-chert composition, clay- and calcite-cemented; interbedded mudstone, light grey, sandy in part, sideritic in part, micromicaceous	2444.4	(8020)	11	(35)
4	Mudstone, brown-grey, silty and sandy, contains expandable clay; minor sandstone, fine grained, calcareous, and ironstone concretions, medium brown	2455.1	(8055)	26	(85)
3	Mudstone, grey, slightly sandy with coaly fragments, expandable clay; poor samples due to casing shoe cement	2481.0	(8140)	40	(130)
2	Mudstone, medium grey, slightly silty and sandy, shaly in part, soft in part; contains scattered pebbles and coaly fragments	2520.6	(8270)	59	(195)
1	Mudstone, as above, with sandstone, very fine to fine grained, calcareous, tight, as thin stringers	2580.1	(8465)	5	(15)
	Reindeer Formation	2584.7	(8480)		

Section 2. Description of type section of *Kugmallit Formation*, including its *Arnak Member*, in the Imperial Nuktak C-22 well, located at Lat. 69°41'07"N, Long. 134°51'30"W. Cuttings samples are poor to fair, in part contaminated by uphole cavings; descriptions are tempered by well-log characteristics. Logged by F.G. Young, May 1978. Samples stored at Institute of Sedimentary and Petroleum Geology, Calgary. Spud date: Dec. 16, 1972. Rig Release: Mar. 8, 1973. K.B. elv. 47.3 m (156 ft).

Unit	Lithology	Top of depth interval m	(ft)	Thickness m	(ft)
	Sand, dark grey, 80 per cent chert, medium to coarse grained; woody and lignitic fragments (*Beaufort Formation*)				
	Disconformable contact				
	Kugmallit Formation (type section) 1420 m (4660 ft)				
	Arnak Member (type section) 565 m (1860 ft)				
69	Sand, medium grey, fine grained, quartz and chert mainly, with interbedded shale, medium grey; abundant coaly fragments	960.1	(3150)	9	(30)
68	Samples missing. Probably as above	969.2	(3180)	18	(60)
67	Sand, medium grey, medium to coarse grained, with woody lignite	987.5	(3240)	6	(20)
66	Probably mudstone, coaly fragments, with minor lignite and sand, as above. Very poor samples below 3300 feet	993.6	(3260)	26	(85)
65	Sand, medium grained, with interbedded woody, lignitic shale	1019.5	(3345)	9	(30)
64	Very poor samples; probably as above	1028.7	(3375)	8	(25)
63	Sand, medium grained, 40-50 per cent chert, subangular to subrounded, well sorted; minor woody lignite, coaly shale with rare resin grains	1036.3	(3400)	31	(100)
62	Sand, fine to medium grained, as above, with black coaly shale interbeds	1066.8	(3500)	6	(20)
61	Sand, medium grained, well sorted, 70 per cent quartz, 30 per cent chert (estimated), subangular to subrounded and minor lignite and coaly shale	1072.8	(3520)	12	(40)
60	Sand, medium to coarse grained, with minor granules and pebbles of sandstone and chert; interbedded mudstone, dark brown, silty, in part coaly	1085.0	(3560)	12	(40)
59	Lignite, woody, in part sandy	1097.2	(3600)	3	(10)
58	Sand, medium grained to gravelly, chert-rich, with interbedded coaly mudstone and lignite	1100.3	(3610)	12	(40)
57	Sand, fine grained, with random chert pebbles; minor coaly shale interbeds in upper part	1112.5	(3650)	18	(60)
56	Mudstone, dark brown, in part coaly, woody, and minor lignite	1130.8	(3710)	18	(60)
55	Sand, fine grained, quartz-rich to 50/50 quartz and chert, speckled grey, subangular to subrounded, moderately sorted	1149.9	(3770)	18	(60)
54	Lignite and very coarse-grained sand	1167.3	(3830)	3	(10)
53	Sand, dark grey, medium to coarse grained, chert-rich, subrounded, minor limonite-cemented sandstone; trace of coaly shale	1170.4	(3840)	24	(80)
52	Sand, grey to yellow-grey, fine to coarse grained, speckled; minor pyritic sandstone, fine grained	1194.8	(3920)	23	(75)

Unit	Lithology	Top of depth interval m	(ft)	Thickness m	(ft)
51	Sand, medium grained, well sorted, 30-40 per cent chert (est.), subangular to rounded, with traces of sulphurous coaly mudstone and ferruginous sandstone	1217.6	(3995)	11	(35)
50	Sand, medium to coarse grained, dark grey; with minor interbeds of woody lignite, ferruginous sandstone, and coaly, sulphurous shale	1228.3	(4030)	47	(155)
49	Sand, coarse grained, gravelly in part, chert-dominated; with minor coaly shale and lignite interbeds	1275.5	(4185)	29	(95)
48	Mudstone, tan, sandy, medium to coarse grained; and clay-cemented sandstone, fine grained	1304.5	(4280)	17	(55)
47	Sand and sandstone, fine to medium grained, with minor clayey, sandy siltstone, tan	1321.3	(4335)	15	(50)
46	Sand, dark grey, medium grained, becoming very coarse grained at base, chert and quartz mainly, argillaceous in part	1336.5	(4385)	12	(40)
45	Mudstone, tan to dark grey, sandy in part, carbonaceous and wood-fragmental in part; minor siltstone; trace clay ironstone, dark brown, hard	1348.7	(4425)	23	(75)
44	Interbedded sand, fine grained, with lignite fragments, mudstone, dark grey, carbonaceous to coaly, and sandstone, medium grained, dark grey, bituminous and clay-cemented, slightly porous	1371.6	(4500)	15	(50)
43	Mudstone, dark grey, coaly plant fragments common	1386.8	(4550)	9	(30)
42	Sand, brown-grey, fine to medium grained, well sorted, pink quartz and grey chert abundant; minor carbonaceous mudstone and lignite	1395.9	(4580)	27	(90)
41	Shale, coaly fragmental, and lignite; minor sand, coarse grained to granular, poorly sorted	1423.4	(4670)	12	(40)
40	Gravel, sandy, with lignite interbeds, woody	1435.6	(4710)	5	(15)
39	Mudstone probably, and sandstone, very fine to medium-grained, iron-oxide cemented, friable	1440.1	(4725)	5	(15)
38	Sand, fine to medium grained, in part gravelly, quartz and chert main components	1444.7	(4740)	6	(20)
37	Mudstone, carbonaceous to coaly; minor sand, very fine to medium grained, in part moderately well sorted, friable sandstone, ferruginous cements	1450.8	(4760)	27	(90)
36	Sand, speckled, medium to coarse grained, some rich in dark grey chert, subangular to subrounded; interbedded mudstone, carbonaceous to coaly	1478.2	(4850)	15	(50)
35	Sand, as above, with minor coaly shale and lignite, wood fragments and in part sandy, sulphurous; trace gravel or pebbly sand	1493.5	(4900)	21	(70)
34	Mudstone, light brown-grey, in part sandy, coal fragments, pebbly	1514.8	(4970)	9	(30)
33	Gravel, pebbly, chert and sandstone clasts	1524	(5000)	3	(10)
	Ivik Member 855 m (2800 ft)				
32	Mudstone predominantly, dark grey to black, carbonaceous to coaly, in part sandy; generally very poor sample	1527.0	(5010)	67	(220)
31	Sand, fine to medium grained, chert and quartz mainly, with coaly shale, black	1594.1	(5230)	6	(20)
30	Mainly missing or poor samples	1600.2	(5250)	27	(90)

Unit	Lithology	Top of depth interval m	(ft)	Thickness m	(ft)
29	Mudstone, light brown-grey, silty to sandy, and minor coaly shale, woody	1627.6	(5340)	12	(40)
28	Sand, very fine grained, speckled grey, well sorted, in part carbonaceous	1639.8	(5380)	6	(20)
27	Mudstone, light brown-grey, silty to sandy	1645.9	(5400)	12	(40)
26	Sand, speckled grey, fine to medium grained, well sorted, angular to subangular, with minor coaly shale, black	1658.1	(5440)	12	(40)
25	Probably soft mudstone predominantly. Very poor samples	1670.3	(5480)	79	(260)
24	Sand, medium to very coarse grained, chert-rich; sandstone, argillaceous, fine to coarse grained, and calcareous in part; minor mudstone interbeds, calcareous in part	1749.5	(5740)	15	(50)
23	Sand, fine grained, pyritic in part, grading into sandstone, moderately sorted, carbonaceous, porous; interbedded mudstone, light grey, in part carbonaceous, calcareous	1764.7	(5790)	21	(70)
22	Mudstone, dark grey, carbonaceous, in part coaly or calcareous, in part sandy	1786.1	(5860)	6	(20)
21	Probably soft mudstone, light to medium grey, silty to sandy in part; small, poor samples	1792.2	(5880)	55	(180)
20	Mudstone, dark brown-grey, carbonaceous, with sand streaks, fine grained, in part weakly cemented; traces of pyrite	1847.0	(6060)	43	(140)
19	Mudstone, as above, with minor coaly wood fragments, and interbedded sandstone, in part pyrite, fine grained, and in part calcareous; tight; minor argillaceous siltstone	1889.7	(6200)	18	(60)
18	Mudstone, dark grey-brown, carbonaceous, with coaly streaks and silty layers grading into siltstone and argillaceous sandstone	1908.0	(6260)	46	(150)
17	Mudstone, tan to dark grey-brown, with silt, sand, and sandstone laminae; coaly wood fragments common	1953.7	(6410)	27	(90)
16	Mudstone, light brown-grey, silty and sandy, with interbedded sandstone, silty to fine grained, friable light grey, quartz-rich, moderately well sorted	1981.2	(6500)	27	(90)
15	Siltstone, light brown, calcareous, sandy, grading into sandstone, very fine grained, slightly argillaceous; coaly wood and resin fragments present	2008.6	(6590)	18	(60)
14	Sandstone, light grey, very fine to fine grained, friable, mainly quartzose, with interbedded mudstone, dark grey, silty, carbonaceous, in part calcareous	2026.9	(6650)	21	(70)
13	Mudstone, as above, containing coaly wood and resin, carbonaceous mainly, and siltstone, calcareous, grading into sandstone, very fine grained, calcareous or argillaceous, tight	2084.2	(6720)	24	(80)
12	Mudstone, dark grey, carbonaceous, in part coaly; minor silty sandstone, as above	2072.6	(6800)	15	(50)
11	Siltstone, carbonaceous, grading into sandstone, very fine grained, calcareous; minor tan or carbonaceous mudstone with coaly fragments and resin grains	2087.8	(6850)	12	(40)
10	Mudstone, carbonaceous to coaly, sandy streaks, minor siltstone; resin and shell fragments	2100.0	(6890)	31	(100)
9	Mudstone, dark grey, coaly, with coal streaks, resinous, cuticular matter; rare argillaceous siltstone and chert-granule sand, fine to coarse grained	2130.5	(6990)	21	(70)
8	Probably mudstone, dark grey, carbonaceous, resinous, with minor sandstone, silty to fine grained with minor grey chert, angular to subrounded, clayey	2151.8	(7060)	15	(50)

Unit	Lithology	Top of depth interval m	(ft)	Thickness m	(ft)
7	Very poor samples. Probably mainly mudstone, soft, silty to sandy, quartzose	2167.1	(7110)	92	(300)
6	Mudstone, grey, silty, in part carbonaceous, with minor calcareous siltstone and friable sandstone, very fine to fine grained, grey, speckled	2258.5	(7410)	21	(70)
5	Sandstone, pale brown-grey, very fine grained, silty, argillaceous, and minor mudstone, light grey	2279.9	(7480)	6	(20)
4	Silty clay, soft, grading into mudstone, with minor sand, very fine grained; poor samples	2286	(7500)	21	(70)
3	Sand, speckled, medium grained, silty, clayey	2307.3	(7570)	3	(10)
2	Siltstone, in part carbonaceous, and carbonaceous shale, dark grey	2310.3	(7580)	9	(30)
1	Shale, dark grey, carbonaceous to coaly, with light brown-grey mudstone having sandy streaks, very fine to fine grained. Very poor samples, residues of sand only to 8050 feet	2319.5	(7610)	61	(200)

Contact with Richards Formation picked at 2366 m (7810 ft), based on well logs.

Section 3. Description of type section of the *Ivik Member, Kugmallit Formation*, as expressed in sample cuttings, cores, and well logs of the Imperial Ivik J-26 well located on Richards Island at Lat. 69°35'42"N, Long. 134°20'38"W. The depth-interval considered to be representative of the Ivik Member is 2054-2943 m (6735-9550 ft). Samples generally poor; logged by F.G. Young, Mar. 1974, samples stored at Institute of Sedimentary and Petroleum Geology, Calgary. Spud date: April 8, 1972. Rig release: Sept. 30, 1972. K.B. elv.: 30.3 m (100 ft).

Unit	Lithology	Top of depth interval m	(ft)	Thickness m	(ft)
	Kugmallit Formation				
	Ivik Member (type section) 859 m (2815 ft)				
	Upper contact with Arnak Member gradational				
30	Mudstone, silty, baked in sample preparation, with interbedded sandstone, brown, silty, fine grained, in part calcareous, tight	2052.8	(6735)	59	(195)
29	Sandstone, brown, very fine grained, calcareous, tight, slightly chert-rich; possibly some coarser grades; interbedded minor mudstone, in part silty	2112.2	(6930)	21	(70)
28	Mudstone probably dominant, soft, pale brown-grey, in part sandy, micromicaceous; minor sandstone, as above, and in part bituminous, argillaceous	2133.6	(7000)	15	(50)
27	Sandstone, dominant at top of unit, giving way to dominantly mudstone towards its base; sandstone, brown, very fine grained, calcareous, in part bituminous, argillaceous, dark grey, tight; minor granular conglomerate with white quartz clasts	2148.8	(7050)	37	(120)
26	Sand, medium to very coarse grained, with minor calcareous, fine grained, tight sandstone	2185.4	(7170)	34	(110)
25	Sandstone, light grey, speckled, very fine to medium grained, silica and calcite cemented	2218.9	(7280)	12	(40)
24	Mudstone, sandy, light brown-grey, soft, with minor interbedded sandstone, as above, and some poor to moderately sorted, silica cement more common	2231.1	(7320)	21	(70)
23	Sandstone, brown, in part calcareous, very fine to fine grained, argillaceous, in part coarse grained, poorly sorted; minor interbedded mudstone and siltstone, some sandy, rare resin (amber) grains	2252.4	(7390)	40	(130)
22	Mudstone, silty, sandy, carbonaceous, and siltstone, pale grey-brown, trace ironstone; minor sandstone, brown, fine grained, tight, with coaly fragments	2292.0	(7520)	24	(80)
21	Sandstone, pale brown-grey, very fine to medium grained, calcareous, chert and quartz mainly, rare porosity; minor siltstone and argillaceous sandstone at top of unit	2316.4	(7600)	61	(200)
20	Sandstone, light grey, speckled, fine to medium grained, slightly calcareous, silica cement, with few mudstone interbeds, and sand-streaked	2377.4	(7800)	31	(100)
19	Probably mudstone and siltstone, dark brown, in part sandy; very poor samples	2407.9	(7900)	58	(190)
18	Sand, grading into sandstone, friable, medium grained, chert and quartz, in part very coarse grained, fine pebbly, porous, oil-bearing unit; minor interbedded mudstone, light to medium grey, silty, sand streaks, coal fragmental laminae, with bioturbation, slump structures in part. (Core observations)	2465.8	(8090)	21	(70)
17	Interbedded sandstone, fine grained, in part clayey, and mudstone, silty, light grey, with bands and mottles of sand, including burrow-fillings; coaly lamellae common, with resin grains; sandstone burrowed largely. (Core observations)	2487.1	(8160)	11	(35)

Unit	Lithology	Top of depth interval m	(ft)	Thickness m	(ft)
16	Interbanded silty sandstone and silty mudstone, with minor expandable clay laminae; bioturbated fabric throughout, mottled; coaly fragments abundant. (Core observations)	2497.8	(8195)	47	(155)
15	Sandstone, dark grey, very fine to fine grained, argillaceous, grading into sandy mudstone containing coal and resin (amber) fragments	2545.0	(8350)	15	(50)
14	Mudstone, grey, soft, hardly preserved in cuttings	2560.3	(8400)	14	(45)
13	Sandstone, light grey, fine to medium grained, weakly cemented by silicia, in part porous; minor soft shale	2574.0	(8445)	8	(25)
12	Mudstone, grey, in part sandy and coaly, with some siltstone, bituminous, many very poor samples	2581.6	(8470)	41	(135)
11	Sandstone, fine grained, well sorted, minor siliceous cement, porous, oil-bearing, quartz with minor chert; interbeds of silty and sandy mudstone 8640-8680 ft; becomes very fine grained, laminated toward base	2622.8	(8605)	45	(148)
10	Interbedded sandstone, very fine grained, laminated, and mudstone, silty, in part laminated, in part bioturbated, minor convolutes, minor coaly laminae, scattered coal and resin (amber) fragments. (Core observations)	2667.9	(8753)	9	(29)
9	Interbedded mudstone, light grey, convoluted, in part silty and sandy, and silty sandstone in irregular lenses; woody coal fragments, rare floating chert pebbles, no burrows. (Core observations)	2676.7	(8782)	3	(11)
8	Sandstone, fine to medium grained, rare coarse grained layers, becoming finer grained below 8805 feet, chert and quartz composition, minor clay cement, porous, indistinct lamination; rare mudstone interbeds, in part sideritic, with sand lenses and mottles. (Core observations)	2680.1	(8793)	10	(32)
7	Sandstone, silty, very fine grained, alternating graded beds, consisting of plane-beds at bases and bioturbated, argillaceous sandstone above; rare coaly laminae. (Core observations)	2689.8	(8825)	6	(20)
6	Silty mudstone, grey, soft, with isolated sand lenses and beds, much bioturbation and slumping; samples very poor	2695.9	(8845)	108	(355)
5	Mudstone, light brown-grey, silty, in part dark grey, bituminous, some coarse sand, with red-coated quartz grains	2804.1	(9200)	40	(130)
4	Interbedded shale and sandstone, coarse grained, and chert-pebble conglomerate; carbonaceous, silty sandstone, very fine grained, tight, common at base of unit	2843.7	(9330)	12	(40)
3	Sandstone, very fine grained, well sorted, porous, interbedded with brown, silty, argillaceous sandstone, indurated, coaly laminae abundant	2855.9	(9370)	21	(70)
2	Mudstone, medium grey, silty, in part sandy and carbonaceous	2877.3	(9440)	18	(60)
1	Sandstone, very fine grained in part, fine to medium grained in part, porous, poorly consolidated; carbonaceous laminae common. Base of Ivik Member	2895.6	(9500)	15	(50)
	Abrupt contact with Richards Formation	2910.8	(9550)		

Section 4. Type section of the *Mackenzie Bay Formation*, as penetrated in the Shell Kumak E-58 well (Lat. 69°17'29"N, Long. 135°14'55"W). Descriptions are based on hand-washed and air-dried cuttings samples (10-foot sampling intervals in well-bore) and well-logs. Borehole was drilled toward the southwest to a point under present distributary channel. Directional surveys indicate angles from true vertical increase gradually from 13° at upper contact to 50° at lower contact. In the descriptions that follow, uncorrected borehole depth-intervals, but corrected thicknesses based on true vertical depth calculations, are given. The interval 710 to 1510 feet (216-460 m) in the neighbouring Shell Kumak C-58 borehole is designated as a reference section; its electric log appears in Figure 7. Samples stored at Institute of Sedimentary and Petroleum Geology, Calgary. Shell Kumak E-58: Spud date: Feb. 28, 1977. Rig release: June 8, 1977. K.B. elv.: 10.7 m (35 ft).

Unit	Lithology	Top of depth interval m	(ft)	Thickness Uncorrected ft	Corrected m	(ft)
	Sand, quartzose, fine grained, and interbedded gravel, chert and carbonate granules (Nuktak Formation)					
	Abrupt, erosional contact					
	Mackenzie Bay Formation (type section) (total corrected thickness: 1300 ft or 396.5 m)					
22	Mudstone, light brown-grey, sandy, fine grained, chert and quartz grains, with rare sandstone, very fine to fine grained, friable, well sorted	252.9	(830)	50	15.3	(50)
21	Mudstone, light grey, friable, slightly sandy, fine grained; rare carbonaceous plant fragments, clay-rich laminae, sand streaks	268.2	(880)	150	43.5	(143)
20	Mudstone, light brown-grey, sandy, very fine- to fine-grained sand laminae, rarely coarse grained; rare carbonaceous streaks, plant fragments	313.9	(1030)	120	32.6	(107)
19	Sand, fine grained with some coarser, and interbedded mudstone, friable; quartz and chert in equal proportions in sand	350.5	(1150)	15	4.0	(13)
18	Mudstone, light grey-brown, in part sandy, very fine to fine grained, rare very coarse grains and granules, rare carbonaceous mud	355.0	(1165)	35	9.4	(31)
17	Mudstone, light grey-brown, sandy, very fine to medium grained, with minor sandstone, argillaceous mud	365.7	(1200)	50	12.7	(42)
16	Mudstone, light grey, silty, sandy in part, very fine to fine grained; rare chert granules	381	(1250)	40	10.2	(33)
15	Mudstone, light grey, slightly fissile, slightly silty, with rare sand	393.1	(1290)	30	7.2	(24)
14	Mudstone, light grey, sandy in part, fine grained mainly with some coarse; rare carbonized wood fragments; slightly bentonitic in part	402.3	(1320)	130	30.0	(98)
13	Mudstone, light grey, fine grained sandy mainly, some chert granules; rare pyritic rods and pyritic, greenish black mudstone	441.9	(1450)	50	11.1	(37)
12	Mudstone, light grey, silty, in part sandy, fine to medium grained, minor coarse grained to granular chert; minor greenish black mudstone, firm, pyritic; rare pyrite tubes and rods and carbonized plant fragments	457.2	(1500)	360	72.2	(237)
11	Mudstone, as above, sandy, coarse grained to granular chert common; charred wood and pyritic patches present rarely	566.9	(1860)	100	19.2	(63)
10	Mudstone, light brown-grey, rarely green-grey, subfissile, in part sandy, fine to very coarse grained, rare coaly fragments, slightly bentonitic (caked habit)	597.4	(1960)	90	17.6	(58)
9	Mudstone, light brown-grey, silty to very fine sandy, minor coarse sand, probably bentonitic (caked habit)	624.8	(2050)	90	17.8	(59)
8	Mudstone, as above, with chert granules and pebbles present	652.2	(2140)	40	8.1	(26)
7	Mudstone, as Unit 9	664.4	(2180)	40	8.1	(26)

Unit	Lithology	Top of depth interval m	(ft)	Thickness Uncorrected ft	Corrected m	(ft)
6	Mudstone, light grey, subfissile, silty and sandy, very fine- to very coarse-grained quartz and chert sand, minor chert granules and pebbles, slightly bentonitic (caked habit)	676.6	(2220)	80	16.1	(53)
5	Mudstone, as above, with rare pebbles and dark green shale	701.0	(2300)	40	7.9	(26)
4	Mudstone, light brown-grey, shaly, silty, in part sandy, with interbedded pea gravel composed mainly of chert and quartzite and similar coarse grained sand	713.2	(2340)	60	11.9	(39)
3	Mudstone, light grey, silty, sandy, very fine to coarse grained, rare sand laminae and thin beds, rare coaly particles	731.5	(2400)	160	32.3	(106)
2	Mudstone, as above, with 50 per cent sand, medium to very coarse grained, chert-dominant	780.2	(2560)	25	5.1	(17)
1	Sand, medium to very coarse grained, chert-dominant, in part very argillaceous	787.9	(2585)	15	3.1	(10)
	Abrupt, unconformable contact	792.4	(2600)			
	Underlying beds: shale, medium grey, silty, micaceous, slightly sandy, of Richards Formation					

Section 5. Type section of the *Nuktak Formation*, as drilled and sampled in the Imperial Nuktak C-22 well on Hooper Island, at Lat. 69°41'07"N, Long. 134°51'30"W. Sampling interval: 30 feet (9.2 m) throughout Nuktak Formation; samples of poor to fair quality. Samples stored at Institute of Sedimentary and Petroleum Geology, Calgary. Imperial Nuktak C-22: Spud date: Dec. 16, 1972. Rig release: Mar. 8, 1973. K.B. elev.: 47.3 m (156 ft).

Unit	Lithology	Top of depth interval m	(ft)	Thickness m	(ft)
	Borehole poorly sampled in top 6 m (20 ft); may be thin Holocene or Late Pleistocene sediments				
	Nuktak Formation (type section) 550 m (1800 ft)				
21	Mud, dark brown, plant and wood fragments, mica flakes	0	(0?)	36	(120)
20	Sand, fine to very coarse grained, composed of quartz (pink and orange commonly), sandstone, shale, and chert grains, containing charcoal, ostracods, and braded radulae of molluscs	36.5	(120)	9	(30)
19	Sand, as above, with interbedded sandy mud, brown, containing ostracods and foraminifers, in part expanding clays	45.7	(150)	31	(100)
18	Mudstone, light brown, sandy, in part ferruginous, with abundant wood, plant, and shell debris	76.2	(250)	24	(80)
17	Interbedded sand, of various grades, and mudstone, as above, containing mica, wood, shale fragments, ostracods, and beetle carapaces	100.5	(330)	18	(60)
16	Mudstone, light grey-brown, silty, very fine-grained sandy, with rare sand lenses and floating chert pebbles, and containing mica, small foraminifers, ostracods, shell and wood fragments	118.8	(390)	34	(110)
15	Mudstone, light grey, silty, containing abundant wood debris and beds of woody peat; mica flakes common, rare foraminifers; many poor samples	152.4	(500)	46	(150)
14	Mudstone, medium brown-grey, sandy, silty, carbonaceous in part, with abundant wood and peat; minor medium- to coarse-grained sand interbeds	198.1	(650)	43	(140)
13	Sand, medium grained, well sorted, quartz mainly, also chert, hard shale, common pink to orange grains; minor carbonaceous shale, dark grey; rare ostracods, mica flakes	240.7	(790)	24	(80)
12	Claystone, shaly, dark grey, carbonaceous, woody, with very minor sandstone, very fine grained, quartz and chert grains, porous	265.1	(870)	31	(100)
11	Claystone, medium brown, light olive, plant-rich, possibly some peat layers	295.6	(970)	9	(30)
10	Sand, medium to coarse grained, moderately sorted, quartz-dominant, with black shale and chert	304.8	(1000)	9	(30)
9	Claystone, light yellow-brown, micromicaceous, sandy in part (seat earth), containing shell fragments, teeth(?), pebbles	313.9	(1030)	15	(50)
8	Sand, medium to very coarse grained, granular in part; colourless and salmon-coloured quartz, chert, shale; in part lightly cemented by clay and hematite	329.1	(1080)	9	(30)
7	Sand, as above, with mudstone, carbonaceous, plant-rich, silty; rare ostracods and beetles	338.3	(1110)	58	(190)
6	Shale, dark grey, coaly mainly, some silty, medium grey shale, and sand, fine to medium grained	396.2	(1300)	9	(30)
5	Mudstone, medium brown, sandy, plant fragmental, with minor interbedded sand, fine to medium grained, quartz and chert, some salmon coloured	405.3	(1330)	9	(30)

Unit	Lithology	Top of depth interval m	(ft)	Thickness m	(ft)
4	Sand, pale brown, speckled, fine to medium grained, well sorted, quartzose; minor coarse sand and gravel, plant fragments	414.5	(1360)	29	(95)
3	Mudstone, light grey-brown, sandy, with interbeds of clayey sandstone, mainly fine grained, with chert pebbles, salmon colours rare; plant fibres present	443.4	(1455)	24	(80)
2	Mudstone, light grey, silty, micromicaceous, in part sandy, as above, in part dark brown, carbonaceous; minor sand, medium to coarse grained	467.8	(1535)	20	(65)
1	Sand, medium to coarse grained, granules and pebbles common in some beds, quartz and chert, rounded; with alternating beds of mudstone, as above, containing mineralized wood fragments; gravel of chert and quartzite in lowest few metres	487.6	(1600)	61	(200)
	Abrupt contact with mudstone of Mackenzie Bay-Beaufort Formation	548.6	(1800)		

SCHEDULE OF WELLS

		Spudded	Completed	T.D. (metres)	Status
1.	BA Shell IOE Reindeer D-27	09/07/65	05/01/66	3861	Dry and abandoned
2.	IOE BA Shell Tununuk K-10	13/08/68	16/06/69	3757	Dry and abandoned
3.	IOE Ellice O-14	19/11/69	04/02/70	2905	Dry and abandoned
4.	Gulf East Reindeer P-60	17/03/70	19/04/70	1920	Dry and abandoned
5.	Shell Beaverhouse Ck. H-13	23/11/70	17/03/71	3748	Dry and abandoned
6.	IOE Taglu G-33	13/04/71	18/08/71	2994	Gas
7.	Gulf Mobil East Reindeer A-01	09/05/71	19/06/71	2954	Dry and abandoned
8.	IOE Taglu West P-03	12/12/71	06/03/72	3310	Suspended gas
9.	IOE Mallik L-38	24/12/71	05/04/72	2532	Gas
10.	Gulf Mobil Kilagmiotak F-48	04/02/72	21/08/72	4772	Temporarily suspended
11.	IOE Taglu D-55	06/04/72	16/07/72	3706	Abandoned; temperature observation
12.	Imperial Ivik J-26	08/04/72	30/09/72	3648	Temperature observation
13.	Imperial Mallik A-06	21/04/72	14/09/72	4137	Dry and abandoned
14.	IOE Taglu C-42	30/04/72	05/09/72	4895	Suspended gas
15.	Shell Unipkat I-22	08/09/72	06/03/73	4361	Observation suspended
16.	Gulf *et al.* Titalik K-26	17/10/72	21/01/73	3840	Potential gas
17.	Shell Niglintgak H-30	24/10/72	07/04/73	2383	Suspended gas
18.	Gulf Mobil Ya Ya P-53	08/12/72	17/03/73	3033	Suspended gas
19.	Imperial Nuktak C-22	16/12/72	08/03/73	3857	Dry and abandoned
20.	Imperial Umiak J-37	17/12/72	22/02/73	3633	Dry and abandoned
21.	Imperial Ivik C-52	19/12/72	07/02/73	3048	Dry and abandoned
22.	Imperial Mallik P-59	30/12/72	22/02/73	2632	Dry and abandoned
23.	Imperial Ivik N-17	10/01/73	15/03/73	3049	Dry and abandoned
24.	Chevron SOBC Upluk C-21	19/02/73	19/05/73	1637	Dry and abandoned
25.	Gulf Imperial Shell Reindeer F-36	13/03/73	05/06/73	1829	Suspended gas
26.	IOE Taglu F-43	23/03/73	19/06/73	4555	Suspended gas
27.	Shell Kugpik O-13	26/03/73	30/08/73	3688	Dry and abandoned
28.	Imperial Ivik K-54	30/03/73	22/05/73	3151	Dry and abandoned
29.	Imperial Langley E-29	08/04/73	29/06/73	3810	Dry and abandoned
30.	Gulf Mobil Ikhil I-37	10/04/73	15/10/73	4704	Dry and abandoned
31.	Shell Kumak C-58	25/04/73	19/10/73	3530	Dry and abandoned
32.	Imperial Immerk B-48	17/09/73	10/12/73	2708	Dry and abandoned
33.	Shell Unak B-11	07/11/73	17/03/74	3345	Dry and abandoned
34.	Shell Kumak J-06	24/11/73	01/05/74	3481	Suspended oil
35.	Gulf Mobil Toapolok O-54	27/11/73	01/04/74	2786	Dry and abandoned
36.	Gulf Imperial Shell Reindeer A-41	22/12/73	20/01/74	1829	Dry and abandoned
37.	Imperial Adgo F-28	28/12/73	19/03/74	3209	Plugged oil and gas
38.	Chevron SOBC Upluk M-38	07/02/74	04/03/75	3764	Dry and abandoned
39.	Gulf Mobil Ya Ya A-28	28/02/74	06/07/74	3944	Gas
40.	Imperial Pullen E-17	21/04/74	11/07/74	3885	Dry and abandoned
41.	Gulf Mobil Toapolok H-24	21/04/74	15/06/74	2623	Dry and abandoned
42.	Shell Niglintgak M-19	01/06/74	20/01/75	4025	Oil and gas
43.	Shell Kipnik O-20	14/07/74	21/11/74	3556	Dry and abandoned
44.	Sun BVX *et al.* Unark L-24	26/09/74	24/05/75	3813	Dry and abandoned
45.	Sun BVX *et al.* Pelly B-35	05/11/74	14/02/75	3328	Dry and abandoned
46.	Gulf Mobil Ya Ya I-17	22/11/74	11/01/75	2682	Dry and abandoned
47.	Gulf Mobil Ya Ya M-33	22/11/74	13/02/75	2789	Dry and abandoned
48.	Gulf Mobil Kikoralok N-46	20/12/74	25/01/75	1877	Dry and abandoned
49.	Imperial Adgo P-25	02/01/75	28/03/75	2538	Abandoned oil and gas
50.	Imperial Netserk B-44	06/01/75	08/06/75	3528	Dry and abandoned
51.	Shell Kugpik L-24	03/02/75	11/04/75	2817	Dry and abandoned
52.	Shell Kumak K-16	23/02/75	15/07/75	3709	Oil and gas
53.	Gulf Mobil Ogeoqeoq J-06	23/02/75	13/03/75	1839	Dry and abandoned
54.	Gulf Mobil Kilagmiotak M-16	24/02/75	01/04/75	3154	Dry and abandoned
55.	Imperial Adgo C-15	21/04/75	28/07/75	3193	Dry and abandoned
56.	Shell *et al.* Titalik O-15	21/04/75	21/08/75	3383	Dry and abandoned
57.	Sun *et al.* Garry P-04	25/08/75	05/01/76	3352	Potential oil and gas
58.	Imp. Ikattok J-17	07/10/75	28/02/76	3810	Dry and abandoned
59.	Shell Niglintgak B-19	18/10/75	22/02/76	3144	Oil and gas
60.	SOBC Can. Sup *et al.* North Ellice J-23	22/10/75	15/03/76	3505	Dry and abandoned
61.	Imp. Netserk F-40	08/11/75	09/05/76	4370	Potential oil and gas
62.	Shell Ulu A-35	15/03/76	22/09/76	3919	Temperature observation
63.	Imp. Sarpik B-35	02/04/76	04/09/76	3291	Dry and abandoned
64.	Gulf Imp. Shell Tununuk F-30	05/04/76	06/07/76	3642	Dry and abandoned
65.	Imp. Kugmallit H-59	30/09/76	10/11/76	2193	Dry and abandoned
66.	Imp. Arnak L-30	05/10/76	16/03/77	4523	Dry and abandoned
67.	Shell Tullugak K-31	18/10/76	01/04/77	2926	Dry and abandoned
68.	Imp IOE Taglu H-54	02/12/76	05/04/77	2793	Suspended gas
69.	Imp. Delta 5 Kurk M-39	16/12/76	09/03/77	3108	Dry and abandoned
70.	CCL Upluk A-42	15/01/77	02/04/77	2794	Dry and abandoned
71.	Shell Kumak E-58	28/02/77	08/06/77	1554	Suspended gas
72.	Imp. IOE Umiak N-10	13/04/77	02/10/77	4814	Dry and abandoned
73.	Gulf Mobil Ogruknang M-31	18/04/77	01/08/77	4429	Dry and abandoned
74.	Chevron Pex *et al.* Fish River B-60	21/06/77	31/10/77	3502	Dry and abandoned