GEOLOGICAL SURVEY OF CANADA
COMMISSION GÉOLOGIQUE DU CANADA

PAPER 80-32

GEOLOGY AND BIOSTRATIGRAPHY OF THE DOME GULF ET AL. UKALERK C-50 WELL, BEAUFORT SEA

D.H. McNEIL,
N.S. IOANNIDES,
J. DIXON

Canada

1982

PAPER 80-32

GEOLOGY AND BIOSTRATIGRAPHY OF THE DOME GULF ET AL. UKALERK C-50 WELL, BEAUFORT SEA

D.H. McNEIL,
N.S. IOANNIDES,
J. DIXON

1982

Available in Canada through

authorized bookstore agents
and other bookstores

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Hull, Québec, Canada K1A 0S9

and from

Geological Survey of Canada
601 Booth Street
Ottawa, Canada K1A 0E8

A deposit copy of this publication is also available
for reference in public libraries across Canada

Cat. No. M44-80/32E Canada: $4.00
ISBN 0-660-11135-7 Other countries: $4.80

Price subject to change without notice

Critical Readers

J.H. Wall
W.S. Hopkins

Authors' Addresses

D.H. McNeil
Institute of Sedimentary and Petroleum Geology
3303 33rd St. N.W.
Calgary, Alberta T2L 2A7

N.S. Ioannides
Esso E.P.R.E.
213 Cours Victor Hugo
33321 Begles, France

J. Dixon
Institute of Sedimentary and Petroleum Geology
3303 33rd St. N.W.
Calgary, Alberta T2L 2A7

Original manuscript submitted: 80-10-22

Approved for publication: 81-12-08

Cartography by CARTOGRAPHY UNIT
Institute of Sedimentary and Petroleum Geology
Calgary, Alberta T2L 2A7

CONTENTS

GEOLOGY AND BIOSTRATIGRAPHY OF THE DOME GULF ET AL. UKALERK C-50 WELL, BEAUFORT SEA

Abstract

The Dome Gulf et al. Ukalerk C-50 well was drilled in 1977, 55 km offshore in the Beaufort Sea, in 27.7 m of water to a total depth of 2304.7 m. Gas was recovered from 2011.7-2017.8 m at a maximum rate of 476 473 m^3/day. The Tertiary section contains a major unconformity at 1571.5 m, identified from physical and biostratigraphic characteristics. A Late Miocene?-Pleistocene age is assigned to the post-unconformity section which consists of a lower mudstone-dominant section gradationally overlain by poorly consolidated to unconsolidated sandstone. These rocks are tentatively interpreted as an overall progradational succession with outer shelf muds at the base, gradationally succeeded by inner shelf muds and sand and finally by deltaic and fluvial sands. The pre-unconformity section is dated as Early to Middle Miocene below the unconformity, and Oligocene below about 2000 m. Pre-unconformity strata are dominantly mudstone with isolated sandstone-rich intervals and are probably of outer shelf origin.

The unconformity is regional and has been recognized in a number of other Beaufort Sea wells. It coincides with major changes in palynomorph and foraminiferal assemblages that record a significant cooling trend across the unconformity. Dating of the event that produced the unconformity is still tenuous but the most likely age is Late Miocene or Early Pliocene.

Résumé

Le puits Dome Gulf et al. Ukalerk C-50 a été foré en 1977 dans la mer de Beaufort à 55 km au large, et dans 27.7 m d'eau, jusqu'à une profondeur totale de 2304.7 m. Du gaz naturel a été récupéré entre 2011.7 et 2017.8 m avec un débit maximum de 476 473 m^3/jour. La section tertiaire comporte une importante discordance stratigraphique située à 1571.5 m, qui se distingue par ses caractères physiques et biostratigraphiques. On a daté au Miocène supérieur?-Pleistocène la section ultérieure à la discordance, consistant en un niveau inférieur principalement composé de mudstone et progressivement recouvert par un grès peu ou pas consolidé. On considère provisoirement ces roches comme une succession entièrement fermée par progradation, caractérisée à sa base par les boues de la plate-forme inférieure, par du sable, et finalement par des sables deltaïques et fluviatiles. On a daté la section antérieure à la discordance au Miocène inférieur à moyen immédiatement au-dessous de la discordance, et à l'Oligocène au-dessous jusqu'à environ 2000 m de profondeur. Les strates antérieures à la discordance sont principalement des mudstones, contenant des intervalles isolés gréseux, elles appartenaient probablement à la portion extérieure de la plate-forme continentale.

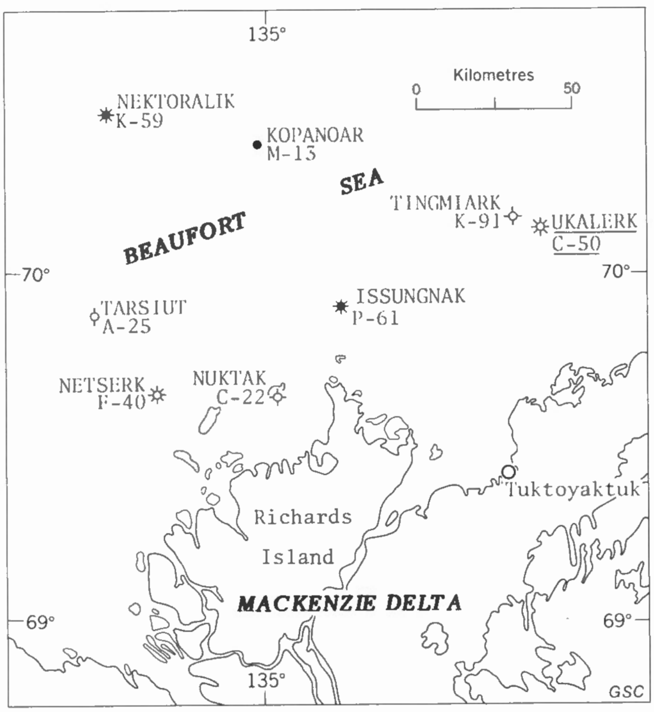
La discordance est un trait regional, observé dans un certain nombre d'autres puits de la mer de Beaufort. Elle coincide avec une importante modification des assemblages des palynomorphes et foraminifères, qui temoigne d'un important abaissement des températures, lorsque la discordance est traversée. Il est encore difficile de dater l'événement qui a engendré cette dernière mais l'âge le plus probable est le Miocène supérieur ou le Pliocène inférieur.

GEOLOGY AND BIOSTRATIGRAPHY OF THE DOME GULF ET AL. UKALERK C-50 WELL, BEAUFORT SEA

INTRODUCTION

The Dome Gulf et al. Ukalerk C-50 well was drilled in the Beaufort Sea during the summer of 1977, approximately 55 km offshore from the Mackenzie Delta in 27.7 m of water (Fig. 1). A total depth of 2304.7 m was attained before drilling problems were encountered which led to its abandonment. A new location, designated Ukalerk 2C-50, was drilled close by in 1978. The nearest other Beaufort Sea well is Dome Gulf et al. Tingmiark K-91, situated about 10 km to the northwest. The geology and geochemistry of the Dome Hunt Nektoralik K-59 well, located about 140 km to the northwest, has been reported on by Dixon and Snowdon (1979). Jones et al. (1980) described the geology and regional setting of the Nektoralik K-59 and Ukalerk C-50 wells.

This report presents the preliminary lithostratigraphic and biostratigraphic results of a study based on the sampled cuttings and mechanical logs of the Ukalerk C-50 well. The authors, in conjunction with others in the Geological Survey of Canada, are continuing to assess the geology of the Beaufort Sea -- a project which began in earnest with the work of Young et al. (1976) and which was spurred recently by petroleum discoveries in the Beaufort Sea, chiefly Dome



Oil and gas well.......................✷
Oil well..................................●
Gas well..................................☼
Dry (abandoned)........................-◊-
Suspended................................◊

FIGURE 1. Location map of Ukalerk C-50 and other offshore wells.

Petroleum Limited (Kopanoar M-13) and Imperial Oil Limited (Issungnak O-61). The current report on Ukalerk C-50 is an interim study which, in combination with future well studies, will contribute to the development of a stratigraphic framework for the offshore Beaufort-Mackenzie Basin linked to that of the Mackenzie Delta area where formal stratigraphic divisions have been established for the entire Cenozoic succession (Young and McNeil, in press).

GEOLOGY

The following account is a general description of the lithological succession based on sampled well-cuttings and geophysical logs (primarily the sonic/gamma logs). Depths are in metres (feet) and measured from Kelly Bushing (KB). Log and sample quality is highly variable due to the weakly consolidated sediments and consequent caving problems.

0-39.3 m (0-129 ft)
KB to sea bed.

39.3.-150.3 m (129-493 ft)
No samples or logs.

150.3-152.4 m (493-500 ft)
Sand: medium grained, pebbly. Contains abundant lignitic wood fragments.

152.4-304.8 m (500-1000 ft)
No samples or logs.

304.8-717.5 m (1000-2354 ft)
Sand and minor interbeds of mud. Cuttings entirely of sand but gamma-ray log indicates clay interbeds. Sand: dominantly fine grained but with some units of medium grained, pebbly sand in top 30 m of unit. Grains are rounded to subrounded, generally well sorted quartz and chert. Gamma-ray log indicates sand units are very thick, some in excess of 60 m. Broken bivalve shells are common in the upper part of the unit. Lignitic wood and black coaly fragments are also common.

717.5-990.6 m (2354-3250 ft)
Interbedded sandstone and mudstone. Sandstone: weakly cemented by clay minerals; dominantly fine grained, locally medium grained. Rounded to subrounded, moderately well sorted quartz and chert grains. Sandstone units are mostly 12 to 15 m thick separated by mudstone. From the character of the gamma-ray log, it is apparent that the sandstones are either relatively clean and thick or contain numerous mudstone or clay-rich intercalations. A pebbly sandstone occurs at 765-783.3 m, containing pebbles of pink or red siltstone, chert and sandstone in a medium grained sand matrix. Mudstone: weakly consolidated; medium grey; silty to sandy; slightly calcareous. Laminae and thin beds of sand or silt. Rare shell (?bivalve) fragments. Traces of limestone within the mudstone beds may represent carbonate concretions.

The lower contact of the unit is drawn at the base of a prominent 13.7 m thick sandstone bed abruptly overlying mudstone.

990.6-1109.5 m (3250-3640 ft)
Mudstone: weakly consolidated; medium grey; very slightly calcareous. Laminae and thin beds of sand or silt.

1109.5-1571.5 m (3640-5156 ft)
Interbedded mudstone (dominant) and sandstone. Mudstone: as above. Sandstone: fine to coarse grained. Rounded to subrounded, poorly sorted quartz and chert grains. Weakly cemented by calcite.

Gamma-ray log indicates unit consists of very thin sandstone beds, usually less than 5 m thick, interbedded with thicker mudstone beds.

----------unconformity----------

1571.5-1580.4 m (5156-5185 ft)
Limestone: light grey to white; very finely crystalline to cryptocrystalline. X-ray analysis indicates mostly calcite with lesser amounts of dolomite, quartz, feldspar, siderite and clay minerals. Logs indicate an abrupt upper contact and a gradational lower contact zone of limestone grading to calcareous mudstone to mudstone below.

1580.4-1991.0 m (5185-6532 ft)
Mudstone: medium grey; very silty; slightly calcareous; noticeably more consolidated than that above 1571.5 m.

Scattered quartz and chert grains in the samples suggest the presence of very thin sandstone beds (too thin for recognition on the logs).

1991.0-2024.5 m (6532-6642 ft)
Sandstone: very fine grained with scattered medium and coarse grains; moderately well sorted; subrounded quartz and chert grains. Unconsolidated to weakly cemented by clay, and rarely calcite. The gamma-ray log indicates an abrupt upper contact and a probably gradational base.

2024.5-2304.6 (T.D.) m (6642-7561 ft)
Mudstone with thin sandstone beds at 2237.2-2253.1 m (7340-7392 ft). Mudstone: medium to light grey; slightly calcareous; very silty. Traces of shell fragments (?bivalves). Rare, orange calcite crystals were noted in the samples between 2106.2-2109.2 m (6910-6920 ft). Chert and quartz sand grains in the samples probably indicate presence of very thin sandstone beds, too thin to be detected on the logs. Sandstone: very fine grained; moderately well sorted; rounded quartz and chert grains. Weakly cemented by clay minerals.

The succession at Ukalerk C-50 shows many similarities to that at Nektoralik K-59 (Dixon and Snowdon, 1979), 140 km to the west-northwest. Dixon and Snowdon compared the limestone at 1571.5 m in Ukalerk C-50 to a similar unit at Nektoralik K-59 and it was suggested that the limestone marks a prominent regional unconformity. Both palynological and foraminiferal assemblages (see later discussion) show abrupt changes above and below the limestone, suggesting a major break in stratigraphy. Also, the mudstones below the unconformity are noticeably more cohesive and strongly lithified in comparison to those above. A velocity profile (Fig. 2) for Ukalerk C-50 shows an abrupt velocity change at 1571.5 m, coincident with the interpreted unconformity. Unlike the K-59 well, the unconformable horizon in C-50 is not within the overpressured zone, hence the break between the velocity gradients above and below the unconformity is not masked, as in K-59.

The post-unconformity succession is similar to that at Nektoralik K-59: a sand-dominant upper part overlying a mudstone-rich lower part. Dixon and Snowdon (1979) interpreted this succession at K-59 as deposits of a prograding shelf edge and continental slope, based primarily on the presence of shelf-slope clinoforms recognized on a published seismic line. At Ukalerk C-50, the apparent landward location, a higher percentage of sand and the presence of coaly material in part of the section favours a shelf to deltaic setting. The vertical succession of mudstone gradationally overlain by sandstone and the lack of clinoform reflectors (see Jones et al., fig. 12, 1980) would suggest a prograding delta system, with prodelta and shelf muds at the base overlain by coastal, deltaic and fluvial sands. These conclusions are supported, in part, by the associated foraminiferal assemblages. Jones et al. (1980, p. 90) named the post-unconformity section Iperk Group, with type section in the Ukalerk C-50 well. Designation as a formal unit is perhaps premature as the group lacks formational divisions and is described on scant knowledge of the succession and its correlation through the basin. Jones et al. (1980, fig. 3) assigned a Miocene to Recent age to the Iperk Group. A more detailed analysis of the foraminifers and palynomorphs recovered from Ukalerk C-50 (see following discussion on biostratigraphy) indicates that a Late Miocene or Early Pliocene to Recent age span is more likely and that Early to Middle Miocene strata immediately underlie the unconformity rather than Oligocene strata as indicated by Jones et al. (1980).

The pre-unconformity section at Ukalerk C-50 is also lithologically similar to that at Nektoralik K-59: mudstone-

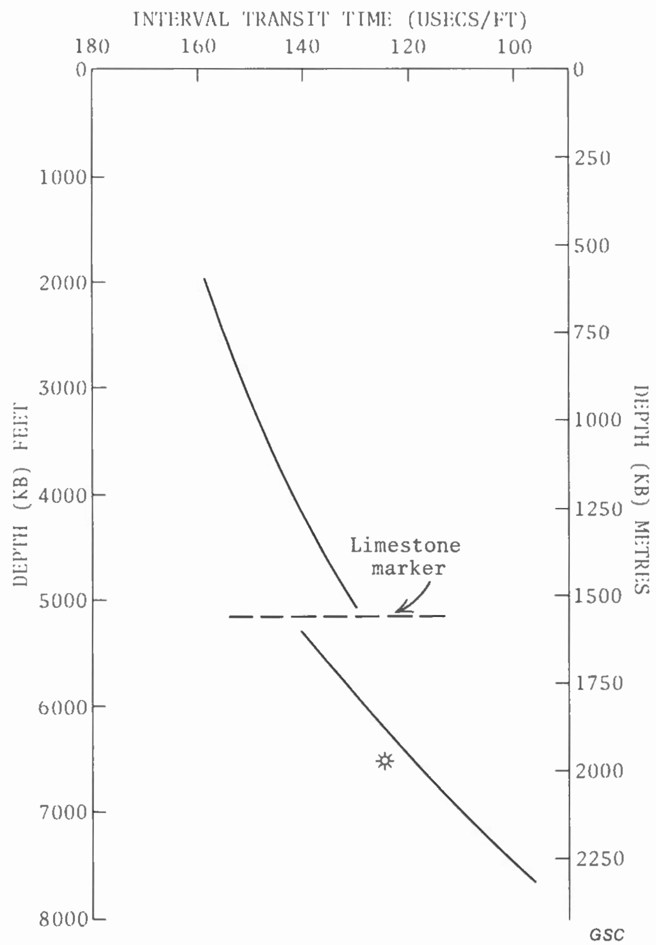


FIGURE 2. *Depth-interval transit time profile, Ukalerk C-50.*

dominant with some sandstone beds. At K-59, this section was interpreted to be of outer shelf to abyssal plain origin but the landward position of the C-50 well would favour a shelf setting, probably outer shelf. The interpretations based on foraminifers tend to support this hypothesis.

Hydrocarbons were recovered from a sandstone in the pre-unconformity section (1991-2024.5 m). Gas was recovered from a drillstem test at 2011.7-2017.8 m and flowed at a maximum rate of 476 473 m^3/day. The test was near the base of the sandstone unit and, as no water was reported in the test data, a gas-saturated reservoir is indicated. The sandstone is weakly cemented by detrital clay and silt with only small amounts of authigenic clay, calcite and quartz overgrowths (Fig. 3). Porosities are high (Fig. 3), between 24 and 30 per cent, according to the density log. Most of these high porosities are in the top 26.8 m of the sandstone unit. Shut-in pressures from the drillstem test data indicate the sandstone to be very permeable.

BIOSTRATIGRAPHY

Introduction

Mid to late Cenozoic foraminiferal and palynomorph assemblages have been recovered from sampled cuttings of the Ukalerk C-50 well. The succession is divided into unnamed biostratigraphic divisions, each characterized by a particular fossil assemblage. The distribution of taxa is recorded in Figure 4 and representative species are illustrated in Plates 1 to 4.

The fossil succession in Ukalerk C-50 is broken by a major discontinuity at 1572.8 m (5160 ft). The discontinuity has been recognized in many other wells in the Beaufort Sea, such as the Nektoralik K-59, and is interpreted as a regional unconformity. Due to the prominence of the unconformity, its age and significance are discussed at some length here, prior to the more detailed account of the fossil assemblages that follows. The cause of the unconformity is not known, but it may be no mere coincidence that its estimated age approximates the Late Miocene eustatic drop in sea-level that has been documented widely in Deep Sea Drilling Reports and effectively portrayed by Vail et al. (1977).

In the section just below the unconformity, a rich foraminiferal assemblage is dated tentatively as Early to Middle Miocene and dominated by **Asterigerina guerichi s. l.** (Franke) and **Trifarina fluens** Todd. A complete faunal change occurs above the unconformity where cool-water, Late Miocene? to Pleistocene foraminiferal assemblages prevail, dominated by **Cassidulina teretis** Tappan and **Elphidium clavatum** Cushman.

An equally dramatic shift in the microfloral spectrum occurs at the unconformity. Below, a mixed assemblage of mainly deciduous, coniferous, and bryophyte palynomorphs was recovered, signifying cool-temperate conditions. Above, the components are mainly coniferous and bryophyte. The disappearance of deciduous pollen marks the onset of a major cooling event, maintained to the present day, judging from the continuous recovery of coniferous and bryophyte palynomorphs above the unconformity in the Beaufort Sea wells.

Neither the time of the local extinction of the deciduous forest, nor the duration of time represented by the unconformity have been established due to the lack of chronostratigraphic indices immediately above and below the unconformity. A time-framework, however, can be constructed on the basis of major climatic, oceanographic, and tectonic events.

It is known from the dating of sediments containing ice-rafted debris in the Arctic Ocean (Clark, 1971) and the Labrador Sea (Berggren, 1972) and from tillites in Iceland (McDougall and Wensink, 1966) that the first Arctic continental glaciation began approximately 3 m.y. ago. This date represents a likely minimum age for the post-unconformity sequence in the Ukalerk C-50 well. The Arctic Ocean record is still poorly known. Clark (1977, p. 62) stated that the first confirmed glacial sediments in the Arctic Ocean basin were 5 to 6 m.y. old and that probably an ice-cover had formed by that time. Herman (1978, p. 420) considered that polar conditions were established in the Arctic Ocean approximately 4 m.y. ago.

Tectonic activity to the southwest of the Beaufort Sea no doubt had a profound affect on the local climate which led to the floral differentiation observed in the Ukalerk C-50

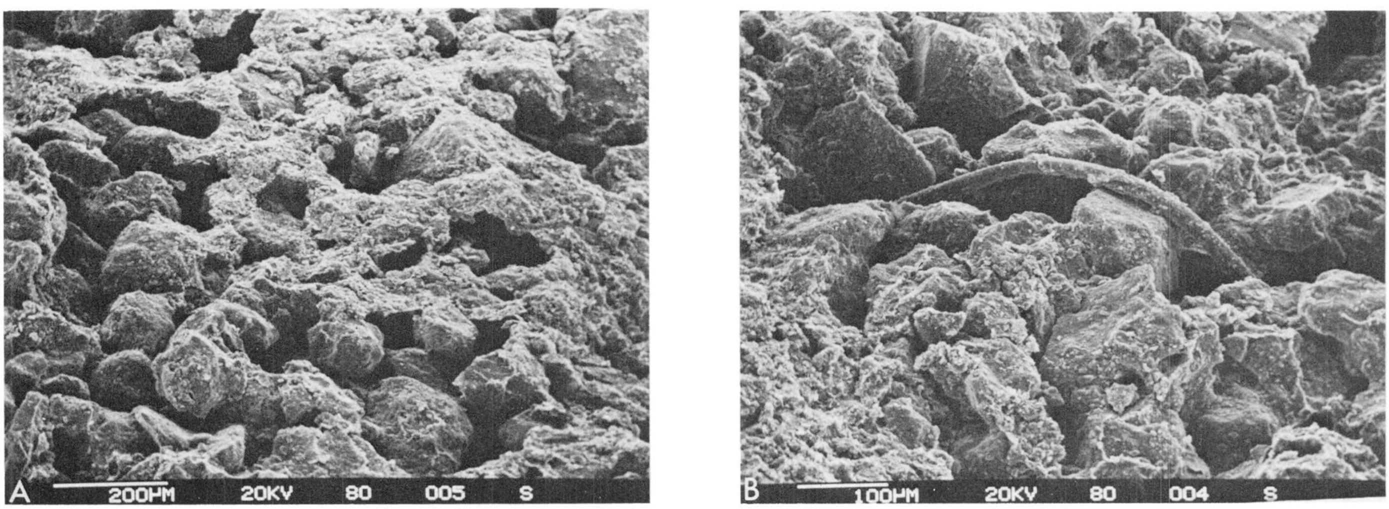


FIGURE 3. Scanning electron microphotographs of samples from the reservoir sandstone at 1991-2024.5 m. Some of the superficial clay coatings may be from the drilling mud. The hair-like feature in photo B is probably a contaminant. Note the high porosity and lack of cements.

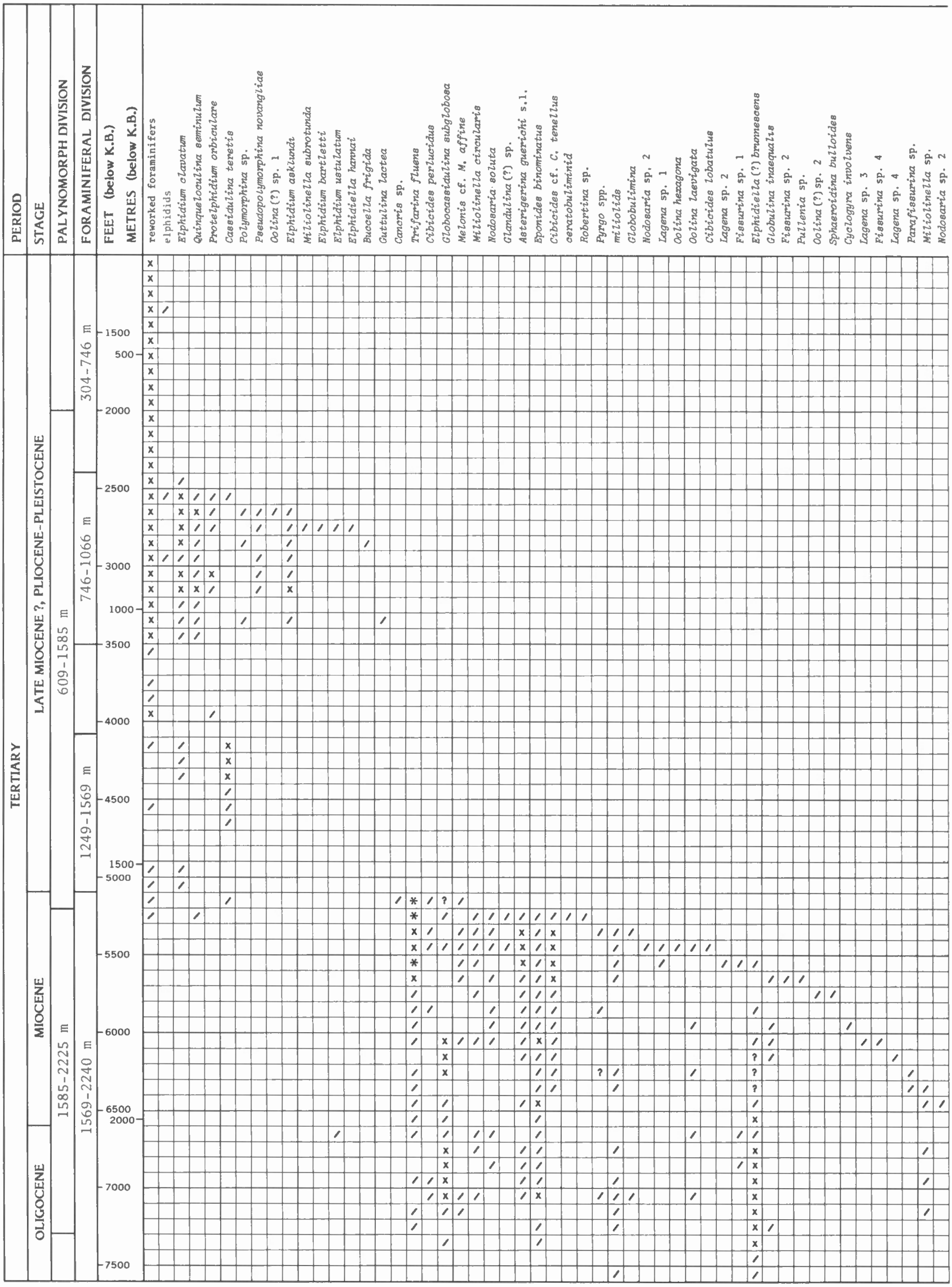


FIGURE 4. *Distribution of foraminifers and palynomorphs in the Dome Gulf et al. Ukalerk C-50 well.*

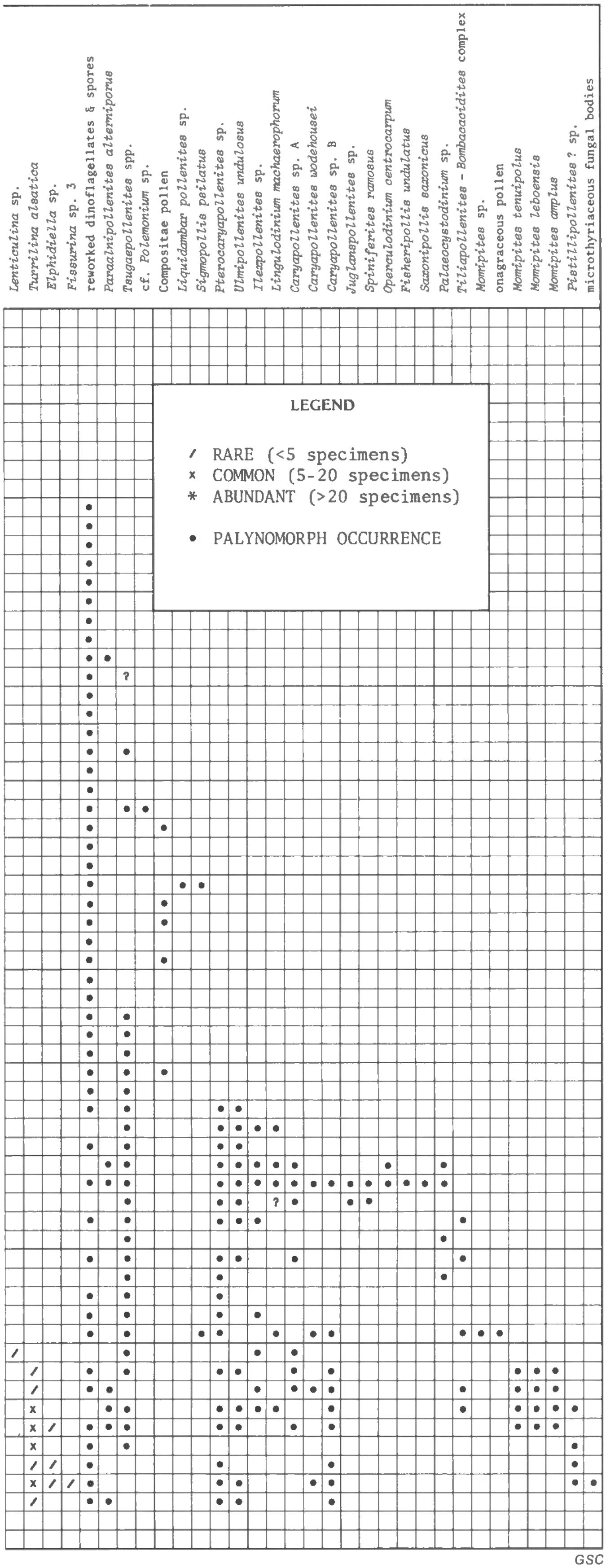


***FIGURE 4** (cont.)*

well. In particular, mountain uplift and associated glaciation in southeastern Alaska must have contributed extensively to the development of continentality in the Mackenzie region, resulting in the elimination of the deciduous forest at the time of the unconformity in the Beaufort Sea. Souther and Stanciu (1975) have shown that the uplift of the St. Elias Mountains in eastern Alaska could be dated Miocene or Pliocene. R.B. Campbell (pers. comm., 1980) considered that this uplift probably has continued to the present day. Based on cold-water planktonic foraminifers from southeastern Alaska, Bandy et al. (1969, p. 607) concluded that the first widespread glaciation in the region occurred during the Late Miocene. Frakes (1979, p. 225) considered that the precise age for earliest northern hemisphere glaciation was not known but that the ice masses in Alaska were definitely in place by Middle Miocene time or possibly in the Early Miocene.

Paleobotanical data indicate pronounced climatic fluctuations during the Tertiary (Wolfe and Hopkins, 1967; Wolfe and Leopold, 1967; Wolfe, 1971, 1975; and Wolfe and Tanai, 1980). Wolfe and Tanai (1980) concluded from a study of Tertiary floral assemblages of the Seldovai Point, Alaska and surrounding areas that a warming trend during the Middle Miocene gave way to a moderate decline in mean annual temperature and a major decrease in mean annual range of temperature. They concluded also that the decline in summer temperature was probably one of the causes of the initiation of glaciation in high latitudes during the late Cenozoic.

Data derived from oxygen isotope studies based on benthonic foraminifers from the North Pacific Ocean show an appreciably cool period during late Middle and Late Miocene times (Savin et al., 1975; Douglas and Savin, 1975; Savin, 1977).

In summary, there is evidence for the beginnings of alpine glaciation during the Miocene in Alaska, the beginnings of an Arctic Ocean ice cover during the latest Miocene or the earliest Pliocene, and the beginnings of continental glaciation at about the boundary between the Early and Middle Pliocene. These ages provide a time-framework for the Arctic "refrigeration" and thus can be used to estimate the date of the regional unconformity as expressed in the Ukalerk C-50 well. A precise date still cannot be assigned to the onset of the cool climatic conditions that were responsible for the succession of coniferous palynomorphs and cool-water foraminiferal assemblages above the unconformity, but considering the above information, a Late Miocene or Early Pliocene age is the most likely approximation.

Foraminifers

Division 304-746 m (1000-2450 ft)

The samples studied from 304-746 m were virtually barren of *in situ* foraminifers (Fig. 4). The occurrence of one specimen of **Protelphidium** cf. **P. orbiculare** (Brady) at 411.5 m (1350 ft) represents the only marine microfossil recovered. A nonmarine depositional environment is indicated by rare occurrences of fresh-water ostracodes and is supported by the general absence of marine fossils.

A feature of this section is the recovery of reworked agglutinated Early Cretaceous foraminifers. They are remarkably well preserved but leave little doubt as to their origin. Many are identifiable at the species level; such forms as **Ammobaculites fragmentarius** Cushman and **Gaudryina nanushukensis** Tappan can be recognized among numerous species of **Haplophragmoides.**

An undifferentiated Pliocene-Pleistocene age is assigned to division 304-746 m. The associated ostracodes are comparable to **Candona candida** (Mueller) and **Candona lactea** Bird; both are common in the Pleistocene Gubik Formation of northern Alaska (Swain, 1963).

Division 746-1066 m (2450-3500 ft)

Division 746-1066 m is distinguished by calcareous benthonic species including common **Elphidium asklundi** Brotzen, **E. clavatum** Cushman, **Protelphidium orbiculare** (Brady), and **Quinqueloculina seminulum** (Linné). Rare species include **Elphidium ustulatum** Todd, **Elphidiella hannai** (Cushman and Grant), **Miliolinella subrotunda** (Montagu), **Polymorphina** sp., **Pseudopolymorphina novangliae** (Cushman) **Guttulina lactea** (Walker and Jacob), **Oolina**(?) sp., **Buccella frigida** (Cushman), and **Cassidulina teretis** Tappan. The interval is also characterized by common marine ostracodes, many being comparable with the ostracode assemblage described from the Pleistocene Gubik Formation of Alaska by Swain (1963). In addition, reworked Early Cretaceous foraminifers are common through this interval.

The assemblage from 746-1066 m equates at least partially with the **Sigmopollis**-ostracode-**Elphidium** assemblage recognized in several Mackenzie Delta wells by Staplin (1976). It equates in part with a Pliocene-Pleistocene complex of inner shelf marine and nonmarine biofacies that Young and McNeil (in press) have mapped extensively in the Richards Island area of the Mackenzie Delta.

Division 746-1066 m is assigned a generalized Pliocene-Pleistocene age. Its species are well known from the boreal Pliocene to Holocene (Loeblich and Tappan, 1953; Feyling-Hanssen et al., 1971). All but **Elphidium ustulatum**, which is confined to the pre-Holocene, are extant.

A qualitative comparison of this assemblage with the Holocene foraminiferal distribution patterns in the Beaufort Sea described by Vilks et al. (1979) indicates similarity to the inner shelf, low-salinity assemblage dominated by **E. clavatum** which in abundance is a reliable indicator of an arctic paleoenvironment (Feyling-Hanssen, 1972, p. 338).

The foraminifers from 746-1066 m compare closely with many other near-shore, shallow-water assemblages dominated by **Elphidium** and related genera. For further information see, for example, quantitatively discriminated nearshore assemblages described from the Pleistocene of the St. Lawrence Lowlands by Cronin (1979).

Division 1066-1249 m (3500-4100 ft)

Foraminifers occur rarely between 1066-1249 m and may have caved from the overlying section. Reworked foraminifers recovered in small numbers may be representative of the sampled interval.

Division 1249-1569 m (4100-5150 ft)

A mere two species were recovered from the fossiliferous upper half of this division; the lower half is essentially barren, containing two specimens of **Elphidium clavatum** and several reworked agglutinated foraminifers. **Cassidulina teretis** and **E. clavatum** constitute the assemblage, with **C. teretis** dominant. Vilks et al. (1979, p. 19) have noted the sensitivity of **C. teretis** to low salinity, which explains the generally exclusive distribution between **E. clavatum** and **C. teretis** in Beaufort Sea Holocene sediments. **E. clavatum** is dominant in the inner-shelf assemblages whereas **C. teretis** increases in dominance across the outer shelf and into the slope regime (Vilks et al., 1979, figs. 26, 27).

A striking aspect of the assemblage is the high percentage of fragmented **C. teretis.** Nearly all recovered specimens were broken.

Given the characteristics of this foraminiferal assemblage, an analogy with foraminiferal biofacies recognized in the Holocene sediments of the Gulf of Alaska by Bergen and O'Neil (1979) is inviting. They recognized two biofacies in the Gulf of Alaska: one characteristic of areas of low relief and fine-grained sediments (low energy) containing **Elphidium, Elphidiella, Buccella,** and **Nonionella;** the other characteristic of coarse-grained sediments (high energy) deposited on submarine banks, ridges, and areas of uneven topography dominated by **Cibicides** and **Cassidulina.** The latter assemblage compares generically with the **C. teretis** dominated assemblage in the Ukalerk C-50 well and the notable number of fragmented **C. teretis** supports this high-energy analogy.

A precise age for this division is not provided directly by its contained foraminifers or palynomorphs. However, a time framework for the Neogene climatic deterioration as discussed previously indicates that cooler climates were likely established in the high latitudes by the Late Miocene. A Pliocene age is tentatively assigned, but a Late Miocene age is possible.

Division 1569-2240 m (5150-7350 ft)

More than 40 species of benthonic calcareous foraminifers were recovered from 1569-2240 m. The assemblage is made up of a lower part 2026-2240 m (6650-7350 ft) defined by the range limits of **Turrilina alsatica** Andreae and a variety of other longer-ranging species of which **Elphidiella**(?) **brunnescens** Todd, **Eponides binominatus** Subbotina, and **Globocassidulina subglobosa** (Brady) are particularly common. The upper part 1569-2026 m (5150-6650 ft) is dominated by **Asterigerina guerichi s. l.** (Franke), **Cibicides** cf. **C. tenellus** (Reuss), **Miliolinella circularis** (Bornemann), and **Trifarina fluens** Todd among numerous other less common species. Rare species confined to the upper part include **Cancris** sp., a ceratobuliminid, **Cibicides lobatulus** (Walker and Jacob), **Cyclogyra involvens** (Reuss), **Glandulina**(?) sp., **Fissurina** sp. 2 and 4, **Lagena** sp. 1, 2, 3 and 4, **Lenticulina** sp., **Melonis** cf. **M. affine** (Reuss), **Nodosaria** sp., **Oolina hexagona** (Williamson), **Oolina**(?) sp. 2, **Parafissurina** sp., **Pseudonodosaria** sp., **Pullenia** sp., **Robertina**(?) sp., and **Sphaeroidina bulloides** d'Orbigny. Species recovered only from the lower part include **Ephidium ustulatum** Todd and **Fissurina** sp. 3. Several species occur in both the lower and upper parts of the assemblage (see Fig. 4).

Besides abundant foraminifers, this division yields abundant pyrite in the form of rods and spheres (burrow fillings and coprolites?). Their distribution coincides with that of the foraminiferal assemblage.

Equivalent foraminiferal assemblages have been recognized in Mackenzie Delta rocks. Staplin (1976) correlated an interpreted Miocene assemblage, characterized by **Asterigerina** sp., between several wells in the delta. Young and McNeil (in press) have distinguished equivalent assemblages dated Oligocene to Miocene through the northern Richards Island area of the Mackenzie Delta.

The generic composition of the assemblage from division 1569-2240 m typifies a shelf environment of deposition. **Asterigerina** and **Miliolinella** are particularly characteritistic of the shelf (Murray, 1973; Boltovskoy and Wright, 1976). Most of the other genera are environmentally wide ranging in Recent environments. **Cibicides, Eponides, Fissurina**, and **Trifarina** are all common in shelf and deeper waters. In the Recent environment, **Asterigerina** occurs in tropical to sub-tropical inner shelf environments (Murray, 1973, p. 248). Its occurrence in the Ukalerk C-50 assemblage indicates it ranged farther in the mid-Tertiary to the north temperate region. Palynomorph assemblages of this division indicate that the neighbouring continental climate was cool-temperate to boreal.

Regarding the age of division 1569-2240 m, **Asterigerina guerichi s. l.** (includes variety **staeschei** ten Dam and Reinhold) is well known in the northwestern European Oligocene to Middle Miocene strata (ten Dam and Reinhold, 1942; Batjes, 1958; Doppert, 1975; and de Meuter and Laga, 1976) and from the Miocene of the Labrador Shelf of Canada (Gradstein and Williams, 1976). **A. guerichi** from Ukalerk C-50 is for the most part comparable to the variety **staeschei** ten Dam and Reinhold. The variety is considered by some workers to be a subspecies or a distinct species and to be an index of the Early or Middle Miocene (ten Dam and Reinhold, 1942; Doppert, 1975, p. 117; and de Meuter and Laga, 1976, p. 142). Batjes (1958, p. 159) and Gradstein and Williams (1976, p. 17), however, recognize only one species, **A. guerichi**, and doubt the validity of variety **staeschei** as an index of the Miocene.

The lower part (2026-2240 m) of the division is distinguished by the common occurrence of **Turrilina alsatica** Andreae, a widespread species which is a marker of the Oligocene in northwestern Europe as well as the Labrador Shelf of Canada (Batjes, 1958, p. 126; Hansen, 1972, p. 39; Doppert, 1975, p. 117; and Gradstein and Williams, 1976, p. 15).

Another common species of this division is **Cibicides** cf. **C. tenellus** (Reuss) which compares closely with **C. tenellus** as figured by Batjes (1958, pl. 9, figs. 3, 4). **C. tenellus** was recorded from Middle Oligocene to Middle Miocene beds in Belgium. Doppert (1975, p. 117) reports it in Upper Oligocene and Lower Miocene beds of the Netherlands. **C.** cf. **C. tenellus** also compares closely with **Cibicides borislavensis** Aisenstat which may be a synonym of **C. tenellus. C. borislavensis** was described from the Oligocene and Miocene of the Precarpathian depression of east-central Europe. Another characteristic species of this Ukalerk C-50 assemblage, **Eponides binominatus** Subbotina, was also first recorded from the Oligocene and Miocene of the Carpathian region (Subbotina et al., 1960).

In summary, **T. alsatica** indicates an Oligocene age for the lower part (2026-2240 m). The upper part (1569-2026 m) is characterized by forms generally known from both the Oligocene and the Early to Middle Miocene in northwestern Europe and to a limited degree from the Oligocene and Miocene of east-central Europe. However, the occurrence of **A. guerichi** var. **staeschei** and the absence of **T. alsatica** in the upper assemblage strongly suggest an Early to Middle Miocene age for the upper part (1569-2026 m).

Close to half of the foraminifers described from 1569-2240 m were recorded from the Nuwok Member of the Sagavanirktok Formation along Carter Creek, Alaska, by Todd (1957) and by Bergquist (in Detterman et al., 1975, p. 49-50). Todd assigned a Miocene or Pliocene age to the Carter Creek assemblage. Bergquist assigned a latest Pliocene or Pleistocene age. Wolfe and Tanai (1980, p. 16) considered the Nuwok pollen assemblage to be of Middle Miocene age. MacNeil (1957, p. 101) assigned a Late Miocene or Early Pliocene age on the basis of molluscan fauna.

Todd's biogeographic comparisons of the Carter Creek assemblage were chiefly with the Recent Arctic faunas, with Miocene and younger assemblages of the east and west coasts of the United States, and with the Pliocene of England and Belgium. Only the lattermost proved to be of any appreciable interest in establishing a correlative bond, but even that was not strong because the species considered were cosmopolitan and long ranging.

The Beaufort Sea assemblage contains common **Asterigerina guerichi s. l.** (not present in the Carter Creek assemblage), **Cibicides** cf. **C. tenellus, Eponides binominatus,** and **Turrilina alsatica,** all of which provide some indication of the age of the Beaufort Sea assemblage and suggest a biogeographic link with the European seas during the Oligocene and the Miocene, presumably by way of the opening North Atlantic in the Early Tertiary. **C.** cf. **C. tenellus, E. binominatus,** and **T. alsatica** were not reported in the Alaskan assemblage, but this contrast is one of taxonomy. **C.** cf. **C. tenellus** and **E. binominatus** were included by Todd in **C. perlucidus,** and Todd's (1957, pl. 1, figs. 19, 20) identification of **Buliminella curta** Cushman seems incorrect; the figured specimens appear to be **T. alsatica.** If so, the occurrence of **T. alsatica,** a marker of the Oligocene, considerably alters the prevailing interpretations on the age of the Nuwok Member, i.e., Oligocene versus Miocene or Pliocene.

Palynomorphs

The sampled section

In the Ukalerk C-50 well, samples were studied between 609 and 2225 m (2000-7300 ft). The remaining section was not studied because of small sample recovery or unavailability of samples.

Division 609-1585 m (2000-5200 ft)

Division 609-1585 m yielded a sparse microflora that includes **Sigmopollis psilatus**, species of **Laevigatosporites** and sphagnum, ericaceous pollen, and bisaccate pollen assignable to **Picea** and **Pinus**, accompanied by rare triporate or tricolporate pollen. They are all stratigraphically long ranging. The general lack of a whole complex of pollen of deciduous plant origin may, at high latitudes, be tentatively used as a criterion for age because their absence may reflect a time-significant climatic deterioration (see previous discussion). Elements of more restricted stratigraphic ranges are occasionally seen in the lower part of this division. The most important are cf. **Polemonium** (a polemoniaceous pollen) at 1097.3 m (3600 ft) and pollen attributable to Compositae at 1127.8, 1249.7, 1341.1, 1524.0 m (3700, 4100, 4400, 5000 ft). Both plant groups are known from Miocene and younger strata, although Compositae may be found in latest Oligocene sediments. Palynomorphs derived from older sources are commonly present and consist of Early and Late Cretaceous spores and dinocysts, Late Devonian and Early Carboniferous spores, and pre-Quaternary pollen and fungal elements. Reworked pollen of the latter category are often difficult to distinguish from *in situ* members and their occurrence, if undetected, would distort the local palynomorph profile.

The boreal aspect of the microflora reflects cool climatic conditions which were initiated possibly as early as the Late Miocene, as discussed previously in this report. A Late Miocene to Pliocene age is tentatively suggested for this division. Supporting evidence is provided by foraminiferal assemblages.

Norris (in prep.) proposed a palynomorph zonation for the Imperial Nuktak C-22 well in the Beaufort Sea. Division 609-1585 m in Ukalerk C-50 broadly compares with the two highest zones in the Nuktak well, namely those of **Laevigatosporites** and **Chenopodipolles** and may also include the uppermost part of Norris's **Tsugaepollenites** zone based on the mutual occurrence of the latter genus. Elements common to division 609-1585 m and the two highest Nuktak C-22 zones include species of ferns, coniferous and bryophyte pollen, and **Sigmopollis psilatus.** For the section spanning these zones, Norris assigned a Miocene to Pliocene age.

Division 1585-2225 m (5200-7300 ft)

At 1585 m (5200 ft) an abrupt microfloral change, which occurs in proximity to a sharp velocity increase on geophysical logs (1571.5 m), is marked by the first downwards appearance of members of the deciduous pollen complex, associated with the foraminifer **Asterigerina.** They include **Pterocaryapollenites, Ulmipollenites,** and also **Ilexpollenites** and the gymnosperm pollen of **Tsugaepollenites.** These pollen are variably represented within the succession due to lithological variations, but frequency of occurrence increases downhole and they persist to 2225 m (7300 ft). Additional microfloral changes are manifest throughout the section, as illustrated in Figure 4. The most prominent are occurrences of **Saxonipollis saxonicus, Fisheripollis undulatus,** and **Juglanspollenites** sp. at 1706.9 m (5600 ft), the incoming of the **Tiliapollenites-Bombacacidites** complex at 1767.8 m (5600 ft), and the downwards appearance of onagraceous pollen and **Momipites** sp. at 1950.7 m (6400 ft). Pollen of **Saxonipollis** and **Fisheripollis** are reported from Eocene to Miocene sediments and are here apparently within the span of their known range (Krutzsch, 1970; Ioannides and McIntyre, 1980). Additionally, foraminiferal evidence suggests an Early to Middle Miocene age for this part of the division. Dinoflagellate cysts which are believed to be in place occur rarely at 1614.4 m (5300 ft), commonly at 1676.4 m (5500 ft) and 1706.9 (5600 ft) to 1767.8 m (5800 ft), and decline numerically below. They comprise **Lingulodinium machaerophorum, Operculodinium centrocarpum, Palaeocystodinium** sp. (probably a poorly preserved **P. golzowense**), **Systematophora**(?) sp., species of **Spiniferites,** and rare fragments of specimens referred to as cf. dinoflagellate genus **Hystrichosphaeridium** by Martin and Rouse (1966, Pl. 11, figs. 121-122). The shelf environment of deposition indicated by a rich benthonic foraminiferal association is compatible with the presence of marine dinocysts within the upper part of this division.

Staplin et al. (1976) reported **Asterigerina** as being associated with cool temperate to boreal palynomorphs **(Abies, Sphagnum, Alnus, Betula)** in the Mackenzie Delta. It is very likely however that hardwood deciduous pollen, signifying temperate conditions, may be present in these **Asterigerina**-bearing sediments because they correlate at least in part with the Beaufort Formation (Young and McNeil, in press) which Hills et al. (1974) dated as Early to Middle Miocene and from which was reported pollen of **Juglans, Carya, Tilia,** and **Tsuga.**

The upper part of division 1585-2225 m in the Ukalerk C-50 well contains a number of taxa in common with the **Tsugaepollenites** zone in the Nuktak C-22 well. They comprise hardwood pollen of **Pterocaryapollenites, Tiliapollenites, Ulmipollenites,** and the gymnosperm pollen **Tsugaepollenites.** For this zone, Norris (in prep.) suggested a Late Oligocene or Miocene age. The dinoflagellate cysts recovered from the subject well are not reported by Norris which probably suggests differences in the depositional environment.

Microfloral changes in the lower part of this division begin at 1950.7 m (6400 ft) and become pronounced at 2011.7 m (6600 ft) where various species of **Momipites** are encountered together with a large number of **Tsugaepollenites.** In addition, at 2042.2 and 2072.6 m (6700 and 6800 ft) **Paraalnipollenites alterniporus** and **Pistillipollenites**(?) sp. are recovered respectively. A similar association was observed in interval D of the Caribou Hills (Ioannides and McIntyre, 1980) but with the exception of **Tsugaepollenites** the association was interpreted as reworked. The presence of **Pistillipollenites**(?) sp., reported also from the Paleocene of Saskatchewan by A.R. Sweet (pers. comm.), indicates that reworking may be the cause of their presence at these horizons. However, their fairly consistent occurrence in several Beaufort Sea wells deserves further attention, as their local ranges may extend as high as observed in the subject well.

For the lower part of this division a generalized Oligocene-Miocene age is provisionally proposed, although the foraminifers recovered suggest an Oligocene age (see previous discussion of foraminifers). The **Ericipites** zone in Nuktak C-22, dated as Late Oligocene by Norris (in prep.), contains the **Tiliapollenites-Bombacacidites** complex (as **Intratriporopollenites**) and also ericoid pollen and **Momipites tenuipolus.**

Direct application of Norris's zones (in prep.) from the southern Beaufort-Mackenzie Basin to the Ukalerk C-50 well is not attempted as the progressive evaluation of data obtained from several Beaufort Sea wells is desirable before any formal subdivision is employed.

REFERENCES

Bandy, O.L., Butler, E.A. and Wright, R.C.
1969: Alaskan upper Miocene marine glacial deposits and the **Turborotalia pachyderma,** datum plane; Science, v. 166, p. 607-609.

Batjes, D.A.J.
1958: Foraminifera of the Oligocene of Belgium; Institut Royal des Sciences Naturelles de Belgique, Mémoire no. 143.

Bergen, F.W. and O'Neil, P.
1979: Distribution of Holocene Foraminifera in the Gulf of Alaska; Journal of Paleontology, v. 53, no. 6, p. 1267-1292.

Berggren, W.A.
1972: Late Pliocene-Pleistocene glaciation; in Initial Reports of the Deep Sea Drilling Project, v. 12, A.S. Laughton, W.A. Berggren et al., eds.; United States Government Printing Office, Washington, p. 953-963.

Boltovskoy, E. and Wright, R.
1976: Recent Foraminifera; Dr. W. Junk b.v. Publishers, The Hague.

Clark, D.L.
1971: Arctic Ocean ice cover and its late Cenozoic history; Geological Society of America, Bulletin 82, p. 3313-3324.

Clark, D.L.
1977: Paleontologic response to post-Jurassic crustal plate movements in the Arctic Ocean; in Paleontology and Plate Tectonics with Special Reference to the History of the Atlantic Ocean, R.M. West, ed.; Milwaukee Public Museum, Special Publications in Biology and Geology, no. 2, p. 55-75.

Cronin, T.M.
1979: Late Pleistocene benthic foraminifers from the St. Lawrence Lowlands; Journal of Paleontology, v. 53, no. 4, p. 781-814.

De Meuter, F.J. and Laga, P.G.
1976: Lithostratigraphy and biostratigraphy based on benthonic Foraminifera of the Neogene deposits of northern Belgium; Bulletin Société Belge de Géologie, v. 85, pt. 4, p. 133-152.

Detterman, R.L., Reiser, H.N., Brosgé, W.P. and Dutro, J.T., Jr.
1975: Post-Carboniferous stratigraphy, northeastern Alaska; United States Geological Survey, Professional Paper 886.

Dixon, J. and Snowdon, L.R.
1979: Geology and organic geochemistry of the Dome Hunt Nektoralik K-59 well, Beaufort Sea; Geological Survey of Canada, Paper 79-1C, p. 85-90.

Doppert, J.W. Chr.
1975: Foraminiferenzonering van het Nederlandse Onderkwartair en Tertiar; in Toelichting bij Geologische Overzichtskaarten van Nederland, W.H. Zagwijn and C.J. van Staalduinen, eds.; Rijks Geol. Dienst, Haarlem, p. 114-118.

Douglas, R.G. and Savin, S.M.
1975: Oxygen and carbon isotope analyses of Tertiary and Cretaceous microfossils from Shatsky Rise and other sites in the North Pacific Ocean; in Initial Reports of the Deep Sea Drilling Project, v. 32, R.L. Larson, R. Moberly et al., eds.; United States Government Printing Office, Washington, p. 509-520.

Feyling-Hanssen, R.W.
1972: The foraminifer **Elphidium excavatum** (Terquem) and its variant forms; Micropaleontology, v. 18, no. 3, p. 337-354.

Feyling-Hanssen, R.W., Jorgensen, J.A., Knudsen, K.A. and Andersen, A.L.
1971: Late Quaternary Foraminifera from Vendsyssel, Denmark and Sandnes, Norway; Geological Society of Denmark, v. 21, pt. 2-3.

Frakes, L.A.
1979: Climates Throughout Geologic Time; Elsevier Scientific Publishing Company, New York.

Gradstein, F.M. and Williams, G.L.
1976: Biostratigraphy of the Labrador Shelf, Part 1; Geological Survey of Canada, Open File 349.

Hansen, H.J.
1972: Two species of Foraminifera of the genus **Turrilina** with different wall structure; Lethaia, v. 5, p. 39-45.

Herman, Y.
1978: Late Cenozoic paleoceanographic events in the Arctic; Geological and Mineralogical Associations of Canada and Geological Society of America, 1978 Joint Annual Meeting, Toronto, Ontario, Abstracts with Programs, p. 420.

Hills, L.V., Klovan, J.E. and Sweet, A.R.
1974: **Juglans eocinerea** n. sp. Beaufort Formation (Tertiary) southwestern Banks Island, Arctic Canada; Canadian Journal of Botany, v. 52, p. 65-90.

Ioannides, N.S. and McIntyre, D.J.
1980: A preliminary palynological study of the Caribou Hills outcrop section along the Mackenzie River, District of Mackenzie; Geological Survey of Canada, Paper 80-1A, p. 197-208.

Jones, P.B., Brache, J. and Lentin, J.K.
1980: The geology of the 1977 offshore hydrocarbon discoveries in the Beaufort-Mackenzie Basin, N.W.T.; Bulletin of Canadian Petroleum Geology, v. 28, no. 1, p. 81-102.

Krutzsch, W.
1970: Zur Kenntnis fossiler disperser Tetradenpollen; Palaeontologische Abhandlungen B, v. 314, p. 399-433.

Loeblich, A.R., Jr. and Tappan, H.
1953: Studies of Arctic Foraminifera; Smithsonian Miscellaneous Collection, v. 121, no. 7.

MacNeil, F.W.
1957: Cenozoic megafossils of northern Alaska; United States Geological Survey, Professional Paper 294-C, p. 99-126.

Martin, H.A. and Rouse, G.E.
1966: Palynology of Late Tertiary sediments from Queen Charlotte Islands, British Columbia; Canadian Journal of Botany, v. 44, p. 171-208.

McDougall, I. and Wensink, H.
1966: Paleomagnetism and geochronology of the Pliocene-Pleistocene lavas in Iceland; Earth and Planetary Science Letters, v. 1, p. 232-236.

Murray, J.W.
1973: Distribution and Ecology of Living Benthic Foraminiferids; Heinemann Educational Books Limited, London.

Norris, G.
in press: Systematic and stratigraphic palynology of Eocene to Pliocene strata in Imperial Nuktak C-22 well, Mackenzie Delta region, District of Mackenzie, N.W.T.; Geological Survey of Canada, Bulletin.

Savin, S.M.
1977: The history of the earth's surface temperature during the past 100 million years; Annual Review of Earth and Planetary Sciences, v. 5, p. 319-355.

Savin, S.M., Douglas, R.G. and Stehli, F.G.
1975: Tertiary marine paleotemperatures; Geological Society of America, Bulletin 86, p. 1499-1510.

Souther, J.G. and Stanciu, C.
1975: Operation Saint Elias, Yukon Territory: Tertiary volcanic rocks; Geological Survey of Canada, Paper 75-1, pt. A, p. 63-70.

Staplin, F.L., ed.
1976: Tertiary biostratigraphy, Mackenzie Delta region, Canada; Bulletin of Canadian Petroleum Geology, v. 24, p. 117-136.

Subbotina, N.N., Pishvanova, L.S. and Ivanova, L.V.
1960: Stratigrafiya Oligotsenovykh i Miatsenovykh otlozheinii pred Karpatya po foraminiferam; Trudy VNIGRI, no. 153, p. 5-127 (Stratigraphy of Oligocene and Miocene deposits from the pre-Carpathians, according to Foraminifera).

Swain, F.M.
1963: Pleistocene Ostracoda from the Gubik Formation, Arctic Coastal Plain, Alaska; Journal of Paleontology, v. 37, no. 4, p. 798-834.

ten Dam, A. and Reinhold, T.
1942: Die stratigraphische Gliederung des niederländischen Oligo-Miozäns nach Foraminiferen; Mededeelingen van de Geologischestichting, Serie C-V-No. 2.

Todd, R.
1957: Foraminifera from Carter Creek, northeastern Alaska; United States Geological Survey, Professional Paper 294-F, p. 223-235.

Vail, P.R., Mitchum, R.M., Jr. and Thompson, S., III
1977: Seismic stratigraphy and global changes of sea level, part 4: global cycles of relative changes of sea level; in Seismic Stratigraphy -- Applications to Hydrocarbon Exploration, C.E. Payton, ed.; American Association of Petroleum Geologists, Memoir 26, p. 83-97.

Vilks, G., Wagner, F.J.E. and Pelletier, B.R.
1979: The Holocene marine environment of the Beaufort Shelf; Geological Survey of Canada, Bulletin 303.

Wolfe, J.A.
1971: Tertiary climatic fluctuations and methods of analysis of Tertiary floras; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 9, p. 27-57.

1975: Some aspects of plant geography of the Northern Hemisphere during the Late Cretaceous and Tertiary; Annals of the Missouri Botanical Garden, v. 62, no. 2, p. 264-279.

Wolfe, J.A. and Hopkins, D.M.
1967: Climatic changes recorded by Tertiary land floras in northwestern North America; Tertiary correlations and climatic changes in the Pacific, p. 67-76.

Wolfe, J.A. and Leopold, E.B.
1967: Neogene and Early Quaternary vegetation of northwestern North America and northeastern Asia; in The Bering Land Bridge, D.M. Hopkins, ed.; Stanford University Press, p. 193-206.

Wolfe, J.A. and Tanai, T.
1980: The Miocene Seldovia Point flora from the Kenai Group, Alaska; United States Geological Survey, Professional Paper 1105.

Young, F.G. and McNeil, D.H.
in press: Cenozoic stratigraphy of Mackenzie Delta, Northwest Territories; Geological Survey of Canada, Bulletin 336.

Young, F.G., Myhr, D.W. and Yorath, C.J.
1976: Geology of the Beaufort-Mackenzie Basin; Geological Survey of Canada, Paper 76-11.

PLATE 1

Figure

1a, b. **Quinqueloculina seminulum** (Linné), x65.
GSC 64619 from 838 m below K.B.

2a, b. **Miliolinella subrotunda** (Montagu), x125.
GSC 64620 from 838 m below K.B.

3a, b. **Polymorphina** sp., x50.
GSC 64621 from 808 m below K.B.

4a, b. **Guttulina lactea** (Walker and Jacob), x125.
GSC 64622 from 1006 m below K.B.

5a, b. **Pseudopolymorphina novangliae** (Cushman), x65.
GSC 64623 from 808 m below K.B.

6. **Oolina**(?) sp. 1, x70.
GSC 64624 from 792 m below K.B.

7a-c. **Buccella frigida** (Cushman), x120.
GSC 64625 from 869 m below K.B.

8a, b. **Elphidium asklundi** Brotzen, x65.
GSC 64626 from 792 m below K.B.

9a, b. **Elphidium clavatum** Cushman, x110.
GSC 64627 from 765 m below K.B.

10a, b. **Elphidium ustulatum** Todd, x90.
GSC 64628 from 838 m below K.B.

11a, b. **Elphidium bartletti** Cushman, x75.
GSC 64629 from 838 m below K.B.

12a, b. **Protelphidium orbiculare** (Brady), x80.
GSC 64630 from 838 m below K.B.

13. **Elphidiella hannai** (Cushman), x45.
GSC 64631 from 869 m below K.B.

14a, b. **Cassidulina teretis** Tappan, x95.
GSC 64632 from 765 m below K.B.

PLATE 1

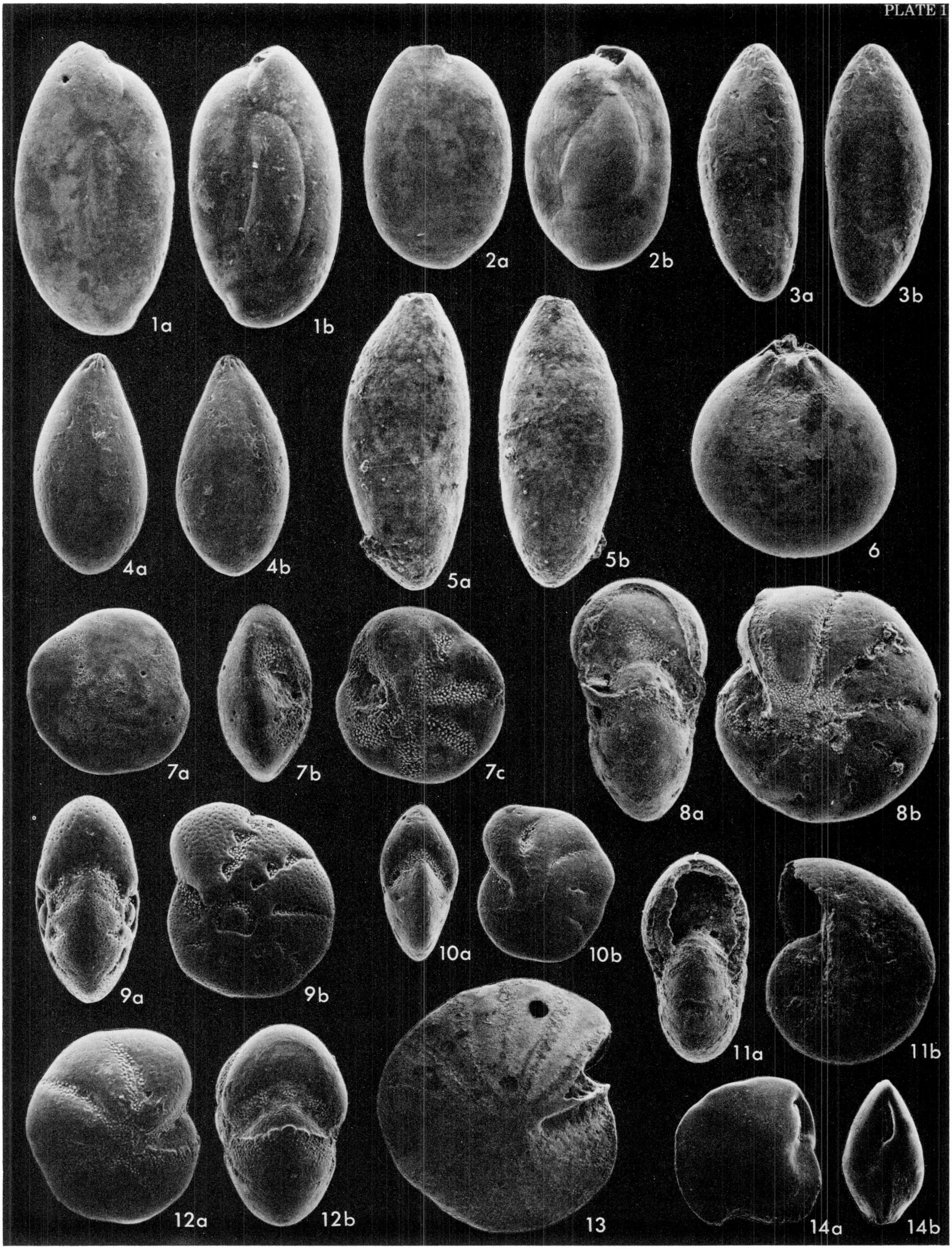

1a
1b
2a
2b
3a
3b
4a
4b
5a
5b
6
7a
7b
7c
8a
8b
9a
9b
10a
10b
11a
11b
12a
12b
13
14a
14b

PLATE 2

Figure

1a, b. **Miliolinella circularis** (Bornemann), x105.
GSC 64633 from 1585 m below K.B.

2a, b. **Miliolinella** sp., x50.
GSC 64634 from 2178 m below K.B.

3. **Pyrgo** sp. 1, x60.
GSC 64635 from 1615 m below K.B.

4. **Pyrgo** sp. 2, x75.
GSC 64636 from 2134 m below K.B.

5. **Lagena** sp. 1, x105.
GSC 64637 from 1676 m below K.B.

6. **Lagena** sp. 3, x97.
GSC 64638 from 1844 m below K.B.

7. **Lagena** sp. 2, x105.
GSC 64639 from 1646 m below K.B.

8. **Lagena** sp. 4, x70.
GSC 64640 from 6150 m below K.B.

9. **Nodosaria soluta** (Reuss), x40.
GSC 64641 from 1829 below K.B.

10a, b. **Lenticulina** sp. 2, x55.
GSC 64642 from 1981 m below K.B.

11. **Pseudonodosaria** sp., x90.
GSC 64643 from 1661 m below K.B.

12. **Oolina**(?) sp. 2, x60.
GSC 64644 from 1753 m below K.B.

13. **Oolina hexagona** (Williamson), x145.
GSC 64645 from 1646 m below K.B.

14. **Fissurina** sp. 2, x130.
GSC 64646 from 1722 m below K.B.

15. **Fissurina** sp. 1, x85.
GSC 64647 from 2027 m below K.B.

16. **Fissurina** sp. 3, x100.
GSC 64648 from 2210 below K.B.

17. **Fissurina** sp. 4, x135.
GSC 64649 from 1844 below K.B.

18. **Parafissurina** sp., x115.
GSC 64650 from 1935 m below K.B.

19. **Globulina inaequalis** Reuss, x85.
GSC 64651 from 1798 m below K.B.

20. **Glandulina**(?) sp., x120.
GSC 64652 from 1661 m below K.B.

21. **Turrilina alsatica** Andreae, x125.
GSC 64653 from 2027 m below K.B.

22a, b. **Globobulimina** sp., x85.
GSC 64654 from 1631 m below K.B.

23a, b. **Sphaeroidina bulloides** d'Orbigny, x115.
GSC 64655 from 1753 m below K.B.

24a, b. **Trifarina fluens** (Todd), x120.
GSC 64656 from 1615 m below K.B.

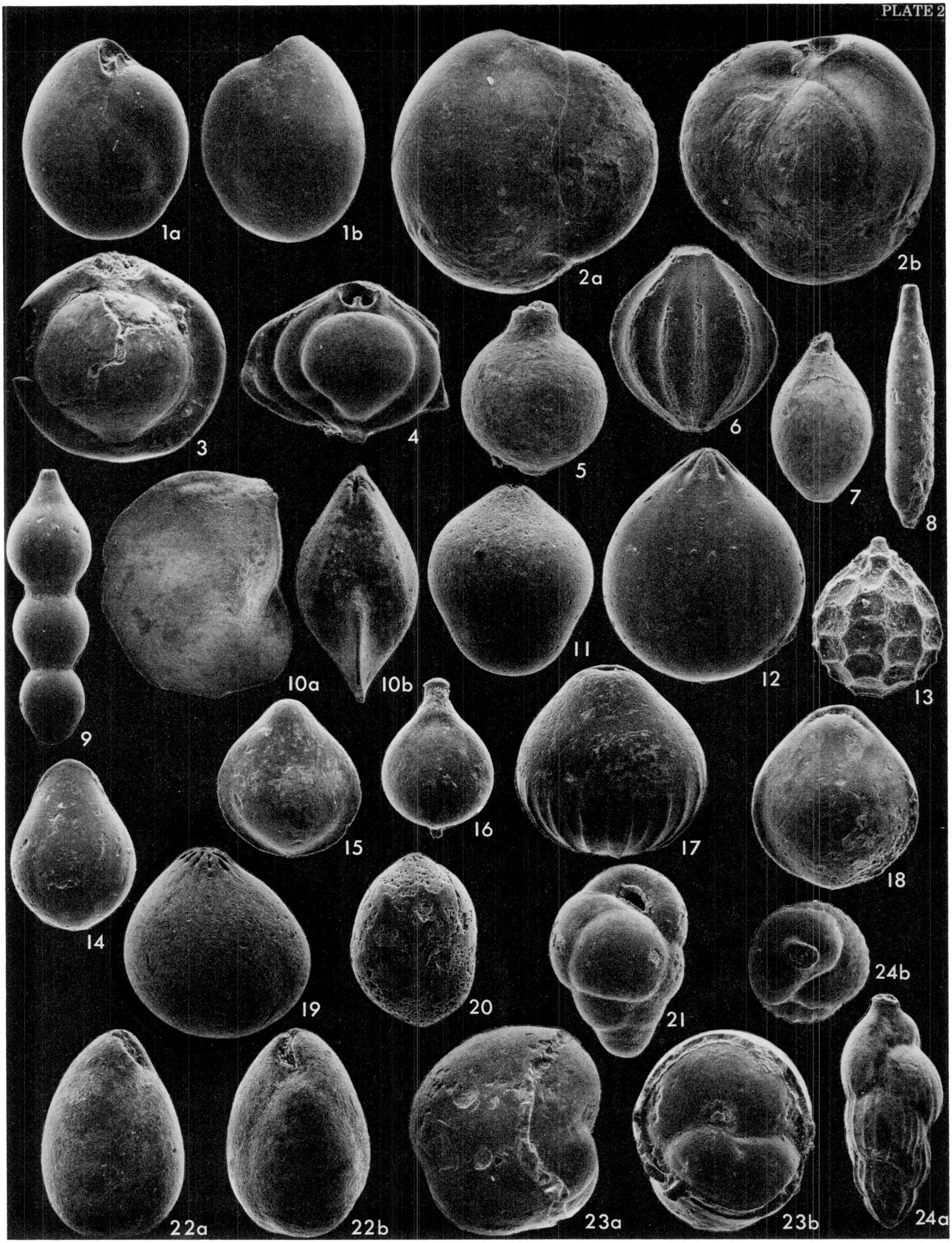


PLATE 2
1a
1b
2a
2b
3
4
5
6
7
8
9
10a
10b
11
12
13
14
15
16
17
18
19
20
21
24b
22a
22b
23a
23b
24a

PLATE 3

Figure

1a-c. **Asterigerina guerichi s. l.** (Franke), x75.
GSC 64657 from 1631 m below K.B.

2a-c. **Cancris** sp., x100.
GSC 64658 from 1568 m below K.B.

3a, b. **Elphidiella**(?) **brunnescens** Todd, x70.
GSC 64659 from 1920 m below K.B.

4a, b. **Elphidium** sp., x90.
GSC 64660 from 2012 m below K.B.

5a, b. **Elphidium ustulatum** Todd, x75.
GSC 64661 from 2027 m below K.B.

6a, b. **Elphidiella** sp., x55.
GSC 64662 from 2118 m below K.B.

7a-b. **Globocassidulina subglobosa** (Brady), x135.
GSC 64663 from 1844 m below K.B.

8a-c. **Eponides binominatus Subbotina**, x125.
GSC 64664 from 2042 m below K.B.

9a-c. **Eponides binominatus** Subbotina, x120.
GSC 64665 from 1966 m below K.B.

10a-c. **Cibicides perlucidus** Nuttall, x70.
GSC 64666 from 1554 m below K.B.

11a-c. **Cibicides** cf. **C. tenellus** (Reuss), x65.
GSC 64667 from 1631 m below K.B.

12a, b. **Pullenia** sp., x130.
GSC 64668 from 1722 m below K.B.

13a, b. **Melonis** cf. **M. affine** (Reuss), x145.
GSC 64669 from 1570 m below K.B.

14. **Robertina**(?) sp., x135.
GSC 64670 from 1586 m below K.B.

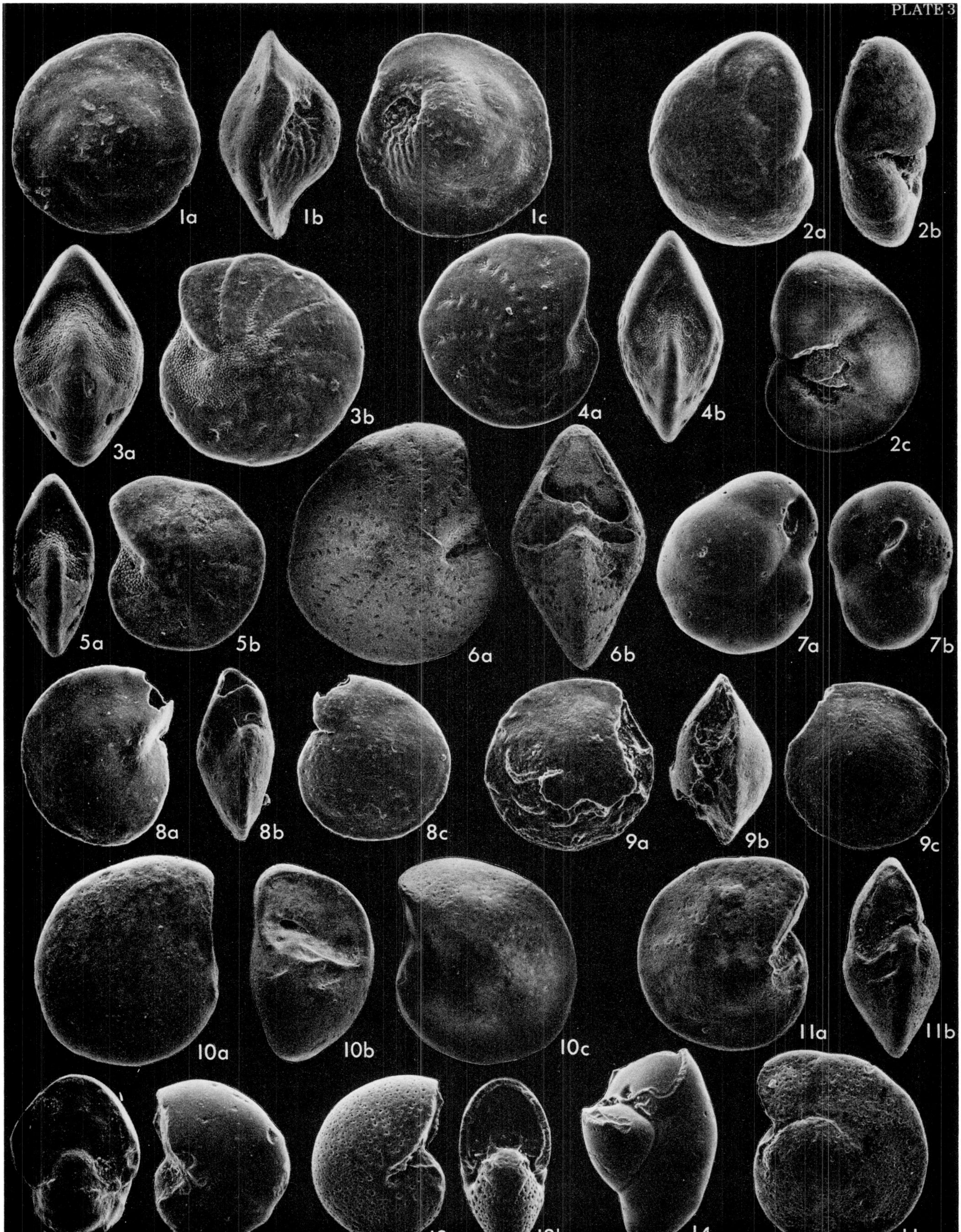

1a
1b
1c
2a
2b
3a
3b
4a
4b
2c
5a
5b
6a
6b
7a
7b
8a
8b
8c
9a
9b
9c
10a
10b
10c
11a
11b
12a
12b
13a
13b
14
11c

PLATE 4

All figures x1000 unless otherwise stated.

Figure

1. **Caryapollenites** sp. B. of Ioannides and McIntyre (1980).
GSC 63163, 6600A:1741247 (from 2012 m below K.B.).

2. **Caryapollenites wodehousei** Nichols and Ott.
GSC 63164, 7300F:3351202 (from 2225 m below K.B.).

3. **Momipites amplus** (Leffingwell) Nichols.
GSC 63165, 6600A:1971353 (from 2012 m below K.B.).

4. **Momipites** sp.
GSC 63166, 7300E:4411263 (from 2225 m below K.B.).

5. **Momipites leboensis** (Leffingwell) Nichols.
GSC 63167, 7200F:1571202 (from 2195 m below K.B.).

6. **Juglanspollenites** sp.
GSC 63168, 5600E:1571186 (from 1707 m below K.B.).

7. **Caryapollenites** sp. A of Ioannides and McIntyre (1980).
GSC 63169, 6700F:1501163 (from 2042 m below K.B.).

8, 9. **Tiliapollenites - Bombacacidites** complex.
8, GSC 63170, 5800A:3201202 (from 1768 m below K.B.); 9, GSC 63171, 6800E:1551341 (from 2073 m below K.B.).

10. Onagraceous pollen.
GSC 63172, 6400E:2931297 (from 1951 m below K.B.).

11. **Saxonipollis saxonicus** Krutzsch.
GSC 63173, 5600A:4551237 (from 1707 m below K.B.).

12. **Fisheripollis undulatus** Krutzsch.
GSC 63174, 5600D:2251294 (from 1707 m below K.B.), layer(s) outside endexine degraded.

13. cf. **Polemonium** sp.
GSC 63175, 3600A:2441325 (from 1097 m below K.B.).

14. Pollen of Compositae.
GSC 63176, 4200E:3761338 (from 1280 m below K.B.).

15. Tricolporate pollen.
GSC 63177, 7000A:1881213 (from 2133 m below K.B.).

16. **Pistillipollenites**? sp.
GSC 63178, 6800E:3721250 (from 2073 m below K.B.); note low and irregular ornament.

17. **Ilexpollenites** sp.
GSC 63179, 5300A:2931330 (from 1615 m below K.B.).

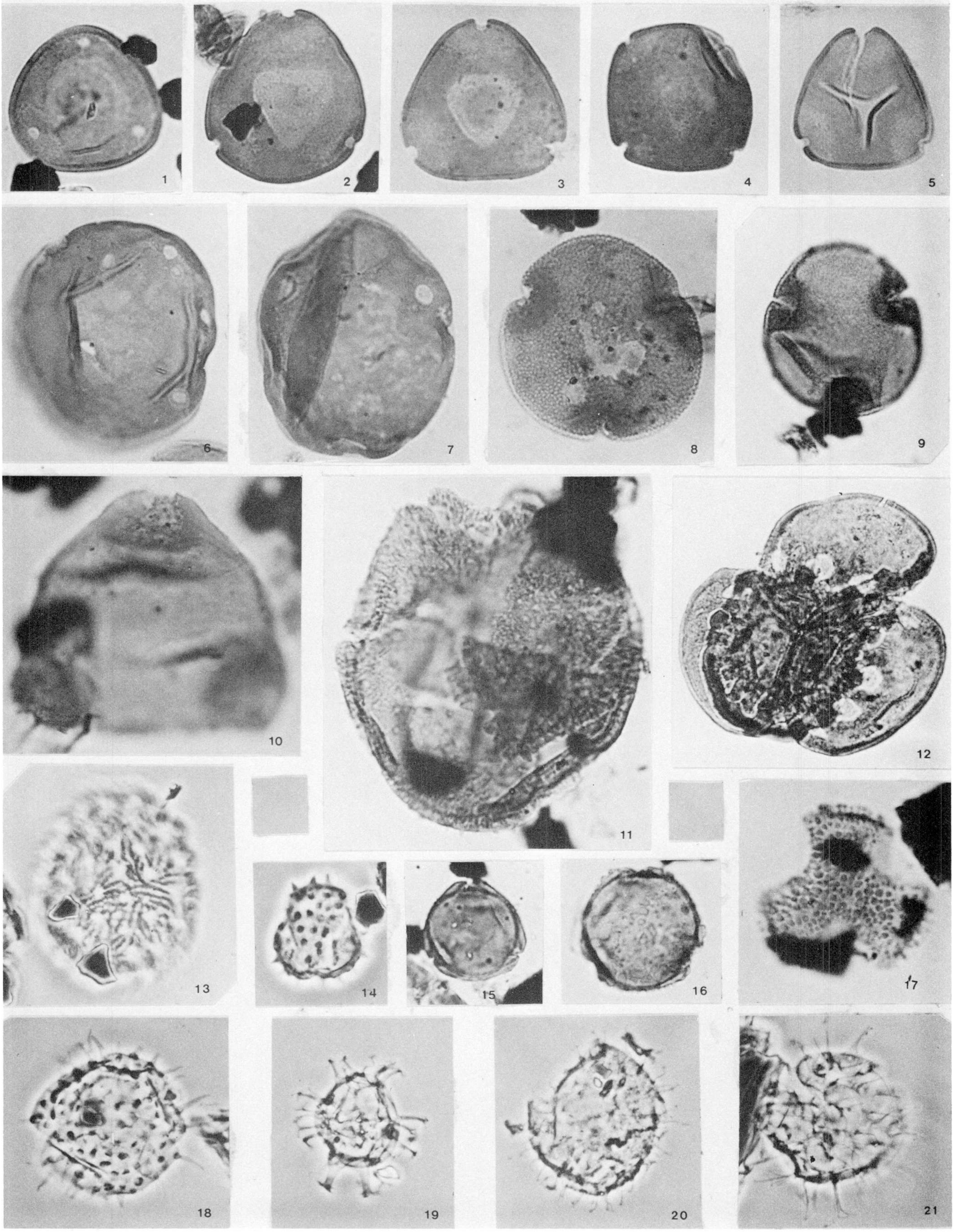
18. **Lingulodinium machaerophorum** (Deflandre and Cookson) Wall.
GSC 63180, 5600C:2101190 (from 1707 m below K.B.).

19. **Spiniferites ramosus** (Ehrenberg) Loeblich and Loeblich.
GSC 63181, 5800D:1161275 (from 1768 m below K.B.).

20. **Operculodinium centrocarpum** (Deflandre and Cookson) Wall.
GSC 63182, 5800D:1651275 (from 1768 m below K.B.).

21. **Systematophora**? sp.
GSC 63183, 5600C:3931332 (from 1707 m below K.B.); due to preservation archeopyle poorly defined.

All samples from the Dome Gulf et al. **Ukalerk** C-50 well are identified by GSC collection number C-76459.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21