GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 70-30

# TERTIARY AND CRETACEOUS BIOSTRATIGRAPHIC DIVISIONS IN THE REINDEER D-27 BOREHOLE, MACKENZIE RIVER DELTA

(Report, 6 figures and 2 charts)

T. P. Chamney



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CONTENTS

Page



Illustrations

## ABSTRACT

Twenty-three biostratigraphic divisions are interpreted from a micropaleontological study of 12,668 feet of strata penetrated in the Reindeer D-27 borehole. This borehole, the first exploratory well to be drilled on the Mackenzie River Delta, penetrated an abnormally thick sequence of Tertiary and Cretaceous sands, shales and mudstones. Thirteen provisional age assignments are interpreted on the basis of Foraminifera recovered from the samples; the oldest strata penetrated are tentatively assigned to the Barremian Substage of the Neocomian Stage. Four known regional microfossil zones are recognized in Divisions 7, 9, 11C and 13. In descending stratigraphic order these four zones are those of *Trochammina ribstonensis*, *Verneuilinoides borealis*, *Miliammina manitobensis* and *Haplophragmoides gigas*. Other classes of fossils and aspects of physical stratigraphy are reported and these support the above scheme of divisions. Because of the limitations of a single borehole only provisional interpretations can be made for ages, correlations and environments of deposition.

A contribution significant for oil and gas exploration in the Delta area is presented. Two primary modes of deposition are interpreted for the total stratigraphic sequence penetrated in the borehole. Longshore current distribution in restricted marine environment of the ancestral "Beaufort Sea" is interpreted for the depositional interval from 12,668 to 9,000 feet. Exploration for potential sandstone reservoirs developed within this interval could be oriented toward those of shoreline or offshore bars. The configuration of these deposits would be arcuate sandstone bars subparallel to the ancient Early Cretaceous shoreline. This was followed by the development in successive stages of an ancestral "Mackenzie River" drainage system. Potential sandstone reservoirs within this depositional interval include latest Late Cretaceous fluviatile-deltaic deposits and those of the final Tertiary marine delta front. The configurations of these sand bodies are quite variable but are confined to the northeast-trending axis of the ancestral "Mackenzie River" drainage channel.

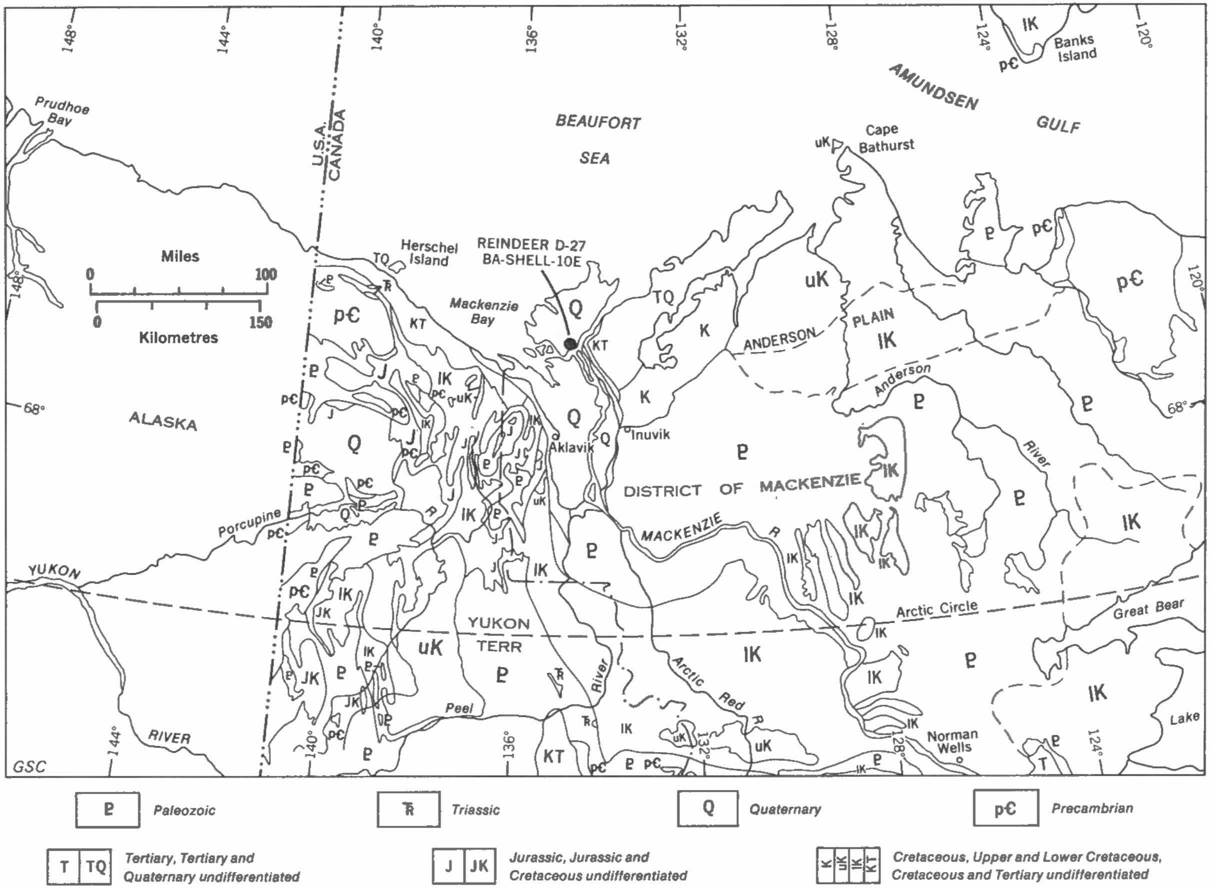


Figure 1. Map showing the geology of the Mackenzie River Delta and adjacent areas, after R.J.W. Douglas (revised by T.P. Chamney)

# TERTIARY AND CRETACEOUS BIOSTRATIGRAPHIC DIVISIONS IN THE REINDEER D-27 BOREHOLE, MACKENZIE RIVER DELTA

## INTRODUCTION

### LOCATION AND HISTORY

The first exploratory well on the Mackenzie River Delta, B.A.-Shell - IOE Reindeer D-27, B.A.-Shell - IOE, 69°06'5"N., 134°36'54"W., penetrated 12,668 feet of strata. The borehole was drilled by the British American Oil Company Limited, Shell Canada Limited and Imperial Oil Enterprises Limited. It is located on the southeast end of Richards Island, 34 miles north and east of Reindeer Depot and 42 miles southwest of Tuktoyaktuk. It is approximately 15 miles upstream and 5 miles west of the East Channel, from Kugmallit Bay in the Beaufort Sea. Drilling commenced 7 August, 1965 and was completed 1 May, 1966. Electrical logs were run from 1,510 to 12,290 feet. The drilling program included the coring of a representative 10 per cent of the drilled interval. Drill stem testing and several mechanical logs provided data which were deposited with the Department of Indian Affairs and Northern Development. The most significant hydrocarbon show was a flow of gassy mud to the surface from the interval 6,838 to 6,855 feet. Electrical devices were placed in the borehole prior to abandonment in order to obtain continuous permafrost data readings; permafrost penetration is recorded to a depth of 106 feet.


### ACKNOWLEDGEMENTS

The author acknowledges the scientific laboratory and drafting support of G.D. Karg and the critical reading of the manuscript by B.S. Norford and F.G. Young, Institute of Sedimentary and Petroleum Geology, Geological Survey of Canada, Calgary, Alberta.


### PURPOSE OF REPORT

This report is primarily intended to aid subsurface correlation by establishing divisions that are presently considered to be genetically related depositional intervals for both the fossil organic content and the deposited sediments. Subdivision of this borehole by physical stratigraphic criteria alone produced only 7 gross divisions (Dept. of I.A. and N.D., 1968); biostratigraphic research has established 23 subdivisions. The biostratigraphic divisions are interpretations of the microfossil recovery from core


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and drill cuttings combined with obvious physical stratigraphic changes in the sequence of beds. These divisions, however, are primarily based on foraminiferal assemblages. Tentative international age assignments are based on index species of Foraminifera which, for reasons stated below, have many limitations in direct application in the Mackenzie River Delta area. The present biostratigraphic report is a refinement of the gross rock unit divisions previously reported as a preliminary biostratigraphic summary (Chamney, 1969d). One major change from this summary is the age assignment of the most distinctive foraminiferal division of "Cyclammina" sp. 1A from Late to Early Cretaceous. The necessity for change in the age of the division became obvious when the total microfaunal sequence was plotted in distribution chart format, revealing the presence of recycled drilling mud that contributed caved microfossil specimens. Interpretations of paleoecology were made in order to detect and outline genetically related depositional intervals. Study of the provenance of these suggests suitable trends for exploration for potential hydrocarbon reservoirs.

## MICROPALEONTOLOGY

### SAMPLING TECHNIQUES

Samples from both core and drill cuttings were utilized in the study in order to compile a complete microfossil sequence from the surface to the total depth of the borehole at 12,668 feet. Twenty-two cores were sampled by selecting 100 grams of material for each 5-foot interval. If obvious lithological changes were present within each 5-foot core box a lesser sampling interval was chosen. The samples were taken in vertical channels by chipping the sides of the cores after carefully removing drilling mud contamination. The selection of sample intervals for drill cuttings varied according to the lithology. The more or less unconsolidated sands and silts from depths 0 to 3,440 feet were primarily sampled using one composite sample for each 100 feet. A portion of the most argillaceous fraction of each of the ten bagged samples of cuttings was taken over the 100-foot interval to make up the 100 gram micropaleontological sample. The strata are more argillaceous lower in the well below the depth of 3,400 feet and three samples per 100 feet were taken.

### PREPARATION OF SAMPLES

Core chips required crushing with pestle and mortar or Chipmunk mechanical jaw crusher, and sieving through a Tyler mesh screen Number 10. All samples were thoroughly dried prior to soaking and boiling in Quaternary O, an ionic dispersal reagent. Some mechanical disintegration by the rolling process (Chamney, 1957) was necessary before washing out the deflocculated mud fraction on a nest of two screens, Numbers 150 and 200 Tyler mesh size; only a small part of the -150 to +200 mesh fraction was retained. The resultant washed residue or disintegrate was then filter-dried and sacked. An average residue of 3 grams was obtained from a 100 gram mudstone core sample; the amount of residue increased proportionately with increase in arenaceous components. Residues from extremely quartzose sandstone and siltstone intervals required processing through the Franz Isodynamic separator in order to segregate the quartz grains from the slightly magnetic, fossil organic remains.

For drill cuttings the average residue was 15 grams from a 100 gram sample. Ultrasonic cleaning, with 25,000 v.p.s. in an alkyl sulphonate reagent, was performed on each disintegrate to wash the fossil organic remains, making them clearly distinguishable from the mineral components in the residue.

## MICROFOSSIL PICKING

All classes of fossil organic remains were picked from the residues. Each residue was picked for an average of 1 1/2 hours which represents a different percentage of residue picked depending on the quantity of each residue. Thus for small residues of 1 to 3 grams the 1 1/2 hours of picking represents 100% of the fossil organic remains retrieved; for large disintegrates of up to 35 grams 1 1/2 hours of picking may represent only 50% of the residue picked. A limitation in the study is the application of results obtained from drill cuttings sampled from intervals of mainly coarse clastics. In these intervals, interbedded marine clays, which would normally provide abundant Foraminifera, are diluted in the original samples by the coarse clastic fractions. Also, the abundant quartz grains in the residues mask the microfossils and cause much difficulty in picking. There are limits in using special disintegration techniques and one must judge the overall control validity in choosing the refinement in which samples are to be prepared in the laboratory.

## PRESENTATION OF DATA

Identifications were made for each disintegrate on individual identification sheets; charts 1a to 1c and 2a to 2d (in pocket) give the complete record of each major class of fossil organisms and the significant minerals identified from the borehole. The distribution charts were compiled from the identification sheets by plotting the contents of the samples in descending stratigraphic order. Distribution charts compiled from subsurface borehole data record occurrences highest in the hole as being "first", as opposed to those drawn up from outcrop sections which are classically plotted from the lowest, first appearance upward, in order to portray evolutionary trends. The necessity for plotting the subsurface distribution charts in descending order is dictated by contamination of the samples from re-cycled drilling fluid, and cavings from the side walls of the borehole. Only the uppermost range or "tops" of fossil species or minerals are useful, because once a zone is penetrated its cuttings can be re-cycled many times in the drilling mud throughout the remainder of the borehole. The drill bit and fluid cause considerable sample disintegration within the borehole. If drill cuttings must be used it is desirable to obtain unwashed samples so that the drilling mud present in the sample contributes more abundant microfauna from the added natural disintegration by the drilling bit in the hole.

The distribution charts use the terms "header" for the columned species and "shoulders" for the steps in descending order of new species forming the "leading edge" of the plotted occurrences (Fig. 2). Significant changes in microfossil biofacies are graphically illustrated by the presence of obvious "shoulders" in the plot. Such evident shoulders are used to select biostratigraphic divisions. The uppermost occurrence is the upper limit of the local range or teilzone for a given species; these species ranges are discussed in detail under the description for each biostratigraphic division.

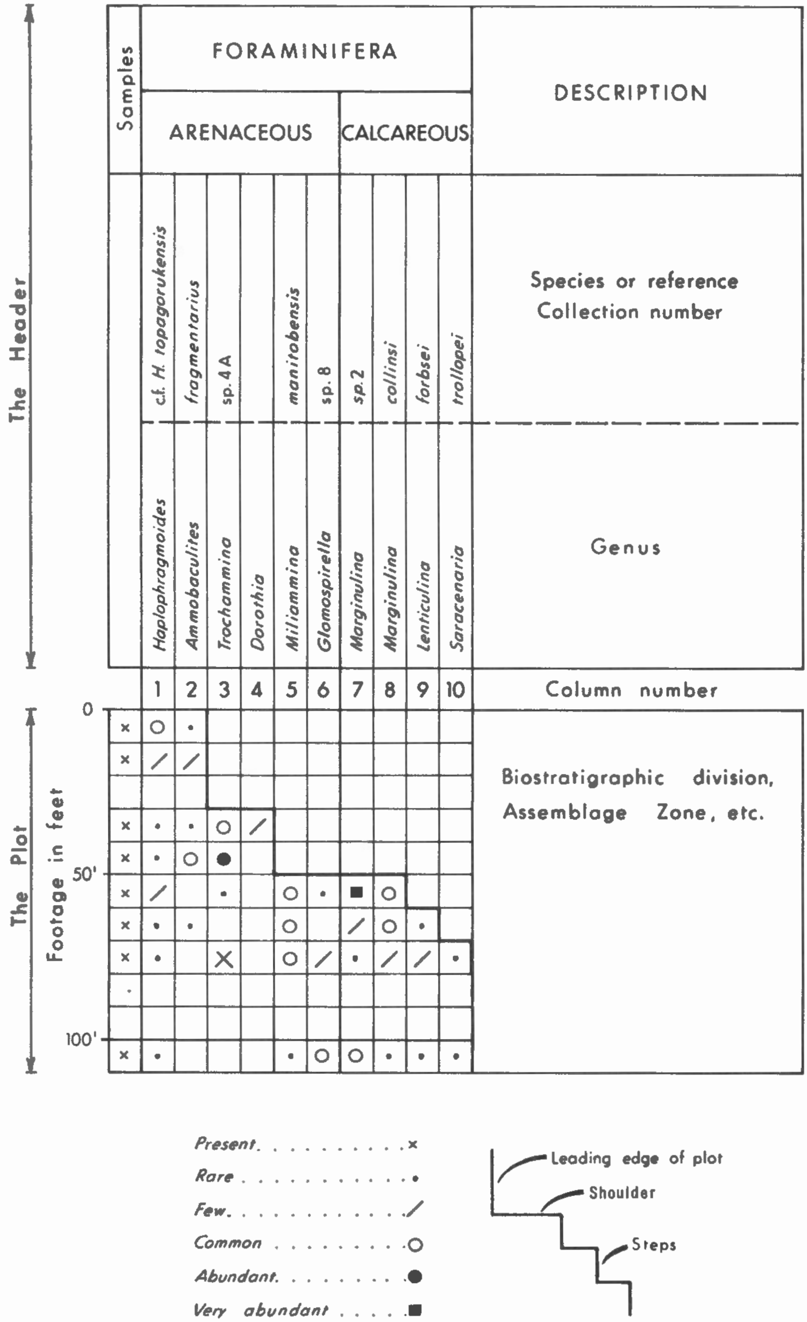


Figure 2. Format used in distribution chart

## CLASSES OF ORGANISMS AND TAXONOMIC LEVELS

All classes of fossil organic remains recognizable in the prepared samples are reported. These include microscopic and macroscopic invertebrates, vertebrates, protistids (algal groups) and plant remains. The Foraminifera are by far the most abundant and important microfossils for interpreting biostratigraphic divisions that are used for correlation, geologic age assignment and paleoecological interpretation. The importance of picking all significant organic remains and mineral occurrences is two-fold. First, the extra time required by the pickers to remove those objects from the residues is minor compared to the time required for future re-examination to obtain non-foraminiferal specimens. Second, the chances of establishing correlative horizons in other subsurface sections are greatly enhanced by the additional control provided by all classes of fossil organisms. For example, the belemnite phragmacone horizon established from the depth of 11,000 feet has been recognized in the equivalent stratigraphic horizon from two additional boreholes in the Mackenzie River Delta area. All classes of fossil remains contribute significantly to the paleoecological interpretations of the intervals.

Agglutinated, benthonic species of Foraminfera are the predominant biofacies of the Reindeer D-27 borehole. With the exception of the biozone Trochamminoides sp. 9 and "Cyclammina" sp. 1A, in the interval 9,000 to 9,880 feet, the intervals of abundant arenaceous benthonic species include quite primitive forms, very tolerant of considerable influx of fresh water. In general the microfossils recovered from the Tertiary and Cretaceous stratigraphic sequence indicate very restricted to brackish-marine environments. Many modes of deposition representing high energy and turbidity are indicated by deposits of deltaic origin or rapid sediment dumping. These environmental conditions were not appropriate for colonization by pelagic or pseudopelagic, calcareous Foraminifera that are customarily used for interbasinal correlation; such conditions favour local or endemic development of rather primitive benthonic species which adapted to active sediment sources near the continental shoreline. Open marine conditions in both the Tertiary and Cretaceous Systems may become prevalent north and east of the well (Chamney, 1969e). The present tentative age assignements of the Reindeer D-27 biostratigraphic divisions will be corroborated, refined or revised when information is available from wells drilled through more open marine successions.

Taxonomic levels of microfossil identifications range from gross to detailed, with those of the Foraminifera being the most precise. Adverse environmental conditions produced many local variations but such forms require considerably more research for their taxonomic description than is necessary for a biostratigraphic report. In view of this, an artificial number system has been used for designating potentially new species. The species number system refers to a regional reference collection; the prefix "G" (for graphed species) has been used for the two most common genera Haplophragmoides and Trochammina. Figures 3 and 4 display graphed parameters of their criticial taxonomic features such as number of chambers per whorl versus coil diameter. The accompanying indexes for the graphs provide similarities to published species, depth of recovery (uppermost species range) and the parameters of the type species of the two genera. Future reports of other subsurface sections in the Delta will record species of these two predominant genera in terms of these graph references. This will ensure consistency in species identifications and will show elucidation of local endemic, morphological series and comparison with described species from other geological provinces.

Figure 3 is a graph representing species of Trochammina recovered from the Reindeer D-27 borehole. The species are referred to in the text by number and the prefix "G" (indicating graphed but undescribed species).

| TROCHAMMINA SPECIES Graph No. | Tentative Identification | Reindeer D-27 Depth in Feet | Graphed Parameters Chamber No. x Diam. (mm) |
|---|---|---|---|
| G1 | ? latumbilicata | 3,350 to 90 | 10 x 0.62 |
| G2 | | 5,520 to 25 (core) | 6- 7 x 0.30 |
| G3 | ex gr. rainwateri | 5,600 to 50 | 4 x 0.37 |
| G4 | ? umiatensis Tappan, lobate | 5,600 to 50 | 5 x 0.60 |
| G5 | ribstonensis | 6,115 to 16 (core) | 5 x 0.26 |
| G6 | trochoid | 6,300 to 30 | 9 x 0.43 |
| G7 | lobate | 7,320 to 50 | 6 x 0.43 |
| G8 | cf. sp. G2 | 7,560 to 90 | 7- 8 x 0.30 |
| G9 | lobate | 7,720 to 50 | 7 x 0.50 |
| G10 | rainwateri | 8,364 to 65 (core) | 6- 7 x 0.3+ |
| G11 | | 8,480 to 90 | 5- 6 x 0.37 |
| G12 | minute umiatensis Tappan | 8,640 to 50 | 7 x 0.20 |
| G13 | moderately high spired | 11,040 to 50 | 8 x 0.8 |
| G14 | deep umbilicus, moderately coarse | 11,416 (core) | 7 x 0.29 |

Figure 4 is a graph representing new species or problematic groups of Haplophragmoides recovered during micropaleontologic research on the Reindeer D-27 borehole samples. They are referred to in the text with corresponding number and the prefix "G" (indicating that they are graphed species not described in this report).

| HAPLOPHRAGMOIDES SPECIES Graph No. | Tentative Identification | Reindeer D-27 Depth in Feet | Graphed Parameters Chamber No. x Diam. (mm) |
|---|---|---|---|
| G1 | spissum | 0 - 90 | 14 x 0.50 |
| G2 | globosa or howardense var. manifestum Stelck and Wall | 0 - 90 | 10-11 x 0.31 |
| G3 | | 700 - 790 | 12-14 x 1.50 |
| G4 | | 3,550 - 90 | 5- 6 x 0.60 |
| G5 | | 3,750 - 90 | 9-10 x 0.62 |
| G6 | | 4,000 - 10 | 5 x 0.26 |
| G7 | | 4,065 (core) | 5 x 0.43 |
| G8 | | 4,650 - 90 | 8- 9 x 0.33 |
| G9 | | 4,763 - (core) | 5 x 0.13 |
| G10 | | 4,770 - (côre) | 13 x 0.30 |
| G11 | | 5,050 - 90 | 18 x 0.50 |
| G12 | ex gr. gigas minor Nauss | 6,105 - 6,110(core) | 7 x 0.37 |
| G13 | cf. gigas minor Nauss | 5,800 - 40 | 6- 7 x 0.43 |
| G14 | | 6,260 - 90 | 8 x 0.43+ |
| G15 | coarse grained | 6,700 - 50 | ?14 x 0.62 |
| G16 | nodular corona | 7,040 - 50 | 14 x 0.56 |
| G17 | | 7,160 - 90 | 9 x 0.50 |

| HAPLOPHRAGMOIDES SPECIES Graph No. | Tentative Identification | Reindeer D-27 Depth in Feet | Graphed Parameters Chamber No. x Diam. (mm) |
|---|---|---|---|
| G18 | | 7,200 - 30 | 8 x 0.37 |
| G19 | straight sutures (cf. G13) | 7,280 - 7,310 | 6 x 0.50 |
| G20 | | 7,480 - 7,510 | 5- 6 x 0.38 |
| G21 | minute <u>gigas</u> <u>minor</u> Nauss | 7,830 - (core) | 6- 7 x 0.25+ |
| G22 | | 7,960 - 90 | 5- 6 x 0.50 |
| G23 | wafer thin | 8,280 - | 4- 5 x 0.13 |
| G24 | distinctive inflation | 8,364 - (core) | 6 x 0.25 |
| G25 | very minute form | 8,379 - 82 (core) | 6 x 0.14 |
| G26 | | 8,640 - 70 | 9-10 x 0.20 |
| G27 | ex gr. <u>topagorukensis</u> Tappan also related to <u>gigas</u> group (sp. 66) | 8,800 - 30 | 14 x 1.00 |
| G27A | slightly perforate (?<u>Cyclammina</u>) | 9,593 - 30 | 11-12 x 0.25+ |
| G28 | inflated sl. evolute (sp. 65) | 9,560 - 90 | 7 x 0.80 |
| G29 | inflated and compressed wafer | 9,588 - (core) | 8- 9 x 0.166 |
| G30 | slight depressed sutures | 9,593 - (core) | 10-11 x 0.37 |
| G31 | | 9,600 - 30 | |
| G32 | | 9,720 - 50 | 12± x 0.29 |
| G33 | moderately coarse | 9,920 - 50 | 5 x 0.40+ |
| G34 | | 10,027 - (core) | 6- 7 x 0.41 |
| G35 | ex gr. <u>gigas</u> sigmoid suture | 10,160 - 90 | 14± x 0.58+ |
| G36 | sl. curved suture, sl. nodular corona | 10,200 - 30 | 11-12 x 0.58 |
| G37 | <u>gigas</u> | 10,240 - 70 | |
| G38 | lobate periphery | 10,280 - 310 | 7 x 0.50 |
| G39 | | 10,280 - 310 | |
| G40 | | 10,760 - 800 | 10-11 x 0.50+ |
| G41 | very coarse agglutinated | 11,416 - (core) | 7 x 1.00 |
| G42 | minute | 11,416 - (core) | 5+ x 0.20 |
| G43 | high silica cement | 11,431 - (core) | 6 x 0.42 |
| G44 | ex gr. <u>goodenoughensis</u> | 11,520 - 50 | 9-10 x 0.70 |
| G45 | ex gr. <u>duoflatis</u> | 11,887 - 90 (core) | 7+ x 0.20 |
| G46 | evolute ? parent stock of <u>Trochamminoides</u> | 12,280 - 310 | 14± x 0.30 |

Other classes of fossils are not as precisely identified; many are represented only by fragmentary remains of macroscopic invertebrates and vertebrates. Worldwide research on megaspores has not yet produced a system of classification referable to extant genera. Megaspores are recovered in considerable quantity by the water soluble disintegration technique used in micropaleontological sample preparation, but are mainly destroyed by the acid maceration technique applied in palynological sample preparation. Therefore, they have been picked from the washed residues and identified using a tentative taxonomic system. The system utilizes letter and number combinations to designate convenient form genera. The following is a brief summary of the megaspore form genera drawn in Figure 5.

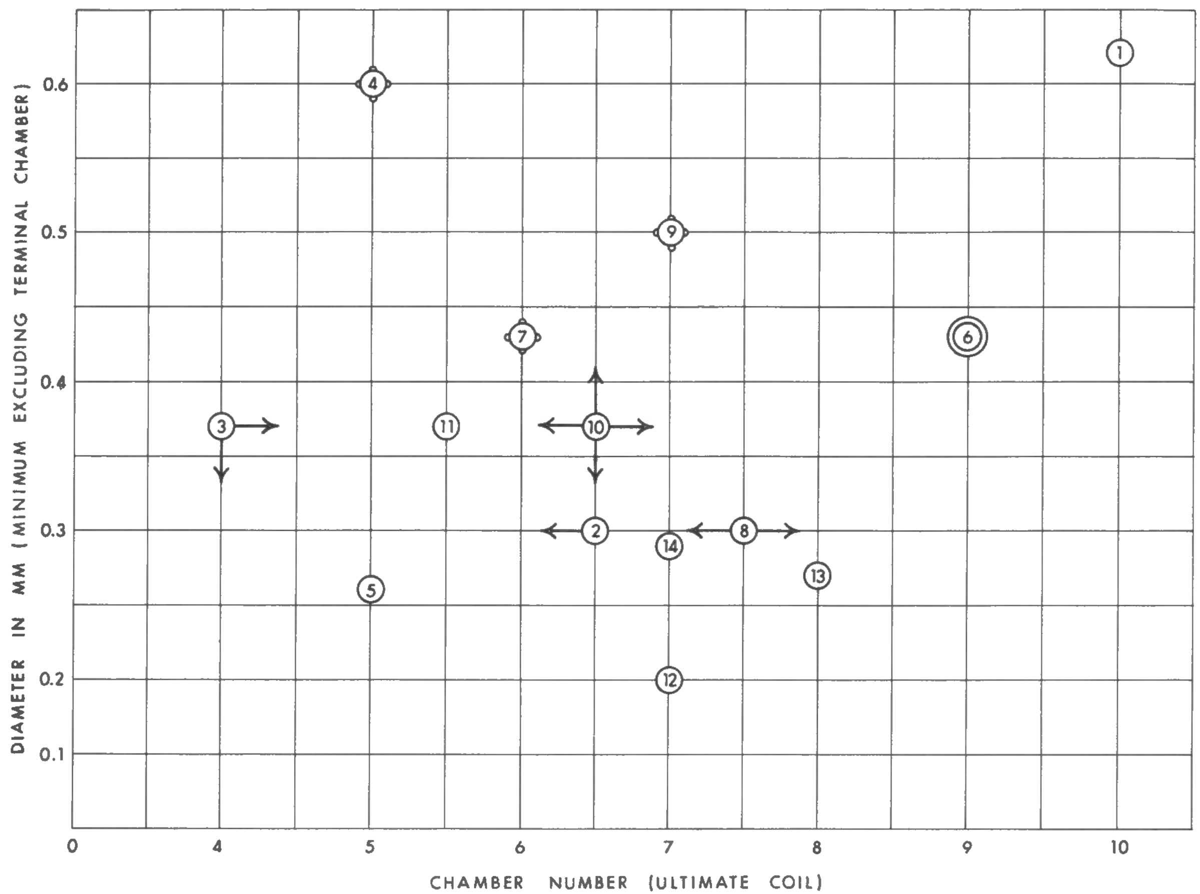


Figure 3. Trochammina - graphed taxonomic parameters for new species

GROUP I: SACK-LIKE FORMS

A. Spheroidal (balls): near spherical forms overlap with forms transitional between discs and "bean shaped" forms. Note: squashed spheres fall into disc or wafer subgroups.

B. Discoid: deflated spheres - these may involve duplication of species with the spherical forms.

C. Wafers: usually amber coloured and crenulated; if a trilete scar is discernible then Group ID is used. These forms are possibly very thin-walled spherical cases which collapsed after burial.

D. Wafer or very thin trilete scarred: some Triletes sp. with thicker carbonized walls are also common in this group.

A few of the taxa referable to Group I are:
Radiatisporites
Superbisporites
?Setosisporites

GROUP II: SACK and ELONGATE FORMS

A. Triletes: scars discernible; the chance orientation of some specimens when the case was compressed probably forced the trilete scar into a spike.

A few of the taxa referable to Group IIA are:
Lagenicula
Lagenoisporites

B. Pyrobolospora: "floating" appendage protrudes from sack-like spore case.

GROUP III: ELONGATE FORMS

A. "Bean-shaped": morphologically overlap with the spheroids, sacks, and the more elongate Group IIIB; an arbitrary division is used.

B. Costatheca (Chrysotheca): elongate, thin-walled, somewhat translucent amber or dark brown; extreme crenulations to actual ridges are common.

C. Cuticle-like: questionable spore cases but commonly occur in fluviatile sediments and should be recorded.

D. "Spear-spore": extreme elongation and translucent amber "grass-like" spore case. It first appears in the uppermost Jurassic and persists to the Recent.

E. Microcarpolithes ("barrel shape"): first appears in the Lower Cretaceous and is thought to be related to spore cases of marshy mangroves. It has hexagonal sides and variable length-diameter proportions.

GROUP IV: BLADDER TO ANGULAR FORMS
(not too common as megaspores but very common in the contained pollen and spores within the megaspores).

A. LOBATE: the form consists of two, three or four sacks.

B. ANGULAR FORM (extreme angular): triangular or quadrate outline.

A few of the taxa referable to Group IV are:
Microsporites
Triangulatisporites
?Zonatesporites

## BIOSTRATIGRAPHY

### CRITERIA FOR BIOSTRATIGRAPHIC DIVISIONS

The twenty-three interpreted divisions of the distribution charts (in pocket) are designated as biostratigraphic divisions although both biological and physical stratigraphy have been assessed for their establishment. They were, for the most part, selected on the basis of foraminiferal assemblages and form practical subsurface units for correlation. Further application of the divisions using additional subsurface sections in the Delta area, may prove many of them to represent Assemblage Zones (ACSN, 1961). Four of these divisions are known to be regional microfossil zones. These are divisions 7, 9, 11C and 13, the zones of Trochammina ribstonensis, Verneuilinoides borealis, Miliammina manitobensis and Haplophragmoides gigas. A possible fifth, zonal index species is the radiolaria sp. 9 (Dictyometra sp.) index to division 14C. This index species has been previously reported from the Early to Middle Albian boundary of the Yukon (Chamney, 1967; Mountjoy and Chamney, 1969) and from equivalent stratigraphic horizons in Alaska (Tappan, 1960).

The micropaleontological elements of the borehole indicate modes of deposition associated with rapid lateral lithofacies changes (see discussion of the depositional framework). Such changes make it difficult to correlate on the basis of physical evidence alone. The biostratigraphic divisions are based on biofacies changes present in this single borehole. For the purpose of correlation with additional borehole sections in the Mackenzie River Delta area, an attempt has been made to make the boundaries of the biostratigraphic divisions coincident with distinctive changes in both the biofacies and the lithofacies. Much of the lithological interpretation has been made from the electric log and, therefore, distinctive electric log features are present at many of the boundaries of the biostratigraphic divisions. Seven depositional intervals from "A" to "G" (Fig. 6) have been established by combining genetically related biostratigraphic divisions. Only one informal rock unit name has been proposed in the well completion report by the drilling consortium (DIA and ND, 1968) which coincides with biostratigraphic division 16, the Siphotextularia spp. from 11,880 to 12,560 feet.

Stratigraphic nomenclature correlation is submitted as a tentative rock unit correlation table (Fig. 6) which may improve the understanding of the proposed biostratigraphic divisions in terms of familar rock-stratigraphic equivalents previously reported from other better known geological provinces.

## BOUNDARY DEFINITIONS

Several species making their first appearance in the same sample result in a prominent "shoulder" in the leading edge of the distribution chart. The prominent shoulders generally form the basis for selecting the upper boundaries of microfaunal assemblages that are the biostratigraphic divisions. The upper boundaries of the divisions thus provide the bases for the overlying microfossil assemblages.

The foraminiferal species listed in the following discussions of each biostratigraphic subdivision are only those making their first appearance in descending stratigraphic sequence. Many additional species are present in the same sample but are present also in the overlying subdivisions. Only in a core sample is the total microfossil assemblage in situ; drill cutting samples are contaminated by microfossils from the up-hole sediments. Chart 1a to 1c shows all identified species recovered from each sample but to repeat many of these species at the greater depths recorded in Charts 2a to 2d, would require twice the "header" widths. For this reason, that portion of the distribution chart repeating species recovered from 0 to 6,960 feet has been omitted from Charts 2a to 2d with the exception of a few diagnostic species whose second acme of occurrence is of utility in the older strata.

With the exception of regional index species, the microfossil nomenclature selected to represent the biostratigraphic subdivisions is based, in part, on experience from the regional, biostratigraphic application of these classes of organisms. As shown in the distribution charts, the Foraminifera, in particular the agglutinated or arenaceous forms, are the most significant. The reasons for selecting one or two species to represent the total microfossil assemblage are given in the following discussions of each subdivision. A binomial system which includes one benthonic, agglutinated form and one pseudopelagic, calcareous form of Foraminifera is applied, where possible, and may allow retention of the subdivision names in subsequent studies of boreholes located in areas of probable ecological differences. The biostratigraphic divisions are not based on the one or two named species alone but are functions of the total assemblages which will vary laterally with changing paleoecological conditions. However, with sufficiently closely spaced control-sections, these changes should not be so drastic as to eliminate all of the common elements required to permit correlation.

## THE BIOSTRATIGRAPHIC DIVISIONS

Seventeen divisions and six subdivisions are defined in this study as summarized in Figure 6. Interpretative subdivisions are shown on the distribution charts but provisional age assignments and tentative stratigraphic correlations are omitted. The electric log was not recorded above a depth of 1,523 feet so that very little physical data are available for the first four subdivisions. The drill cuttings provide some lithological information but considerable sample contamination in the uncased borehole above 1,523-foot depth prevents accurate interpretation of the strata. An asterisk preceding species in the following subdivision microfossil lists denotes index species used for naming the subdivisions.

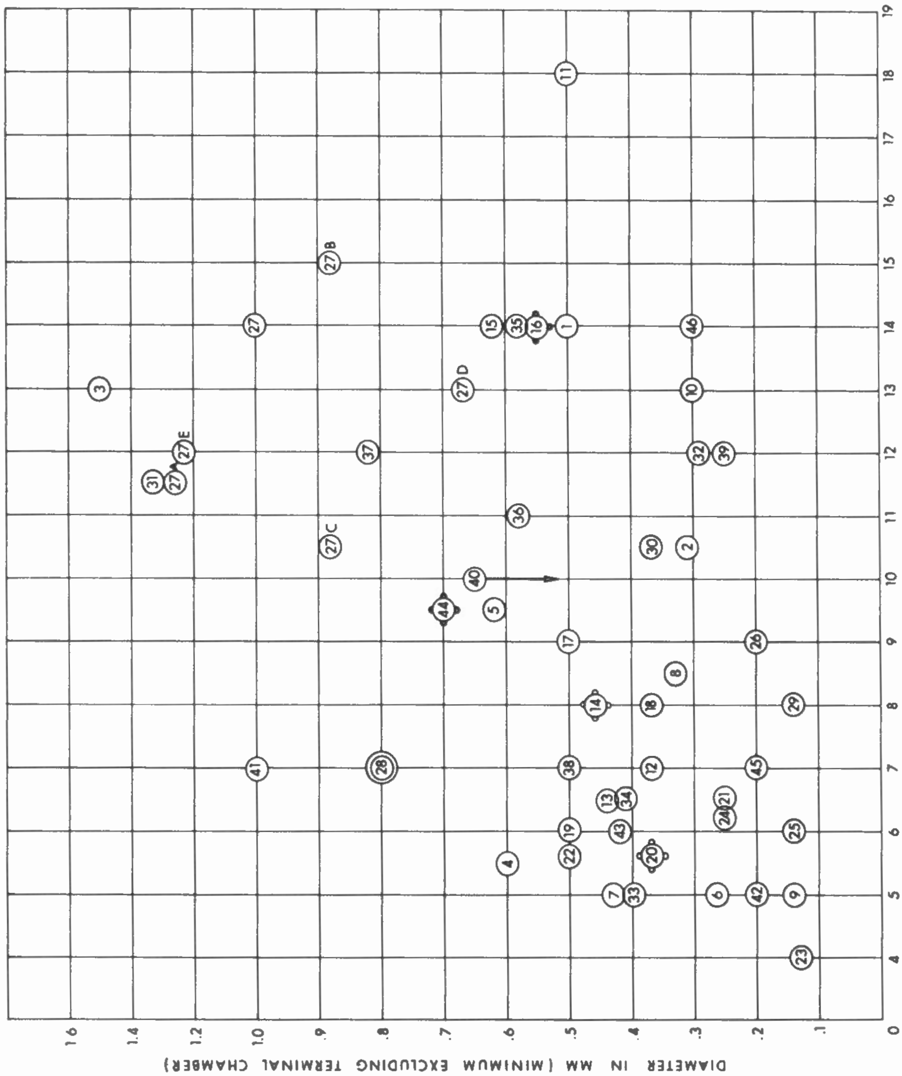


Figure 4. Haplophragmoides - graphed taxonomic parameters for new species

## QUATERNARY, TERTIARY AND UPPER CRETACEOUS, CHARTS 1a to 1c. (0 - 6,960 feet)

### Recent deposits; division 1. (0 to 40 feet)

The upper boundary of this division is the surface elevation of the borehole recorded as 90 feet above sea level. The drill cutting samples were very poor consisting of quartz and coloured mafic grains. These grains are very fine to medium, and are subrounded to sharp angular with some frosted and pitted. Fossil remains recovered include algal spheres, plant megaspore cases (ovoid) and echinoderm fragments. Reworked or derived Foraminifera include the following species:

Haplophragmoides ex gr. H. spissum
H. ex gr. H. globosa
Ammobaculites euides

Age assignment to the Recent is based on the fragments of recently buried invertebrates within this interval. The bedding relationship with the underlying Pleistocene deposits is transitional throughout a thickness of about 100 feet.

### Ostracods and Chara; division 2. (40 to 500 feet)

The upper boundary of this division is based on the appearance of ostracods and Chara and the downward lithological change to slightly calcareous, light grey (?marly) clay fragments in the drill cutting samples. Megaspore cases, pelecypod shell fragments (?Unio sp.), gastropods and fish bones also begin to appear in division 2. The recovered Foraminifera are probably derived:

Bathysiphon sp. 3
Glomospirella sp. indet.

The age assignment is established tentatively on the basis of the ostracods and Chara which form part of a similar assemblage to those of known Pleistocene deposits in the area (ref. Rond Lake No. 3, Decalta et al., 0 - 10', 67°07'N., 128°22' 36"W.).

### Reworked transition with Cyclammina sp.; division 3. (500 to 1,180 feet)

The upper boundary of this division is based on the sudden influx of many foraminiferal species. Some of these are possibly indigenous forms but others are derived from older, reworked Upper Cretaceous strata. The following species of Foraminifera were recovered:

Miliammina sp.
Ammodiscus sp.
Trochammina sp.
Haplophragmoides sp.
Miliammina sp. 1B
Trochammina ex gr. T. ribstonensis

Verneuilinoides sp.
Cyclammina sp.
Ammodiscus sp.
Haplophragmoides sp. G3
Reophax sp.
Trochammina ex gr. T. rainwateri
?Elphidium sp. fragments

Megaspore cases are absent but some coal fragments and pyritized wood are present. These may indicate a predominantly fluviatile-delta mode of deposition with some marine intertonguing that provided a few Foraminifera. Ostracods and Charophyta stems, gastropods and smooth shell fragments of pelecypods may indicate also considerably brackish water conditions of lagoon or salt marsh environments. The interval appears to be transitional with the overlying zone and is tentatively assigned a Pleistocene/Tertiary age.

## Derived Foraminifera in reversed stratigraphic sequence; division 4. (1,180 to 2,170 feet)

A considerable number of foraminiferal species were recovered from this depositional interval. The most striking feature of these microfossils is that they indicate a sequence of geological ages in reverse stratigraphic order with a short repetitive cycle at the bottom. The following is a list of Foraminifera in descending order of occurrence with reference to their geologic age:

Arenoturrispirillina cf. A. waltoni (Late Jurassic)
Haplophragmoides cf. H. goodenoughensis (Neocomian)
Ammodiscus cf. A. aspera (Cretaceous/Jurassic boundary)
Ammobaculites luekei (Early Cretaceous)
Glomospirella cf. G. arctica (Barremian)
Bathysiphon scintillata (Barremian)
Arenobulimina torula (Late Cretaceous)
Trochammina cf. T. whittingtoni (Late Cretaceous)
?Cyclammina sp.
Pseudoclavulina cf. P. hastata (Late Cretaceous)
Haplophragmoides ex gr. H. gigas, sp. 9C (Albian)
Textularia sp.
Reophax cf. R. densa (Early Jurassic)
Haplophragmoides cf. H. inflatigrandis (Neocomian)
Triplasia kingakensis (Late Jurassic)
Psamminopelta sp.
Haplophragmoides ex gr. H. canui (Cretaceous/Jurassic boundary)

The implications of this reversed sequence cannot be fully resolved from the evidence of only one borehole. The reversal in age sequence may reflect the erosional history of the source rocks and thus of the detritus carried by the ancient Mackenzie River drainage system. This biostratigraphic division is tentatively assigned to the Tertiary System.

Radiolaria-spherical and discoid; division 5. (2,170 to 4,740 feet)

The division consists of three distinctive biostratigraphic subdivisions within the total species range of certain Tertiary radiolarians. The boundaries, microfossil content and age assignments are discussed in detail for each subdivision.

Radiolaria-spherical and discoid; subdivision 5A. (2,170 to 3,600 feet)

The upper boundary of this subdivision is selected at the uppermost occurrence of orbicular and discoid radiolaria. These minute organisms are very common in the Tertiary in association with common to abundant algal remains of the Chareacea. The upper boundary also coincides with a very pronounced change in the electric log character. The corresponding lithological change is from overlying, porous sands and silts, possibly unconsolidated, to better consolidated (cemented), less porous sands and silts with clayey interbeds. The Foraminifera recovered from this depositional interval are agglutinated, benthonic forms similar to those encountered in the overlying zones. Only one calcareous Foraminifera (Lagena sp., at a depth of 3,560 feet near the base of the subdivision) is present, indicating that open marine conditions were very rare during the deposition of this sequence. Species of Foraminifera making their first appearance are, in descending stratigraphic sequence:

Arenobulimina sp.
Ammobaculites sp.
Reophax (Proteonina) sp.
Haplophragmoides ex gr. H. crickmayi
Hippocrepina sp.
Pelosina (Hyperamminoides) sp.
Haplophragmoides sp. 5
Trochammina ex gr. T. latumbilicata
Haplophragmoides sp. G4

Megaspore cases are rare, but fossil wood and carbonized plant remains are abundant; a coal horizon is present at 3,400 to 3,410 feet. Fish bone and teeth remains are common and amber fragments are abundant. The following taxa of radiolarians are tentatively identified and are similar to some of the species in reported Paleocene assemblages (Frizzel and Middour, 1951):

Dorylonchidium (Dorylonchella) exlineae Middour
Spongolonchis grawei Middour
?Cenellipsis (Cenellipsula) pecki Middour

The rare megaspores present are represented by species of the Group IC, referable to the genus Sporitoides. Recovery of these megaspores has been from the Maestrichtian (Upper Edmonton Formation) and the Paleocene (Paskapoo and Ravenscrag Formations) of the Western Interior geological province. The youngest microfossils identified indicate a Paleocene age assignment but younger beds of Eocene or Miocene ages may be present in this upper subdivision 5A.

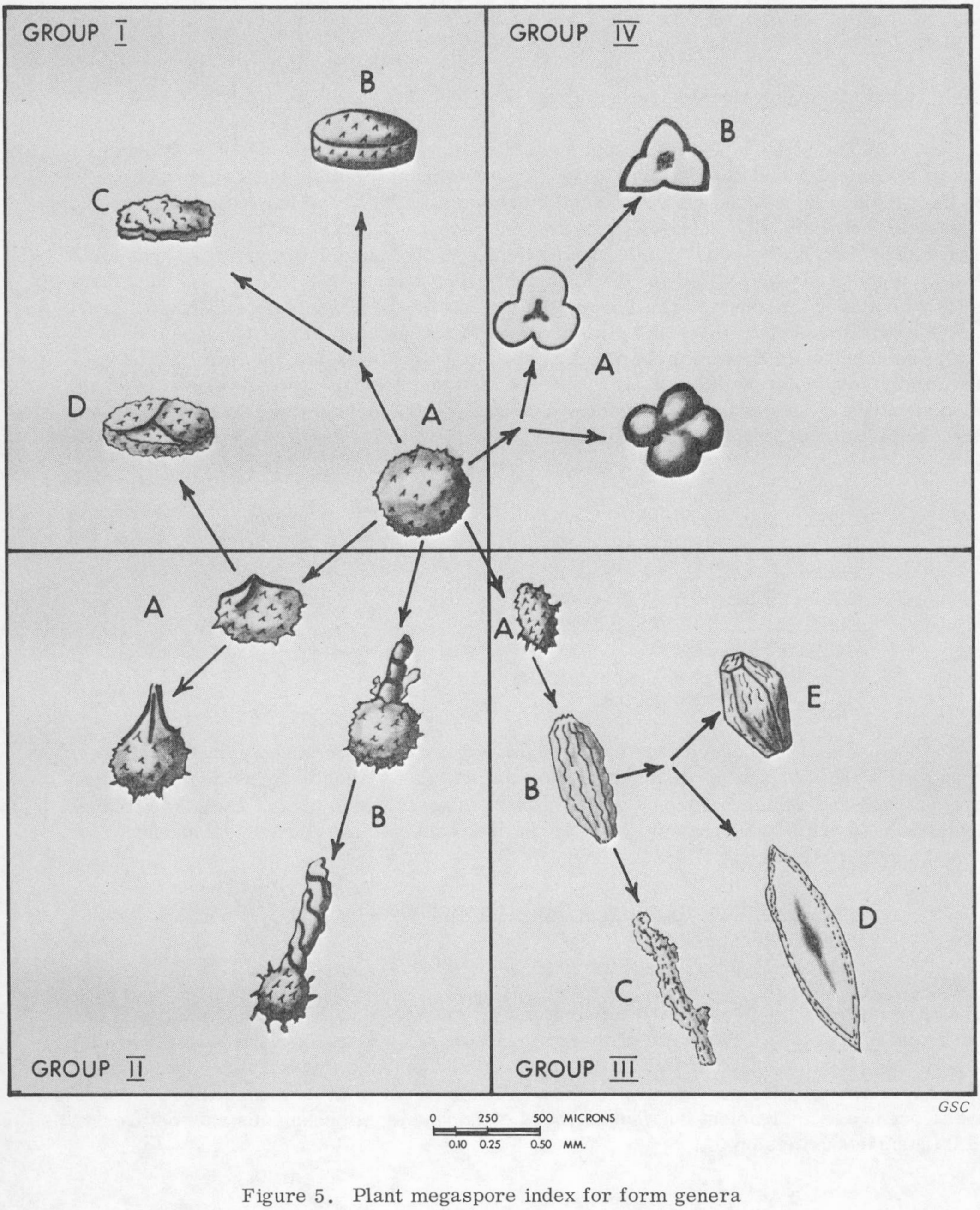


Figure 5. Plant megaspore index for form genera

Hippocrepina sp. 6; subdivision 5B. (3,600 to 4,200 feet)

The upper boundary is based on the sudden first appearance of several Foraminifera at 3,680 feet. Drill cutting sample intervals comprise rather large vertical intervals and thus do not indicate the precise horizons between the microfossil assemblages. On the basis of significant physical evidence from the electric log, a depth of 3,600 feet was selected for the upper boundary. Continued recovery of abundant orbicular and discoid radiolaria suggests a genetic relationship with the overlying assemblage. The depositional environment is marine but shallower and more restricted than the overlying interval as indicated by the recovery of several primitive, unilocular, benthonic species and the absence of calcareous species of Foraminifera. Species of Foraminifera making their first appearance are:

*Hippocrepina sp. 6
Verneuilinoides ex gr. V. fischeri
Ammobaculites wenonahae
Gaudryina sp.
Plectina sp.
Flabellammina sp.
Haplophragmoides sp. G5
H. sp. G6
Saccammina sp.
Haplophragmoides sp. G7
Hippocrepina sp. G7
Haplophragmoides sp. G8

Because Hippocrepina sp. 6 is the most abundant foraminiferal species in the assemblage the name has been selected for the subdivision. The subdivision is tentatively assigned to the Paleocene Epoch of the Tertiary.

Deltaic transition beds; subdivision 5C. (4,200 to 4,740)

The distinctive feature of this subdivision is the paucity of Foraminifera and other marine invertebrates and vertebrates, and the abundance of fossil wood and plant remains. Radiolaria and algal species are present in this depositional interval and are similar to those of the orbicular and discoid radiolaria subdivision but the depositional environment seems to be predominantly fluviatile-deltaic. For this reason it is designated as the "Deltaic Transition Beds". The subdivision is tentatively assigned to the Paleocene Epoch of the Tertiary.

Haplophragmoides sp. G21 and Anomalina cf. A. moniliformis; division 6. (4,740 to 5,600 feet)

The upper boundary of this division is quite distinctive and shows the first major influx of marine species. The predominant element consists of species of Haplophragmoides. Several occurrences of calcareous Foraminifera, and marine invertebrate and vertebrate remains suggest an open marine environment. The following are the first occurrences of Foraminifera for this division:

Haplophragmoides sp. G9

H. sp. G2
H. sp. G10
H. sp. G12
*H. sp. G21
?Hippocrepina sp.
Haplophragmoides cf. H. eocalcula
Thuramminoides sp. 3
Bathysiphon (?Hyperammina) sp.
Miliammina ex gr. M. manitobensis
Haplophragmoides sp. G11
H. sp. G10
Verneuilinoides ex gr. V. borealis
Saccammina (?Hippocrepina) sp.
Hippocrepina sp. 1
Haplophragmoides cf. H. excavata
Trochammina sp. G2
Glomospira sp.

calcareous form:

*Anomalina cf. A. moniliformis

Haplophragmoides cf. H. excavata, Cushman and Waters, 1927 is an index species for the Upper Cretaceous of the Western Interior of North America and was originally described from the Navarro Stage of the Gulf Coast area (Cushman and Waters, 1930). The uppermost teilzone range of this species is associated with Gaudryina bearpawensis Wickenden in the Maestrichtian portion of the uppermost Bearpaw Formation (Russel and Chamney, 1967). The lower limit of the teilzone is within the Bearpaw Formation.

## Trochammina sp. G3 and Anomalina sp. 4 Assemblage Zone; division 7. (5,600 to 6,220 feet)

This biostratigraphic division shows the following changes from the overlying interval:

(a) numerous first appearances of new agglutinated, benthonic, foraminifers dominated by Trochammina spp.

(b) presence of calcite prisms from the prismatic shell layer of the pelecypod Inoceramus sp.

(c) very distinctive change in the electric log character.

The Foraminifera are as follows in descending stratigraphic sequence:

?Gaudryina sp.
*Trochammina sp. G3
T. sp. G4
Pelosina (?Hippocrepina) sp.
?Ammobaculites sp. indet.
Haplophragmoides sp. G13
Ammodiscus cf. A. planus
Gaudryina (?Tritaxia) sp. indet.

Saccammina sp. 2
Haplophragmoides sp. 12
Trochammina sp. G5
calcareous form:
*Anomalina sp. 4

The variations in taxonomic criteria separating Trochammina sp. G3 from T. whittingtoni Tappan are not too great; hence, there appears to be a similarity to the microfaunal assemblage of the Early Senonian portion of the Schraeder Bluff Formation of Alaska (Tappan, 1962). Some specimens of Trochammina sp. G3 are referable to T. ribstonensis of Senonian age (Chamney, 1969d).

Trochamminoides spp. and Lenticulina sp. 6B; division 8. (6,220 to 6,960 feet)

The upper boundary is selected at the first appearance of evolute coiled Trochamminoides-like species of Foraminifera. This is the uppermost range of a morphological series showing the development of these forms that is developed in the older strata of the borehole. The electric log character also indicates a marked change in the lithostratigraphy to more argillaceous intervals approaching a mudstone sequence. From this boundary at 6,220 feet to the total depth of the borehole, organic remains are more common and may indicate a decrease in the rate of sediment deposition. First appearing species of Foraminifera are:

Haplophragmoides sp. G14
*Trochammina (?Trochamminoides) cf. T. sp. G6
Haplophragmoides cf. H. sp. G15
*Trochamminoides sp.
*Lenticulina sp. 6B

Orbicular radiolaria form a minor part of the assemblage. Similar radiolarian species are reported from the Roger's Creek Member of the Schraeder Bluff Formation of Alaska (Tappan, 1962, p. 127) and from the "Pale Shale zone" (Yorath and Balkwill, in press) of the Anderson Plains (Chamney, 1969d). Associated with these orbicular radiolarians in Alaska is Trochammina whittingtoni Tappan (1962, Pl. 39, Fig. 3) which is quite similar to the evolute forms of this study referred to the genus Trochamminoides. The division is tentatively dated as Campanian (?Early) to ?Santonian of the Upper Cretaceous Series.

LOWER CRETACEOUS, CHARTS 2a to 2d. (6,960 to 12,668 feet)

Verneuilinoides borealis and Ammobaculites fragmentarius with Citharina spp. Assemblage Zone; division 9. (6,900 to 8,360 feet)

The paucity of microfossils suggests a rapid rate of deposition. The most significant species are those used to name the division. The upper boundary is selected at a very abrupt change in electric log character, 170 feet above the first occurrence of the index species. This change represents a major unconformity correlative with the "Morden" unconformity known on the Anderson Plains and, to a lesser degree, southward into the Western Interior Plains region (Chamney, 1969b). Thus, the stratigraphic

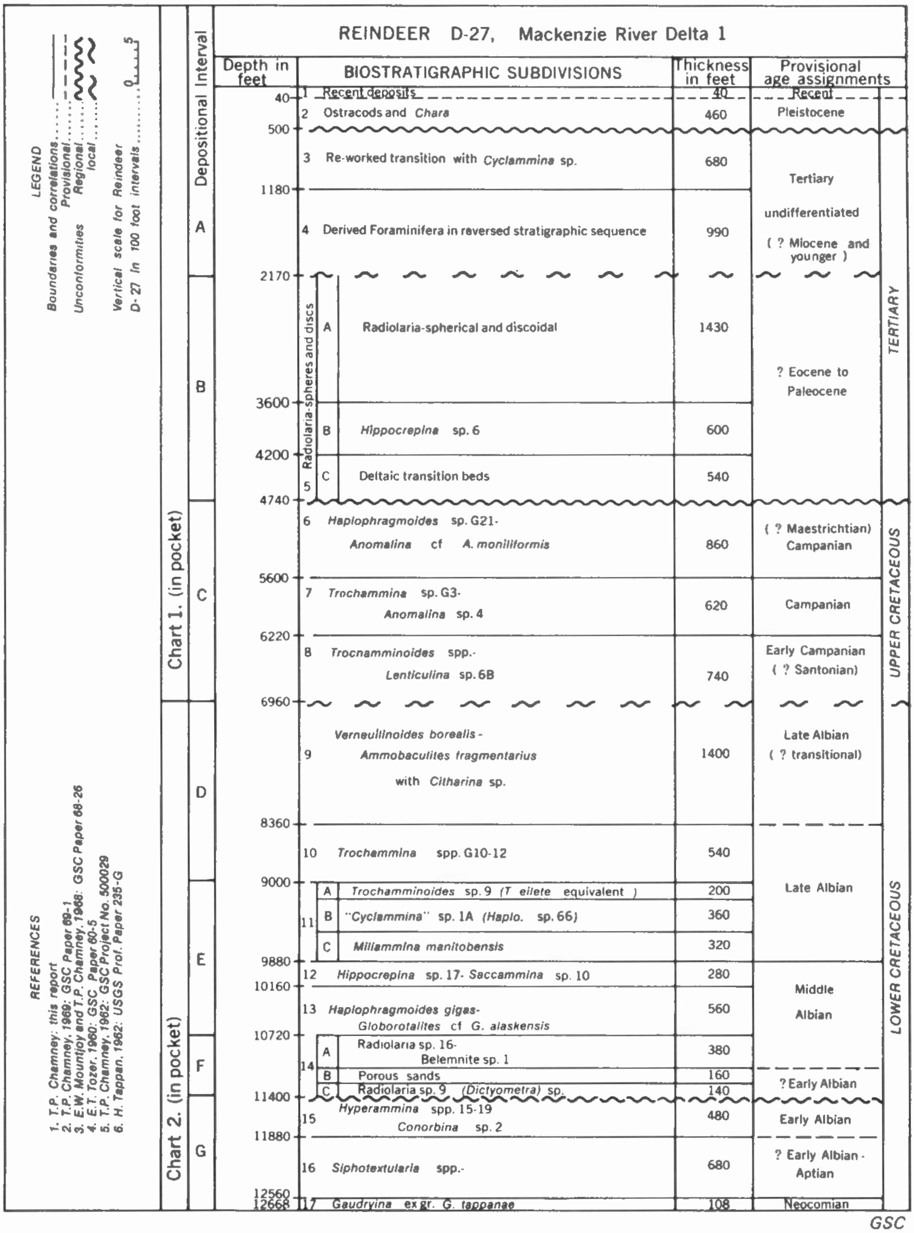


Figure 6. Summary of biostratigraphy, age and rock unit correlation

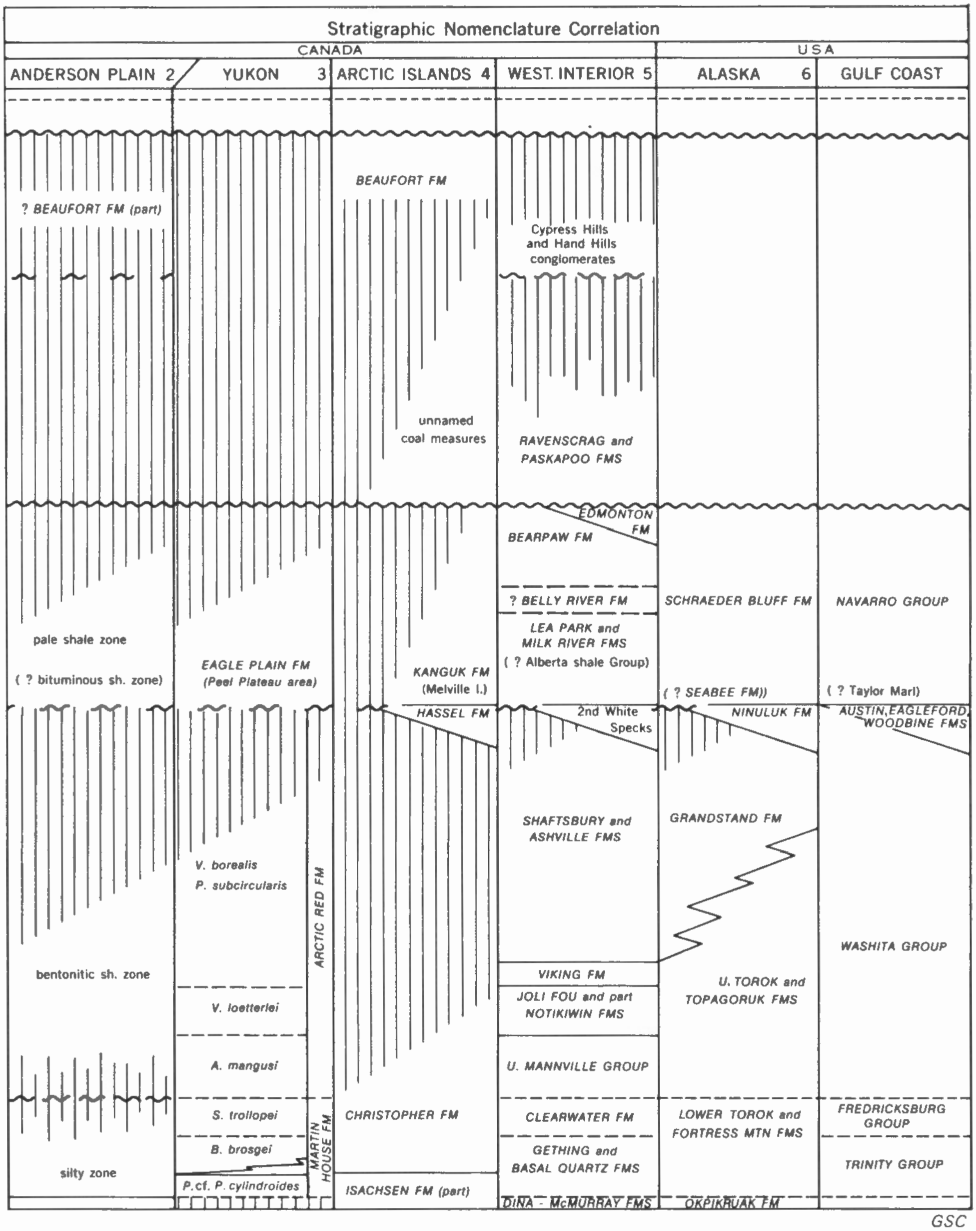


Figure 6. Continued

relationship is Upper Cretaceous (?Santonian or Campanian) resting unconformably on Division 9 of the Lower Cretaceous (Upper Albian). The Coniacian, Turonian and Cenomanian Stages are missing and are represented in Manitoba and eastern Saskatchewan by the rock-stratigraphic sequence including the Morden, Favel (2nd White Speckled Shale) and the upper part of the Ashville (Bell Fourche) Formations. In Alaska the missing rock units are represented by the Seabee and Ninuluk Formations. Very little Upper Albian is missing at the well, whereas in the Anderson Plain, some 120 miles further east, all the Upper and part of the Middle Albian are missing beneath the Post-Early Cretaceous unconformity (Chamney, 1969a).

First appearances of Foraminifera are:

Reophax (Proteonina) sp. 3B
Psamminopelta sp. 2
Haplophragmoides sp. 16
*Verneuilinoides cf. V. borealis
Haplophragmoides sp. G17
H. sp. G18
H. sp. G19
*Ammobaculites ex gr. A. fragmentarius
Trochammina sp. G7
Ammodiscus rotalarius
Gaudryina ex gr. G. nanushukensis
Haplophragmoides sp. G20
Saccammina sp. 8
Trochammina sp. G8
T. sp. G9
Haplophragmoides sp. G22
Miliammina awunensis
Haplophragmoides sp. G23

calcareous forms:

Tristix sp.
*Citharina sp. 8
*C. cf. C. acuminata
Nodosaria cf. N. proboscidea

In addition to Late Albian index species of the division, the first appearance of Psamminopelta relates the interval to the Late Albian Psamminopelta subcircularis - V. borealis Zone of the Yukon (Mountjoy and Chamney, 1969). The several calcareous species recovered from the 7,400 to 7,410 foot interval may correlate with the V. loetterlei - G. subcretacea zone of the Late-Middle Albian boundary of this Yukon sequence; division 9 is tentatively dated as Late Albian.

### Trochammina spp. G10-12; division 10. (8,360 to 9,000 feet)

The upper boundary of this division is selected at a prominent shoulder of the leading edge of the chart at depth 8,360 feet. The rapid rate of deposition interpreted for all higher depositional intervals, is not as evident for this division. In particular, the top 100 feet has abundant arenaceous, benthonic Foraminifera which indicates a much lower rate of sediment deposition. There is an increase of algal remains associated with invertebrate marine shell material and increased amounts of pyrite.

First appearance of Foraminifera are:

*Trochammina sp. G10
Haplophragmoides sp. G24
H. sp. G25
*Trochammina sp. G11
Hippocrepina cf. H. sp. 5
*Trochammina sp. G12
Haplophragmoides sp. G26
Ammodiscus sp. 1C

The division is dated as Late Albian because it is above the index species Miliammina cf. M. manitobensis of subdivision 11C.

"Cyclammina" sp. 1A and Trochamminoides sp. 9; division 11. (9,000 to 9,880 feet)

This division is composed of three significant subdivisions based on distinctive foraminiferal facies changes. The division boundaries are primarily selected on the basis of the Foraminifera and some index species range throughout the subdivision. The depositional interval shows homogeneous electric log characteristics and, therefore, the subdivisions are regarded as such and not discrete divisions. From the microfossils, the interval appears to represent a time of marine inundation bounded above and below by shallow, restricted marine intervals. Maximum marine transgression occurs in the middle of the interval, at a depth of 9,560 to 9,600 feet and represents the greatest marine transgression in the whole stratigraphic sequence of the borehole. This interval provides the most distinctive and abundant index species: "Cyclammina" sp. 1A and Trochamminoides sp. 9. There appears to be a morphological series between the two species, ranging from the large diameter (1.00 mm), involute "Cyclammina" sp. 1A and varieties, to a smaller diameter (0.5 mm), evolute form of Trochamminoides sp. 9. Some of the intermediate forms with slightly recurved sutures indicate an ancestral stock from the Haplophragmoides gigas group. The generic assignment of specimens referred to Cyclammina is not satisfactory. Drs. Berquist and Cifelli of the U.S.G.S. and Smithsonian Inst., Washington, D.C. (pers. com.) feel that a new genus is possibly warranted. Dr. J. Van Hinte of Imperial Oil Enterprises, Calgary, (pers. com.) favours their assignment to the genus Reticulophragnium. In addition to some minor taxonomic differences, the major difference from true Cyclammina is the absence of multiple apertures. The strata in which these index species are most abundant appear to be composed of a very poorly consolidated shale, prone to sloughing into the drillhole. Specimens of "Cyclammina" sp. 1A and Trochamminoides sp. 9 are recovered nearly continuously as contamination in drill cuttings for some 3,460 feet below their first occurrence.

Trochamminoides sp. 9 (T. eilete equivalent) and Neobulimina cf. N. subcretacea; subdivision 11A. (9,000 to 9,200 feet)

The upper boundary was selected at the first occurrence of Trochamminoides sp. 9. This form is similar to Trochammina eilete (Tappan, 1957) which occurs in the Torok Formation of Alaska; the upper part of the Torok Formation is a lateral facies of the Grandstand Formation (Late Albian) and the lower part is a lateral facies of the Topagoruk Formation (Early to Middle Albian) (Tappan, 1957, Fig. 10). Species making their first appearance in this Upper Albian subdivision are:

> *Trochamminoides sp. 9
> T. ex gr. T. sp. 3B
> Saccammina sp.
> Dorothia sp.
> calcareous form:
> *Neobulimina cf. N. subcretacea

"Cyclammina" sp. 1A (Haplophragmoides sp. 66) and Hippocrepina barksdalei; subdivision 11B. (9,200 to 9,560 feet)

The selection of 9,200 feet as the boundary was primarily based on the electric logs which indicate that a similar lithology extends from this level down through the subdivision. "Cyclammina" sp. 1A first appears 80 feet below the upper boundary and its acme occurs at the base of the subdivision. Thus, it would appear that the environment became increasingly marine toward the base of the subdivision. In more open marine localities that can be expected to the north, the species may persist stratigraphically higher in the geological column and, for this reason, the present subdivision may be of a very local nature. First appearances of species for this unit:

> *"Cyclammina" sp. 1A
> *Haplophragmoides sp. 66
> Ammodiscus cf. A. grandis
> *Hippocrepina barksdalei
> Haplophragmoides cf. H. sp. 40

The subdivision directly overlies the Upper Albian subdivision 11C and is dated also as Late Albian. The uppermost range of H. barksdalei occurs in the Grandstand Formation of Alaska (Tappan, 1957) which also represents the Late Albian. "Cyclammina" sp. 1A is a new species but has many similarities to specimens recovered from the upper portion of the "Bentonitic zone" (Yorath and Balkwill, in press) of the Anderson Plain. The parent stock for this very robust species of "Cyclammina" was probably Haplophragmoides ex gr. H. gigas of the Middle Albian; later forms of "Cyclammina" appeared in the Canadian Western Interior during the marine incursions of the Lower Lea Park or Lower Milk River Formation of the Williston and Alberta Basins in Late Santonian to Early Campanian time. "Cyclammina" sp. 1A was first referred to the Cyclammina sp. 1 of these latter formations (Chamney, 1969a) but now is interpreted to be a Late Albian older species.

Miliammina manitobensis and Lenticulina cf. L. Macrodisca Assemblage Zone; subdivision 11C. (9,560 to 9,880 feet)

The top of this subdivision is selected at the top of the unit indicating the pronounced marine inundation. The two index species are very abundant in the uppermost 20 feet of the subdivision in association with several first appearances of calcareous species. First appearances of Foraminifera are:

> Haplophragmoides sp. 62
> Trochamminoides sp. 9B

Hyperammina cf. H. sp. 6
Ammobaculites cf. A. minimus
Reophax (Proteonina) sp.
*Miliammina cf. M. manitobensis
Textularia cf. T. topagorukensis
Haplophragmoides sp. 65A
H. sp. 66A
H. sp. 66B
H. sp. 62C
Trochammina cf. T. wetteri
Haplophragmoides sp. G32
Hyperammina sp. 1A
Bathysiphon sp. 5C
Dorothia (Marssonella) sp. 2A
Reophax (Proteonina) sp. 27B

calcareous forms:

Neobulimina cf. N. subcretacea
*Lenticulina cf. L. macrodisca
?Globigerina sp.
Marginulina sp. G89

M. manitobensis is a zonal index species for the Late Albian of the prairie provinces (Wickenden, 1932) and has been reported from the upper part of the Upper Albian Topagoruk Formation of Alaska (Tappan, p. 94, 1962).

Hippocrepina sp. 17 and Saccammina sp. 10; division 12. (9,880 to 10,160 feet)

The organic remains indicate a very restricted marine to brackish water environment. The Foraminifera are represented by predominantly simple, tubular, benthonic forms, extremely tolerant of a considerable influx of fresh water. The upper boundary is selected at the top of relatively porous siltstone and very fine sandstone at a depth of 9,880 feet which may correspond to the Middle Albian - Upper Albian boundary. Carbonized plant remains, pyrite and ?limonite spheres also are common. It represents a transitional interval between the marine transgressions of the overlying M. manitobensis subdivision (Mowry Sea) and the underlying H. gigas division (Joli Fou Sea) to which it is assumed to be more closely related. It is, therefore, Middle Albian. This interpretation places division 12 in an equivalent stratigraphic position to the Viking Formation of the Western Interior Plains. First appearance of species in this division are:

Haplophragmoides sp. G33
*Hippocrepina (Hyperamminoides) sp. 17A
Pelosina n. sp. 18
Bathysiphon n. sp. 13
Glomospirella sp. 2B
Hyperammina sp. 1
*Saccammina sp. 10
*Hippocrepina sp. 17
Haplophragmoides sp. 34

## Haplophragmoides gigas and Globorotalites cf. G. alaskensis Assemblage Zone; division 13. (10,160 to 10,720 feet)

The upper boundary is based on the first occurrence of Haplophragmoides ex gr. H. gigas and the abrupt first appearance of the numerous species listed below. Megaspore cases, carbonized wood fragments, fish (?) and common pyrite are also associated with the following first appearances:

*Haplophragmoides ex gr. H. gigas
Bathysiphon sp. 13
B. cf. B. vitta
Trochammina sp. 31A
Reophax (Proteonina) sp. 29
*Haplophragmoides ex gr. H. gigas (sp. 9G)
H. sp. 65
Ammobaculites cf. A. laevigata
*Haplophragmoides ex gr. H. gigas (sp. 9E)
Hyperammina sp. 13
Haplophragmoides sp. G38
H. sp. G39
Gaudryina sp. 13B
Saccammina sp. 10A
Gaudryina sp. 22
Saccammina lathrami
*Haplophragmoides gigas
calcareous forms:
*Globorotalites cf. G. alaskensis
Pseudonodosaria sp. 5

The zonal species H. gigas is an uppermost Middle Albian species described from the Joli Fou Formation of the Canadian Western Interior (Cushman, 1927). Globorotalites alaskensis was first described from the Grandstand, Torok and Topagoruk Formations of Alaska (Tappan, 1957, 1962) of Albian age. The associated species Saccammina lathrami is similarly a general indicator of the Albian in Alaska but both species predominate in the Topagoruk Formation of Middle Albian age.

## Haplophragmoides sp. G40 and Polymorphina sp. 4; division 14. (10,720 to 11,400 feet)

This division consists of three subdivisions that illustrate the significance of the range of certain radiolarian species within the division. In regional studies these species of radiolaria are useful for Early and early Middle Albian age interpretations (Chamney, 1969b). The division is predominantly a coarse clastic unit and, therefore, the samples contain relatively few Foraminifera because of dilution and masking of the microfossils by sand particles in the washed residues. These Foraminifera and other marine organisms indicate that these sands are, in part, open marine deposits. Inoceramus sp., belemnites and common faecal pellets are a few of the marine indicators recovered from this depositional interval; glauconite is also present in division 14B.

First appearances in this interval are:

*Haplophragmoides sp. G40
Hyperammina sp. 14
Trochammina sp. G13
Bathysiphon cf. B. brosgei
calcareous form:
*Polymorphina sp. 4

The radiolaria sp. 9 (Dictyometra sp.), first recovered at 11,280 feet has been previously recorded from the Clearwater Formation equivalent in the Lower to Middle Albian, Arctoplites (Lemuroceras) sp. Zone (Chamney, 1967, Mountjoy and Chamney, 1969).

Radiolaria sp. 16 and Belemnite sp. 1; subdivision 14A. (10,720 to 11,100 feet)

Only a slight microfossil facies change marks the upper boundary of this subdivision at the depth of 10,720 feet. Selection of the boundary was based primarily on the lithofacies change from shale to coarser siltstone and fine sandstone. The upper part contains algal-like fruit bodies of the ?Characea oogonium and other common pyrite-replaced organic remains. The lower part contains abundant faecal pellets and belemnites (at the base) associated with a new species of radiolaria (sp. 16) of the genus Dictyometra. Three species of agglutinated and one species of calcareous foraminifers are found in this interval:

Haplophragmoides sp. G40
Hyperammina sp. 14
Trochammina sp. G13
calcareous form:
Polymorphina sp. 4

Very characteristic, minute belemnite phragmacones (belemnite sp. 1) recovered from the basal 100 feet can be correlated with similar belemnite occurrences in other Delta boreholes. The Middle-Early Albian boundary has been tentatively placed at the base of an abnormally high accumulation of pyritized, invertebrate remains at the base of the subdivision. There are no index species within the interval and the tentative Middle Albian age assignment is based primarily on the occurrence of Radiolaria sp. 9 (Dictyometra sp.) in the underlying subdivision 14C.

Porous Sands (Radiolarian Sands); subdivision 14B. (11,100 to 11,260 feet)

The upper boundary was selected at the first occurrence of Radiolaria sp. 9 at a depth 11,100 feet. Both the upper and lower boundaries are coincident with maximum intensities of the self-potential electric log. Drill cutting samples contained grey to light grey, fine- to medium-grained, poorly sorted, subrounded to subangular sandstone with brown staining present in abundant voids and in part of the rock matrix. Some secondary faceting is present on quartz grains but good porosity is still present between many of the grains. The texture in the lower part of this sandstone unit is "sugary" in appearance as a result of lesser amounts of silica cement. In this same portion more pyrite infilling of the matrix was observed in some fragments but again good porosity is retained. The marine nature of the sandstones is suggested by the common occurrence of glauconite throughout this interval (DIA and ND, 1968). Subdivision 14C is possibly the stratigraphic equivalent of the Lower Albian Glauconitic member of the Martin House Formation of the Yukon (Mountjoy and Chamney, 1969).

There were no first appearances of species of Foraminifera in this 140-foot interval; species representing division 14 assemblage are still present.

Radiolaria sp. 9 (Dictyometra sp.); subdivision 14C. (11,260 to 11,400)

The upper boundary is the base of the overlying porous sands and the top of the range of pyritized radiolaria sp. 9 (Dictyometra sp.). Other significant occurrences are calcite prisms from the shell layers of Inoceramus sp. and the first appearance of Bathysiphon brosgei. Radiolaria sp. 9 (Dictyometra sp.) was previously reported from the Clearwater (Moosebar) Formation equivalent of Early to Middle Albian age of the Snake and Peel Rivers, Yukon Territory (Chamney, 1967). Bathysiphon brosgei is known from the Fortress Mountain and lower Topagoruk Formations of Alaska (Tappan, 1962) and from the Martin House Formation of the Yukon (Mountjoy and Chamney, 1969). The subdivision is assigned an Early to Middle Albian age.

Hyperammina spp. 15-19 and Conorbina sp. 2; division 15. (11,400 to 11,880 feet)

Both a physical facies change and a major alteration in the microfossil content marks the upper boundary of this biostratigraphic division. The change in microfossils consists of a sudden influx of very abundant primitive, simple tubular, siliceous, benthonic foraminifers of the genus Hyperammina. The shoulder formed by species of Foraminifera making their first appearance is the most prominent in the leading edge of all the plotted microfossils and represents a major microfaunal change that may be due to the presence of an unconformity. The presence in this interval of B. brosgei suggests an Albian age (Chamney, 1967) whereas the presence, also, of the species Glomospirella cf. G. elongata indicates a Neocomian (?Barremian) age (Chamney, 1969c).

The electric log indicates a change from the overlying coarse siltstones and sandstones to mudstones and silty shales with minor siltstone and sandstone beds. The division includes abundant plant remains such as megaspore cases, rootlets, cuticle and carbonaceous fragments. Some pelecypod shell fragments and a few vertebrate (?fish) remains occur and abundant pyrite is present at the upper contact. First appearances in this interval are:

Haplophragmoides sp. G41
H. sp. G42
Trochammina sp. 15B
*Hyperammina sp. 15
*H. sp. 16
*H. sp. 17
Hippocrepina sp. 4A
*Hyperammina sp. 18
H. sp. 15B
Haplophragmoides sp. 43
Reophax sp. 11

Glomospirella cf. G. elongata
Ammobaculites ex gr. A. parvispira
Ammodiscus cf. A. mangusi
*Hyperammina sp. 19
Arenoturrispirillina sp. 5
Haplophragmoides sp. G44
Hippocrepina sp. 14
Reophax sp. 19

calcareous forms:

*Conorbina sp. 2
Lenticulina cf. L. topagorukensis

Conorbina sp. 2 may be derived from the overlying division 14 and is similar to Conorbina sp. fide Tappan, (1962) from the Early to Middle Albian equivalent of the Topagoruk Formation. Conorbina sp. 2 is also similar to Discorbis norrisi Mellon and Wall, (1956), from the Early to Middle Albian of the Clearwater Formation of northeastern British Columbia. Tappan (1962) places some specimens assigned to Discorbis norrisi (part, not the holotype) in the synonomy of Conorbina sp. Similarily, A. cf. A. mangusi and L. cf. L. topagorukensis represent depositional intervals overlying the Clearwater Formation equivalents (Mountjoy and Chamney, 1969) and may be derived from the upper part of division 14.

It is difficult to establish the age of division 15 because some species present suggest Neocomian to Early Jurassic age. These species are respectively G. cf G. elongata Chamney, found in the Barremian of the District of Mackenzie (Chamney, 1969c) and Arenoturrispirillina sp. 5 is present in the Late Jurassic of Arctic America (Chamney, 1970); these species may be either long ranging or derived species. Thus a mixed microfauna of questionable age is present but because the youngest possible age is most significant to age assignments, it is tentatively reported as Early Albian. Some Late Aptian also may be represented in the lower part of this interval for part of the mixed microfauna is similar to that of the underlying division 16 which is assigned an Aptian age. The derived older microfauna of this mixed microfauna may be the result of a period of pre-Albian, tectonic adjustment that rejuvenated the sediment source area exposing older strata of Neocomian and Late Jurassic age.

## Siphotextularia spp.; division 16. (11,880 to 12,560 feet)

The upper boundary of this division corresponds to the first appearance of Siphotextularia spp. The acme of development of this genus is best represented in the basal Cretaceous "Silty zone" and the lower part of the "Bentonitic zone" of the Anderson Plain area. Coincident with the first appearance of Siphotextularia spp. are the first appearance of numerous additional species which form a very pronounced shoulder on the distribution chart at depth 11,880 feet. This division represents a new microfaunal facies which also includes rare ostracods, some new megaspore cases, common plant remains, abundant coproliths and teeth, scales and bones of fish. There is also common pyrite replacement near the upper contact.

First appearances are:

Miliammina sp. 3B
Saccammina sp. 11B

Ammodiscus sp. 2B
*Siphotextularia sp. 12B
Haplophragmoides ex gr. H. duoflatis
*Siphotextularia cf. S. sp. 10
Psamminopelta sp. 3
Hippocrepina sp. 19A
Bathysiphon ex gr. B. scintillata
Hippocrepina sp. 19B
Thuramminoides ex gr. T. septagonalis
*Siphotextularia sp. indet.
Gaudryina ex gr. G. leffingwelli
Haplophragmoides ex gr. H. neocomiana
Arenoturrispirillina ex gr. A. jeletzkyi
Reophax (Proteonina) sp. 27D
Haplophragmoides sp. G46
Hippocrepina sp. 19
Glomospirella sp. 16
*Siphotextularia sp. 12C
Hyperammina cf. H. aljutovica
Verneuilinoides sp. 2A
Ammobaculites cf. A. agglutinans

Siphotextularia rayi ranges from the Upper Albian (Grandstand Formation) to Lower Albian (Torok Formation) in Alaska (Tappan, 1957). Tappan's figured specimens from the Torok Formation are similar to the specimens recovered from the "Silty zone" of the basal Cretaceous of the Anderson Plain and to the specimens of this division. The Siphotextularia sp. Assemblage Zone of the Anderson Plain is tentatively assigned to a transitional Albian-Aptian boundary interval. Species of division 16, perhaps referable to the Neocomian (Chamney, 1969c), include H. ex gr. H. duoflatis, B. ex gr. B. scintillata, T. ex gr. T. septagonalis and H. ex gr. H. neocomiana. These could be related varieties of the species or they may have been derived from exposed older strata. One species referred to Arenoturrispirillina jeletzkyi, is an Upper Jurassic form (Chamney, in press).

## Gaudryina ex gr. G. tappanae; division 17. (12,560 to 12,668 feet)

The upper boundary is not well defined by foraminiferal changes. No physical stratigraphic assistance (electric log) is available below 12,290 feet. Sample cuttings from division 17 showed little distinctive difference from those of the overlying intervals. Little control is provided by other fossils except for a new species of belemnite and megaspores referable to Microcarpolithes sp. A few fragments of bitumen recovered at a depth of 12,640 feet may be a significant indication of some hydrocarbon accumulation.

First appearances are:

Glomospirella ex gr. G. elongata
*Gaudryina ex gr. G. tappanae
Haplophragmoides ex gr. H. canui

G. tappanae Chamney, and G. elongata Chamney, are from the Barremian Substage of the Richardson Mountains on the west flank of the Mackenzie River Delta (Chamney, 1969c). H. canui Cushman, 1930, has been reported from the Late Jurassic of Alaska (Tappan, 1955). The specimens of division 17 referred to this species differ slightly from H. canui fide Tappan and are known to range from the Late Jurassic upwards into the Neocomian. Division 17 can be tentatively correlated with the Neocomanian Stage (Fig. 6) which includes the Barremian as the uppermost substage.

## THE DEPOSITIONAL FRAMEWORK

### INTRODUCTION

Seven depositional intervals (A to G, Fig. 6) are proposed for the 12,668 feet of strata penetrated in the Reindeer D-27 borehole. These intervals represent ecologically related biofacies interpreted from the 23 biostratigraphic divisions. The boundaries for the depositional intervals are based primarily on biofacies changes interpreted from the distribution charts. These changes are, in most cases, the result of changes in the physical environment and should thus be impressed on the lithofacies and, hence, show as changes in the character of the electric log. Not all biofacies changes are coincident with these physical changes, but when a distinctive change in the electric log character is evident within reasonable vertical separation from the biofacies boundary, these electric log markers are chosen to represent the boundary. The reason for this selection is to provide the working geologist with recognizable physical markers that relate to this biostratigraphic research and which will permit him to recognize the same divisions from electric logs of other subsurface sections. Thus the time-consuming investigations required to establish biostratigraphic control can be applied to only a few selected borehole sections in order to validate physical stratigraphic correlations between widely separated areas.

### BIOFACIES CRITERIA

Establishment of genetically related biofacies is an interpretative process obtained from all of the organic and from some mineral evidence plotted on the distribution charts. In order to expedite interpretation of the 353 species plotted in the distribution charts the following very general foraminiferal criteria serve as guide-lines for illustrating relationships to the physical environments of deposition.

(a) Quantity of specimens:

The number of specimens for each species recovered from a sample can be an indication of the rate of sediment deposition. A general paucity of specimens can be assumed to be the result of dilution of the organic remains by copious quantities of detritus. Common to abundant specimens can indicate low rates of sediment deposition permitting both optimum production and accumulation of the dead organisms. The quantity of specimens is graphically represented on the charts by quantitative symbols.

(b) Frequency of species:

The number of species making their first appearance in the descending stratigraphic succession of the borehole can be a significant indication of changes in the biofacies, hence the physical environment. These first appearances from drill cuttings are the uppermost species ranges. In addition to species extinction from natural evolutionary causes, the local extinctions generally revealed by this study are assumed to be primarily caused by unfavourable physical conditions in the marine environment. Thus a reduction in the number of species recovered indicates adverse marine conditions, the actual cause of which can be interpreted from the associated physical evidence in terms of the energy level of sediment deposition (turbidity), toxic chemical conditions (euxinic), etc. Prolonged favourable marine conditions permitted the migration of more numerous, salinity-sensitive, open marine forms into the inundated area. Subsequent adverse changes in the physical environment correspondingly reduced the number of open marine forms and these changes can be interpreted from the leading edge of the distribution chart. Low frequencies produce nearly vertical leading edges; high frequencies produce horizontal shoulders and numerous steps in relatively short vertical intervals.

(c) Comparative morphology:

Approximately 95 per cent of the Foraminifera recovered from this study are agglutinated, benthonic forms; the calcareous, more open marine forms with a pseudopelagic habitat represent only 5 per cent of the biofacies. In order to obtain meaningful and consistent paleoecological criteria from the predominantly agglutinated, benthonic assemblage, guide-lines within this group are established. Foraminiferal tests include a wide range of forms but can be grouped into two categories pertaining to paleoecology of the agglutinated tests. These two categories are the simple or primitive unilocular form and the complex or more advanced multilocular form. The primitive forms appear to be very tolerant to adverse marine conditions of higher energy levels of sediment transportation, to brackish water conditions and to temperature extremes. A few of the forms included in this category are simple tubular forms such as the most primitive Hyperammina to the complex coiling Glomospirella; also included in this category is the sack-like Saccammina. The multilocular category includes forms from the most simple uniserial Reophax to the trochoid coiled Trochammina with corresponding increase in sensitivity to adverse marine conditions. The occurrences of calcareous forms, whatever their chamber arrangement, are interpreted as representing the most open marine conditions. But even the most open marine conditions that can be interpreted from micropaleontological evidence in the borehole, are not much more marine than one would expect in shallow neritic environments of lagoon embayments in juxtaposition to the open sea.

## ENVIRONMENTS OF DEPOSITION

The seven depositional intervals (A to G, Fig. 6) can be grouped into three very general environments of deposition based on the preceding biofacies criteria and interpreted from the quantitative plotting of the distribution charts, in descending stratigraphic succession:

1. Delta sand - shale "sandwiches"

2. Transitional delta

3. Shoreline and offshore deposits

1. Delta sand - shale "sandwiches", 0 to 4,740 feet

Depositional intervals A and B are considered to be genetically related in their mode of deposition, although a local diastem is indicated at their boundary. The following biofacies criteria are interpreted:

(a) predominantly rare individuals for each species

(b) Very high angle to the slope of the leading edge of the plot indicating only a few species making their first appearance in the descending sequence

(c) with the exception of the radiolarians which indicate access to open marine, there are very few complex multilocular forms in situ

There is thus a dilution of the microfauna and adverse marine conditions that probably result from very high energy levels of deposition. The recovery of some rare calcareous forms indicates intermittent open marine flooding of the delta area. The upper depositional interval "A: from 0 to 2,170 feet is characterized by much reworking of older strata. The older, derived microfauna recovered from this interval could not have been transported for any great distance or the specimens would have been fragmented. Therefore, quite rapid dumping is indicated. The lower depositional interval B from 2,170 feet to 4,740 feet exhibits sand - shale sandwich electric log features similar to those of the overlying interval A. A somewhat lower energy level of deposition is indicated by the presence of scattered pelagic radiolarians and distinctive horizons of primitive unilocular forms of Foraminifera. The basal 540 feet represents the thickest interval of vertical slope for the leading edge of the distribution charts. No additional species of Foraminifera were recovered from this interval, represented by the biostratigraphic division 5C, designated as the "deltaic transition beds". A local unconformity or diastem is considered to be present at the boundary of the two depositional intervals. This interpretation is based on the premise of possible scouring action of the drainage channel prior to deposition of the overlying reworked detritus; additional evidence is suggested by the obvious difference in microfossil content.

2. Transitional delta 4,740 to 9,000 feet

Depositional intervals C and D are considered to be similar in their mode of deposition. The local unconformity separating the two intervals is equivalent to the "Morden" unconformity, (Chamney, 1969b) but in the Delta area there appears to be more or less similar modes of deposition above and below this boundary. The depositional intervals C and D are both considered to be anomalously thick when compared regionally with the equivalent stratigraphic intervals on the mainland east and west of the Delta (Chamney, 1969d). The biofacies criteria observed from the distribution chart are as follows:

(a) a few to common specimens for each species

(b) a rather large angle to the slope of the leading edge of the plot consisting of many very short steps indicating a few species making their first appearance in the descending sequence

(c) a few to common multilocular forms

Dilution of the microfauna is still apparent throughout this transitional interval. There is also a noticeable admixture of unilocular and multilocular forms indicating improved marine conditions favouring the survival of the more salinity-sensitive multilocular forms. The upper depositional interval C from 4,740 to 6,960 feet has more numerous sandstone beds and a corresponding decrease in the number of specimens for each species. The interval is thus approaching the higher energy levels of sediment transportation of the overlying active delta. The lower depositional interval D from 6,960 to 9,000 feet represents deposition during the inception of the ancestral Mackenzie River drainage system. It is composed of rapidly dumped mudstones showing a marked increase in the argillaceous fraction of the sediment compared to interval C. The actual point of change from shallow marine conditions supporting a considerable number of sensitive, multilocular forms to the less open marine conditions is at about 8,360 feet.

3. Shoreline and offshore deposits, 9,000 to 12,668 feet

There is a noticeable change in slope of the leading edge of the distribution chart; the change is from a moderately large angle of the overlying depositional interval to a smaller angle with prominent horizontal shoulders of this group of strata. The upper boundary of this group is most distinctive and is the first major horizon of abundant Foraminifera encountered in descending sequence in the borehole and includes some of the largest specimens recovered ("Cyclammina" sp. 1A and Trochamminoides sp. 9). The following are the biofacies criteria observed for this group of strata:

(a) common to abundant individuals for each species

(b) common to abundant species making their first appearance

(c) predominantly complex, multilocular forms or in the horizons of simple forms, there is an acme of development to very abundant which indicates a persistent, restricted marine environment for a considerable duration of time

The above observations indicate quiet waters of lagoons or protected near-shore environments with intermittent access to open marine. The lithology of the interval is predominantly shale and mudstone with scattered beds of argillaceous siltstone and sandstone. This argillaceous sequence is interrupted by 680 feet of sandstones in the depositional interval F from 10,720 to 11,400 feet. The sediment source for these coarse clastics is possibly a nearby active delta. The presence of radiolarians, belemnites and glauconite in these sandstones indicate an energy level of transportation similar to that of marine longshore currents. The deposits could thus represent shoreline sands or offshore bars with porosity developed in the upper portions resulting from the influence of winnowing by wave action.

## SIGNIFICANCE FOR OIL AND GAS EXPLORATION

### SANDSTONE RESERVOIRS

The first borehole in Mackenzie River Delta area for oil and natural gas exploration has shown that the potential reservoirs are Cretaceous and Tertiary sandstones. Two major paleomorphological frameworks, hence two modes of deposition, are reconstructed. First, deposits can be directly related to an indicated ancient Mackenzie River drainage system (0 to 9,000 feet); second, deposits are related to restricted marine, longshore current distribution (9,000 to 12,668 feet). These two concepts aid in exploration by postulating the areas of most favourable development of potential reservoir sands and possible geometrics of actual sand bodies. Three general types of sandstone reservoirs are possible and could have originated within the two postulated modes of deposition. The first two are present within the ancestral and active Mackenzie River deposits and include, respectively, deltaic-marine sands and fluviatile-deltaic sands. The third type refers to longshore current distribution resulting in shoreline and offshore bars of coastal marine sediments.

Depositional intervals A to C (0 to 6,960 feet) represent deltaic-marine distributary sands deposited in shallow prodelta and restricted bay environments. The lower part of this interval may include sandstones deposited on the landward side of the delta in an upper deltaic plain and, as such, could be in part fluviatile-deltaic. The deltaic-marine sands can be expected to prograde progressively north and east with the advance of each successive distributary fanning out into the ancestral Beaufort Sea. The general axis of deposition for this interval has been previously reported as trending northeast (Chamney, 1969e). Configuration of potential reservoir sand bodies will be determined as much by the present structural conditions as by the original pattern of distributary channels and delta margins. Intermittent marine incursions from the north inundated the delta deposits as indicated by the rare, open marine, complex, calcareous, multilocular Foraminifera of pseudopelagic habitat. These marine tongues could contribute potential hydrocarbon source rocks and provide porous channelways for the migration of hydrocarbons from marine muds probably present to the north. Gassing to the surface is reported (DIA and ND, 1968) from the basal part of depositional interval C at a depth of 6,835 to 6,855 feet. The porous sands yielding this gas are closely related to the local diastem postulated for the boundary between depositional intervals C and D. What may be the same diastem has been reported from the east flank of the Delta in the Anderson Plain (Chamney, 1969b) as the "Morden" unconformity.

Depositional interval D (6,960 to 9,000 feet) is thought to represent fluviatile-deltaic sandstones very similar to those developed in the lower part of the overlying interval. They are coarse clastics deposited within drainage channels on the landward side of the first indication of the ancestral Mackenzie River drainage system. These deposits appear to form sigmoid deposits trending north and east bordering the Early Cretaceous coast, considered to be south of the Reindeer D-27 location.

Depositional intervals E, F and G (9,000 to 12,668 feet) represent shoreline and offshore, restricted marine deposits. The sediment source for coarse clastics within this interval possibly was a nearby active delta. Deposition is thought to have been caused by marine longshore currents as shoreline sands and offshore bars with arcuate trends subparallel to the Early Cretaceous shoreline. The most porous sand development in these strata is subdivision 14B (11,100 to 11,260 feet, porous sands).

These 160 feet of glauconitic sandstones are characterized by the open marine radiolarian Dictyometra sp. These sandstones are considered to represent an offshore bar; the porosity developed as a result of reworking by currents and waves. This interval may be widespread in the Delta area; in combination with favourable structure these sandstones could be very important exploration objectives.

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# APPENDIX

## Foraminiferal Index

# APPENDIX

## Foraminiferal Index

Species of Foraminifera reported from this study are arranged in alphabetical order and are cross-indexed to the distribution charts by reference to the chart column number of their first appearance in descending stratigraphic sequence. Chart number 1 or 2 is the prefix for the corresponding column number, e.g., Ammobaculites cf. A. agglutinans, 2-124, is first reported on chart 2, column 124. Some reworked microfauna make their first appearance at shallow depths but are valid markers in situ at greater depths, double entries are made for such species.

| Genus and species | Chart and Column No. | Genus and species | Chart and Column No. |
|---|---|---|---|
| Ammobaculites | | Bathysiphon | |
| cf. A. agglutinans | 2-124 | sp. 5C | 2- 50 |
| ex gr. A. euides | 1- 3 | n. sp. 13 | 2- 56 |
| ex gr. A. fragmentarius | 2- 8 | sp. 13A | 2- 63 |
| cf. A. laevigata | 2- 69 | sp. 15 (ex gr. B. scintillata) | 2-110 |
| cf. A. luekei | 1- 29 | (?Hyperammina) sp. | 1- 64 |
| cf. A. minimus | 2- 39 | Citharina | |
| ex gr. A. parvispira | 2- 95 | cf. C. acuminata | 2-130 |
| ex gr. A. wenonahae | 1- 46 | sp. 8 | 2-129 |
| sp. | 1- 36 | Conorbina | |
| ?sp. | 1- 78 | sp. 2 | 2-139 |
| Ammodiscus | | Cyclammina | |
| cf. A. aspera | 1- 20 | sp. 1A | 2- 31 |
| cf. A. grandis | 2- 33 | sp. | 1- 13 |
| cf. A. mangusi | 2- 96 | ?sp. | 1- 26 |
| cf. A. planus | 1- 80 | Discorbis | |
| rotalarius | 2- 10 | sp. | 1- 93 |
| sp. 1C | 2- 26 | Dorothia | |
| sp. 2 | 1- 14 | (Marssonella) sp. 2A | 2- 51 |
| sp. 2B | 2-104 | sp. | 2- 30 |
| sp. | 1- 7 | Flabellammina | |
| Anomalina | | sp. | 1- 49 |
| cf. A. moniliformis | 1- 92 | fusulinid sp. | 1- 90 |
| sp. 4 | 1- 94 | Gaudryina | |
| Arenobulimina | | ex gr. G. leffingwelli | 2-114 |
| torula | 1- 24 | ex gr. G. nanushukensis | 2- 11 |
| sp. | 1- 35 | cf. G. tappanae | 2-126 |
| Arenoturrispirillina | | sp. 13B | 2- 74 |
| ex gr. A. jeletzkyi | 2-116 | sp. 22 | 2- 76 |
| cf. A. waltoni | 1- 18 | sp. | 1- 47 |
| sp. 5 | 2- 98 | ?sp. | 1- 74 |
| Bathysiphon | | (?Tritaxia) sp. | 1- 81 |
| cf. B. brosgei | 2- 82 | Globigerina | |
| scintillata | 1- 23 | sp. | 2-134 |
| cf. B. vitta | 2- 64 | Globorotalites | |
| sp. 3 | 1- 4 | cf. G. alaskensis | 2-136 |

| Genus and species | Chart and Column No. | Genus and species | Chart and Column No. |
|---|---|---|---|
| Glomospira | | Haplophragmoides | |
| sp. | 1- 73 | sp. G12 | 1- 59 |
| Glomospirella | | sp. G13 | 1- 79 |
| cf. G. arctica | 1- 22 | sp. G14 | 1- 85 |
| cf. G. elongata | 2- 94 | sp. G15 | 1- 87 |
| ex gr. G. elongata | 2-125 | cf. H. sp. G15 | 1- 87 |
| sp. 2B | 2- 57 | sp. G17 | 2- 5 |
| sp. 16 | 2-120 | sp. G18 | 2- 6 |
| sp. | 1- 5 | sp. G19 | 2- 7 |
| Haplophragmoides | | sp. G20 | 2- 12 |
| ex gr. H. canui | 1- 34 | sp. G21 | 1- 60 |
| ex gr. H. canui | 2-127 | sp. G22 | 2- 16 |
| ex gr. H. crickmayi | 1- 38 | sp. G23 | 2- 18 |
| ex gr. H. duoflatis | 2-106 | sp. G24 | 2- 20 |
| cf. H. eocalcula | 1- 62 | sp. G25 | 2- 21 |
| cf. H. excavata | 1- 71 | sp. G26 | 2- 25 |
| gigas | 2- 78 | sp. G32 | 2- 48 |
| ex gr. H. gigas (sp. 9C) | 1- 28 | sp. G33 | 2- 53 |
| ex gr. H. gigas (sp. 9F) | 2- 62 | sp. G34 | 2- 61 |
| ex gr. H. globosa | 1- 2 | sp. G38 | 2- 72 |
| cf. H. goodenoughensis | 1- 19 | sp. G39 | 2- 73 |
| cf. H. inflatigrandis | 1- 31 | sp. G40 | 2- 79 |
| ex gr. H. neocomiana | 2-115 | sp. G41 | 2- 83 |
| ex gr. H. spissum | 1- 1 | sp. G42 | 2- 84 |
| sp. 5 | 1- 41 | sp. G44 | 2- 99 |
| sp. 9E | 2- 70 | sp. G46 | 2-118 |
| sp. 9G | 2- 67 | sp. | 1- 9 |
| sp. 12 | 1- 83 | Hippocrepina | |
| sp. 16 | 2- 3 | barksdalei | 2- 34 |
| cf. H. sp. 40 | 2- 35 | sp. 1 | 1- 70 |
| sp. 43 | 2- 92 | sp. 4A | 2- 89 |
| sp. 62 | 2- 36 | cf. H. sp. 5 | 2- 23 |
| sp. 62C | 2- 46 | sp. 6 | 1- 44 |
| sp. 65 | 2- 68 | sp. 7 | 1- 54 |
| sp. 65A | 2- 43 | sp. 14 | 2-100 |
| sp. 66 | 2- 32 | sp. 17 | 2- 60 |
| sp. 66A | 2- 44 | (Hyperamminoides) sp. 17A | 2- 54 |
| sp. 66B | 2- 45 | sp. 19 | 2-119 |
| sp. G2 | 1- 57 | sp. 19A | 2-109 |
| sp. G3 | 1- 15 | sp. 19B | 2-111 |
| sp. G4 | 1- 43 | sp. | 1- 39 |
| sp. G5 | 1- 50 | ?sp. | 1- 61 |
| sp. G6 | 1- 51 | Hyperammina | |
| sp. G7 | 1- 53 | cf. H. aljutovica | 2-122 |
| sp. G8 | 1- 55 | sp. 1 | 2- 58 |
| sp. G9 | 1- 56 | sp. 1A | 2- 49 |
| sp. G10 | 1- 67 | cf. H. sp. 6 | 2- 38 |
| cf. H. sp. G10 | 1- 58 | sp. 13 | 2- 71 |
| sp. G11 | 1- 66 | sp. 14 | 2- 80 |

| Genus and species | Chart and Column No. |
|---|---|
| Hyperammina | |
| sp. 15 | 2- 86 |
| sp. 15B | 2- 91 |
| sp. 16 | 2- 87 |
| sp. 17 | 2- 88 |
| sp. 18 | 2- 90 |
| sp. 19 | 2- 97 |
| Lagena | |
| sp. | 1- 91 |
| Lenticulina | |
| cf. L. macrodisca | 2-133 |
| cf. L. topagorukensis | 2-140 |
| sp. 6B | 1- 95 |
| Lingulina | |
| sp. | 1- 89 |
| Marginulina | |
| sp. G89 | 2-135 |
| Miliammina | |
| awunensis | 2- 17 |
| cf. M. manitobensis | 2- 41 |
| ex gr. M. manitobensis | 1- 65 |
| sp. 1B | 1- 10 |
| sp. 3B | 2-102 |
| sp. | 1- 6 |
| Neobulimina | |
| cf. N. subcretacea | 2-132 |
| Nodosaria | |
| cf. N. proboscidea | 2-131 |
| Pelosina | |
| n. sp. 18 | 2- 55 |
| (?Hippocrepina) sp. | 1- 77 |
| (Hyperamminoides) sp. | 1- 40 |
| Plectina | |
| sp. | 1- 48 |
| Polymorphina | |
| sp. 4 | 2-138 |
| Psamminopelta | |
| sp. 2 | 2- 2 |
| sp. 3 | 2-108 |
| sp. | 2- 33 |
| Pseudoclavulina | |
| cf. P. hastata | 1- 27 |
| Pseudonodosaria | |
| sp. 5 | 2-137 |
| Reophax | |
| cf. R. densa | 1- 30 |
| (Proteonina) sp. 3B | 2- 1 |
| sp. 11 | 2- 93 |
| sp. 19 | 2-101 |

| Genus and species | Chart and Column No. |
|---|---|
| Reophax | |
| (Proteonina) sp. 27B | 2- 52 |
| (Proteonina) sp. 27D | 2-117 |
| (Proteonina) sp. 29 | 2- 66 |
| sp. | 1- 16 |
| (Proteonina) sp. | 1- 37 |
| ? (Proteonina) sp. | 2- 40 |
| Saccammina | |
| lathrami | 2- 77 |
| sp. 2 | 1- 82 |
| sp. 8 | 2- 13 |
| sp. 10 | 2- 59 |
| sp. 10A | 2- 75 |
| sp. 11B | 2-103 |
| sp. | 1- 52 |
| sp. | 2- 29 |
| (Hippocrepina) sp. | 1- 69 |
| Siphotextularia | |
| cf. S. sp. 10 | 2-107 |
| sp. 12B | 2-105 |
| sp. 12C | 2-121 |
| sp. | 2-113 |
| Textularia | |
| cf. T. topagorukensis | 2- 42 |
| sp. | 1- 29 |
| Thuramminoides | |
| ex gr. T. septagonalis | 2-112 |
| sp. 3 | 1- 63 |
| Triplasia | |
| kingakensis | 1- 32 |
| Tristix | |
| sp. | 2-128 |
| Trochammina | |
| ex gr. T. latumbilicata | 1- 42 |
| ex gr. T. rainwateri | 1- 17 |
| ex gr. T. ribstonensis | 1- 11 |
| cf. T. wetteri | 2- 47 |
| cf. T. whittingtoni | 1- 25 |
| sp. 15B | 2- 85 |
| sp. 31A | 2- 65 |
| sp. G2 | 1- 72 |
| sp. G3 | 1- 75 |
| sp. G4 | 1- 76 |
| sp. G5 | 1- 84 |
| (Trochamminoides) cf. T. sp. G6 | 1- 86 |
| sp. G7 | 2- 9 |
| sp. G8 | 2- 14 |
| sp. G9 | 2- 15 |
| sp. G10 | 2- 19 |

| Genus and species | Chart and Column No. | Genus and species | Chart and Column No. |
|---|---|---|---|
| Trochammina | | Trochamminoides | |
| sp. G11 | 2- 22 | sp. 9B | 2- 37 |
| sp. G12 | 2- 24 | sp. | 1- 88 |
| sp. G13 | 2- 81 | Verneuilinoides | |
| sp. | 1- 8 | ex gr. V. fischeri | 1- 45 |
| Trochamminoides | | cf. V. borealis | 2- 4 |
| ex gr. T. sp. 3B | 2- 28 | ex gr. V. borealis | 1- 68 |
| sp. 9 | 2- 27 | sp. 2A | 2-123 |
| | | sp. | 1- 12 |

ADDENDUM, May, 1971

Many limitations unique to this particular borehole have resulted in considerable variance in interpretation of the major stratigraphic boundary of the Upper/Lower Cretaceous. New microfossil evidence obtained since completion of this borehole study in 1969, agrees with the author's original interpretation for the boundary which was selected at a depth of 10,160 feet (Chamney, GSC Paper 69-1 Part B, pp. 69-72). The new evidence involves the provisional age assignment of early Upper Cretaceous for the foraminiferal assemblage "Cyclammina" sp. 1A. Correlation has now been established for this Assemblage Zone (Division 11) from the subsurface of the Delta to the mainland on the west flank of the Mackenzie River Delta. The rock samples from which this discovery was made were submitted for study by Dr. F.G. Young from the Moose Channel Formation on Fish River and Cache Creek (Young, F.G., GSC Paper 71-1, Part A, pp. 245-247). The change in provisional age assignment of the interval 6,960 to 10,160 feet to Early Cretaceous in this report was based on the occurrence of the zone species Verneuilinoides borealis Tappan (Tappan 1962) in the interval overlying the "Cyclammina" sp. 1A. However, more detailed study of Tappan's reported specimens for this species and their true stratigraphic position is required. The specimen of Verneuilinoides assigned to the species borealis in this paper present the following alternatives:

(a) Extension of the species range into the Upper Cretaceous.

(b) There is a possibility that the specimens illustrated by Tappan to describe the new species do in fact represent two species such as the elongate, smoother, inflated chambered species (figs. 1, 2, 7, 9) and the more flaring, coarser, larger species (figs. 3, 4, 6, 8). Figure 3 of the latter split is recorded to be from drill cuttings hence could very well be derived from strata overlying the Late Albian, Grandstand Formation. This latter specimen is similar to those recovered from Division 9 of the Reindeer D-27 borehole thus resulting in change of age assignment in order to agree with Tappan's age assignment.