FORAMINIFERS AND OTHER MICROFOSSILS
FROM THE EARLY CRETACEOUS MANNVILLE GROUP
IN SASKATOON

A Thesis
Submitted to the Faculty of Graduate Studies and Research
in Partial Fulfilment of the Requirements
For the Degree of
Master of Science
in Geology
Department of Geological Sciences
University of Saskatchewan

by

Kenneth Thomas James Atkin
Saskatoon, Saskatchewan
April, 1986

The University of Saskatchewan claims copyright in conjunction with the author. Use shall not be made of the material contained without proper acknowledgement.
The author has agreed that the Library, University of Saskatchewan, may make this thesis freely available for inspection. Moreover, the author has agreed that permission for extensive copying of this thesis for scholarly purposes may be granted by the professor or professors who supervised the thesis work recorded herein, or, in their absence, by the Head of the Department or the Dean of the College in which this work was done. It is understood that due recognition will be given to the author of this thesis and to the University of Saskatchewan in any use of the material in the thesis. Copying or publication or any other use of the thesis for financial gain without approval by the University of Saskatchewan and the author's written permission is prohibited.

Requests for permission to copy or to make other use of material in this thesis in whole or in part should be addressed to:

Head of the Department of Geological Sciences
University of Saskatchewan
Saskatoon, Saskatchewan
ABSTRACT

Deposition of the basal Cretaceous Mannville Group in the Lloydminster area and in adjoining areas of Saskatchewan farther to the east was profoundly influenced by the Clearwater sea, which formed a gulf over what is now the western Prairie Provinces during Early Albian time. The presence of between twenty-five and thirty species of foraminifers, which are dominantly agglutinated but in part calcareous walled and which occur in diminishing variety and number through the Mannville sequence, provide the principal evidence of marine influence. The foraminifers belong to the assemblage diagnostic of the Marginulinopsis collinsi-Verneuilinoides cummingensis Zone. Alternation of beds containing foraminifers with those lacking foraminifers but containing numerous megaspores suggest alternation of marine and non-marine environments of deposition and, thus, repetition of transgression and regression over the Lloydminster and adjacent areas.

Within the deposits of the Clearwater marine gulf as a whole, calcareous-walled foraminifers form a greater proportion of the foraminiferal fauna in the Rocky Mountain foothills than in Saskatchewan. The calcareous-walled component also becomes more prevalent to the north-
northwest, the direction from which the sea advanced, and likely reflect increasingly open-marine (less restricted) environments of deposition. Be that as it may, the presence of marine foraminifers now establishes that marine conditions prevailed within Saskatchewan at least as far east as Prince Albert and as far south as Saskatoon.

Pense sediments were deposited during the earliest temporary phase of marine transgression that led ultimately to deposition of the Late Albian Joli Fou sediments. Hence, the Pense Formation, upper of the two formations that constitute the Mannville Group across much of southern Saskatchewan, should be removed from the Mannville Group and classified with the Joli Fou Formation in the Colorado Group.
ACKNOWLEDGEMENTS

My wife, Verna provided invaluable support during the tenure of my post-graduate studies.

Dr. J.E. Christopher, Director of the Saskatchewan Geological Survey, advised me on the most appropriate cores through the Mannville Group of the Lloydminster and adjacent areas to study for their marine microfossil content. Dr. Malcolm Wilson of the Saskatchewan Department of Energy and Mines also assisted me in evaluating and sampling cored sections, as did Dr. Jim Lorsong of Serendipity Research Ltd., in Regina.

I am the beneficiary of help from a number of faculty members in the Department of Geological Sciences of the University of Saskatchewan. These include Dr. J. Basinger (plant material), Dr. W.K. Braun (ostracods and concepts in stratigraphy), Dr. A. McCracken (various microfossil groups). Professional Research Associate B.R. North assisted me with taxonomy and paleoecology of the foraminiferal fauna. Dr. W.G.E. Caldwell supervised the study. I appreciate also the stimulating discussions I had with a number of fellow graduate students, most notably Mr. L. Craig.

The study was supported financially through a research grant to Dr. Caldwell from the National Sciences and Engineering Research Council of Canada.
# CONTENTS

I. **INTRODUCTION** ................................................. 1

I.1 Regional Stratigraphic Correlation ..... 3
I.2 Previous Work .............................. 6
I.3 Scope and Objective ......................... 8

II. **MICROFOSSILS OF THE MANNVILLE GROUP** ............... 9

II.1 Studied Sections ............................ 9
II.2 Distribution of Microfossils ............... 9
II.3 Systematics of Foraminifera and Tintinnina ................. 12

III. **INTERPRETATION** ........................................... 36

III.1 Biostratigraphy .......................... 36
III.2 Transgressive-Regressive Sequences ....... 40
  III.2.1 The Cummings Formation .......... 41
  III.2.2 The Lloydminster Formation ........ 44
  III.2.3 The Rex Formation .................. 44
  III.2.4 The General Petroleums (G.P.) and Sparky Formations ................. 45
  III.2.5 The Waseca, McLaren, and Colony Formations .................. 46
III.3 Paleoenvironments ....................... 47
  III.3.1 Fossils of the Mannville Group .... 47
  III.3.2 Geographic Variations in the Fauna and Character of the Mannville Group .................. 58
III.4 Paleogeography .......................... 63
  III.4.1 The Western Margin ................. 64
  III.4.2 The Southern Margin ................. 65
  III.4.3 The Eastern Margin .................. 67

IV. **A NOTE ON THE PENSE FORMATION** .................... 67

V. **PRINCIPAL CONCLUSIONS** ...................... 73

VI. **REFERENCES CITED** ......................... 76
TEXT - FIGURES

1. Correlation chart of the Mannville Group and equivalent strata in part of the Western Interior basin of Canada.

2. Location map of studied sections.

3. Distribution chart of the foraminifers and other microfossils in the Paradise Hill cored section.

4. Distribution chart of the foraminifers and other microfossils in the Dee Valley cored section.

5. Distribution chart of the foraminifers and other microfossils in the Choiceland cored section.

6. Map showing the distribution of sections through the Mannville Group and equivalents in Alberta and Saskatchewan from which foraminifers and other microfossils have been recovered. Alberta sections are mostly those studied by McLean and Wall (1981), but also include the Athabasca River section studied by Caldwell and North (unpublished). Saskatchewan sections are those studied for this thesis. Combination of all sections provides the data base for the generalized paleoenvironmental reconstructions.

7. Graphical representation of the different kinds of foraminifers and ostracods (to generic level) present in the Mannville and equivalent rocks of Alberta and Saskatchewan.

8. Graphical representation of the different kinds of foraminifers and ostracods (to specific level) present in the Mannville and equivalent rocks in Alberta and Saskatchewan.


10. Distribution chart of the microfossils recovered from the Pense Formation in the Calderbank cored section.

11. Distribution chart of the microfossils recovered from the Pense Formation in the Duval section.
MICROFOSSIL PLATES

1. Foraminifera and other microfossils of the Mannville Group in Saskatchewan.

2. Foraminifera of the Mannville Group in Saskatchewan.
1. INTRODUCTION

The Lower Cretaceous Mannville Group extends across much of Alberta and Saskatchewan and rests with great unconformity on pre-Cretaceous rocks of various ages, but mainly on those belonging to the Devonian, Mississippian, and Jurassic systems. The top of the Mannville Group is also marked by an unconformity, but one of much lesser magnitude and of diminishing magnitude northwards. Formations of the Mannville Group and their relationship to one another are depicted in Figure 1. This paper will concentrate on the Lloydminster area.

Deposition of sediments that form the Mannville Group was strongly affected by transgressions and regressions of the Clearwater sea, which inundated much of the Western Interior basin of North America in Early Albian time (Caldwell, 1984, p. 188), when it formed an extensive U-shaped gulf reaching from what is now the Beaufort Sea into southern Alberta and Saskatchewan. To the west the sea was bordered by the Cordillera, to the east by the Precambrian Shield, and to the south and southeast by a low-lying, eroded pre-Cretaceous landmass. A chain of islands likely extended from what is now southwestern Saskatchewan, through north-central and northwestern Alberta, to northeastern British Columbia and divided the gulf into eastern and western segments. This chain of islands may have represented an early paleogeographic expression of the
Figure 1. Correlation chart of the Mannville Group and equivalent strata in part of the Western Interior basin of Canada.
foreland bulge of the basin, which developed in response to early tectonic loading of the western margin of the Craton during the Columbian orogeny (Caldwell, 1984, p. 188).

I.1 Regional Stratigraphic Correlation

Regional correlation of the Mannville Group and its component formations is hindered by gradual southward facies change from marine to non-marine deposits. Non-marine deposits dominate the Mannville Group in southern Alberta and Saskatchewan. An exception is the Pense Formation of southern Saskatchewan which is largely marine or marginal-marine in origin, but the Pense Formation should probably be excluded from the Mannville Group and linked to the Joli Fou Formation which overlies the Mannville Group throughout the study area. In the Lloydminster area, marine and marginal-marine deposits are complexly intertongued, and each of the eight formations that succeed the basal Dina formation* may represent a transgressive-regressive event of the Boreal Clearwater sea. In the Fort McMurray area of northeastern Alberta, each of the three major stratigraphic divisions of the Mannville Group represents a change in depositional environment: the McMurray Formation is largely terrestrial in origin and correlates approximately with the Dina

* The non-geographical components of lithostratigraphic names are capitalized only when the division has been established formally.
formation in the LloyDMINSTER area; the Clearwater Formation is a product of deposition in an offshore environment and is approximately equivalent to part or all of five formations in the lower and middle parts of the Mannville Group in the LloyDMINSTER area; and the Grand Rapids Formation records mixed marine and marginal-marine deposition and may be equivalent to the upper three formations of the Mannville Group in the LloyDMINSTER area. The top of the Mannville Group is well defined in the Fort McMurray area by the Grand Rapids-Joli Fou unconformity. Farther north and west, stratigraphic relations with the Mannville sequence are obscured by nomenclatural changes. The Moosebar Formation, however, includes off-shore marine muds that accumulated in the western arm of the Clearwater sea (west of the median chain of islands), and that formation is essentially equivalent to the Clearwater Formation. Underlying formations, such as the Gething, Gladstone, and Bluesky, are non-marine to marginal-marine in origin, as are those above the Moosebar Formation, such as the Gates and Beaver Mines. They record, therefore, the onset of marine conditions and later waning of these conditions.

In the LloyDMINSTER area, it is commonly accepted that the Dina formation was deposited in a fluvial setting and filled many irregularities in the eroded pre-Cretaceous surface (Orr et al., 1977, p. 1195; Vigrass, 1977, p.
It is also commonly accepted that sediments of the middle Mannville Group (Lloydminster, Rex, General Petroleums or G.P., and Sparky formations) were deposited in marine to marginal-marine settings (Vigrass, 1977, p. 1012; Orr et al., 1977, p. 1195). The origin of the upper Mannville sediments is, however, much disputed. Some investigators have advocated a fluvial origin (Putnam, 1980, p. 213), and others a mixed marine and non-marine origin (Orr et al., 1977, p. 1195; Vigrass, 1977, p. 1026).

Stratigraphic analysis of the Mannville Group is based on rock-units that are readily identifiable on geophysical logs. Whereas this kind of analysis is valuable in exploration locally, it is of limited value in effecting long-range regional correlations. The off-shore environment is the most widespread of all marine environments and the one most likely to produce laterally persistent beds. Hence it is not surprising that the most laterally persistent beds in the Mannville sequence are those shales that were deposited as off-shore muds. Such shales are recognized most reliably by their faunal contents, particularly the relatively common occurrence and high diversity of foraminifers. The faunas themselves may be useful too in biostratigraphic considerations of the deposits.
I.2 PREVIOUS WORK

Nauss (1945) established the Mannville Formation in the Lloydminster area and divided it into six members. He interpreted it as non-marine in origin, except for one thin marine shale from which he collected a variety of foraminifers. It is doubtful that Nauss sampled the entire Mannville sequence for microfossils; had he done so, he likely would have recognized a much greater marine influence. Much has been learned about the Mannville deposits since the early work of Nauss, and many changes have been made in its stratigraphic divisions. The nomenclature proposed by Nauss (1945) was replaced by the 'driller's terminology' (Figure 1), which was first introduced to the literature by Edmunds (1948) and later revised by Vigrass (1977) and Orr et al. (1977). Badgeley (1952) proposed that the Mannville should be elevated to the status of group, but its rank is still a subject of dispute. Thus, although the divisions proposed by Vigrass and by Orr et al. are similar, the former referred to them as members and the latter as formations. The 'driller's terminology' was based largely on sandstones and did not recognize intervening shales. Vigrass (1977, p.1012) included within the members shales subjacent to the sandstones and interpreted the members as progradational sequences. It is now common practice to differentiate between sandstones and shales by referring to them by name,
as in the Lloydminster sandstone and the Lloydminster shale. Of the stratigraphic divisions proposed by Nauss (1945), only the names Mannville, Dina, and Cummings remain, and it is doubtful that the Dina and Cummings formations, as defined by Orr et al. (1977) and by Vigrass (1977), accord with the definition proposed by Nauss.

Among the numerous studies of the Mannville Group, only Nauss (1945, 1947) and Fuglem (1970) have emphasized investigation of the microfauna. Nauss appears to have studied the microfauna from only a very limited portion of the Mannville sequence. In contrast, Fuglem (p. 7) found foraminifers in parts of the sequence from "the top of the Dina to near the top of the Mannville". He thus established that marine conditions were repeated throughout deposition of most of the Mannville sediments in the Lloydminster area. Fuglem (1970) also helped establish the importance of megaspores in unravelling the depositional environments and stratigraphy of Mannville sediments. The comparatively large size of megaspores relative to pollen grains reduces the likelihood that megaspores will be transported, and thereby enhances their potential for use in paleoenvironmental reconstructions (Hopkins and Sweet, 1976, p. 60). In a study of the Upper Cretaceous Pakowki, Foremost, and Oldman formations, Speelman and Hills (1976) demonstrated that low concentrations of megaspores typify open-marine (off-shore) deposits and high concentrations
marginal- to non-marine deposits. The absence of megaspores does not necessarily point to an off-shore environment of deposition, but a concentration of megaspores strongly suggests a marginal- to non-marine environment.

1.3 SCOPE AND OBJECTIVE

This project was undertaken to extend what is known about the fossil content of the Mannville Group in Saskatchewan, with emphasis on the foraminiferal content. Nauss (1945, 1949) and Fuglem (1970) studied the foraminiferal fauna of the Lloydminster area of Alberta and Saskatchewan but did not study as large an area as covered by this study and did not present the distribution of their faunas in a detailed fashion. In this study, interpretation of the paleogeographic history of the Mannville Group is based mostly on the distribution of fossils. The paleogeographic history is then related to the stratigraphy.

Examination of a two cores from the Pense Formation for microfossils revealed the presence of tintinnids and foraminifers previously thought to be absent from this rock-unit. Interpretation of the fossil assemblage supports a transgressive origin for the Pense Formation, as proposed by Maycock (1967, p. 46) and Price and Ball (1974, p. 22).
II. MICROFOSSILS OF THE MANNVILLE GROUP

II.1 Studied Sections

The area of study and location of cored sections are illustrated in figure 2. The seven cored sections that were examined are Shell-Husky Paradise Hill (A13-19-52-23W3M), Shell Dee Valley (A11-18-48-21W3M), Choiceland No. 1 Choice (13-3-50-18W2M), Duval Corporation Pilothole (6-18-36-6W3M), C.D.R. Calderbank (13-28-19-7W3M), Mobil Oil South Grassdale #32-10 (10-32-6-15W2M), and Imperial Steelman Source 11-17-4-5 (11-17-4-5W2M). The Paradise Hill, Dee Valley, Choiceland, and Duval sections span the entire Mannville sequence. A complete Mannville section is not available in southeastern Saskatchewan, and therefore two partial sections, Grassdale and Steelman, were sampled largely to ascertain if there was any evidence of the Clearwater sea having extended so far to the southeast. The Calderbank section is situated in southwestern Saskatchewan and comprises only the Pense Formation. It was included to determine if microfossils useful for paleoenvironmental or biostratigraphic purposes are present, and if so, if they are recognizably different from those of the underlying Mannville Group.

II.2 Distribution of Microfossils

The distribution of microfossils in the most fossiliferous sections studied is depicted in graphical
Figure 2. Area of study and distribution of studied sections.
form in figures 3, 4, and 5. Opposing histograms recording concentrations of foraminifers and megaspores are included and, assuming the usual interrelationship of these organisms, provide a measure of relative proximity to the shoreline. They may also express the numerous transgressions and regressions during Mannville deposition.

Foraminifers also were found in the Cantuar and Pense formations of the Mannville Group in the Duval section. The occurrence of the foraminifers *Hippocrepina barksdalei* Tappan, *Saccammina lathrami* Tappan, *Bathysiphon cf. B. brosgei* Tappan, and the tintinnid *Dicloeopella borealis* Eicher between 538.6 and 541.7m (Cantuar Formation) proves that the Clearwater sea advanced at least as far east and south as the Duval section, which is near Saskatoon. The low diversity and simple test structure of the assemblage suggests that the sea was brackish, circulation highly restricted, and the shoreline in close proximity.

The fossil assemblage of the Pense Formation in the Duval and Calderbank sections is shown in figures 10 and 11. In general, the distribution reveals an assemblage of megaspores near the base grading up into foraminifer-dominated assemblages near the top, which suggests increasingly marine conditions up-section. Thus the Pense Formation may well be a transgressive sequence.

The Grassdale section was found to be barren of foraminifers. The Steelman section yielded a few highly
enigmatic structures from a thin bed of mudstone. These structures may be either very simple unilocular agglutinated foraminifers or burrows. There is no clear evidence from organic remains, therefore, of the Clearwater sea having extended as far east and south as what is now southeastern Saskatchewan.

II.3 Systematics of Foraminifera and Tintinnina

PHYLUM PROTOISTA

CLASS SARCODINA

ORDER FORAMINIFERA

SUBORDER TEXTULARIINA

SUPERFAMILY AMMODISCACEAE

FAMILY ASTORHIZIDAE

SUBFAMILY RHIZAMMININAE

BATHYSIPHON Sars, 1872

Bathysiphon cf. B. brosgei Tappan

Plate 1, figures 18-20

1975. Bathysiphon cf. brosgei Tappan; North and Caldwell, pl.1, fig.1
1981. Bathysiphon brosgei Tappan; McNeil and Caldwell, p.129, pl.9, fig.1

Description. Test unilocular, small, elongate, tubular, flattened, without visible constrictions, and with sides of test parallel or divergent; wall very finely agglutinated, without visible grains, smoothly
finished; aperture at open ends of tube.

Figured specimens. Figure 18; G.M.U.S. Pf 4516; length 0.70 mm; width 0.13 mm. Figure 19; G.M.U.S. Pf 4517; length 0.54 mm; width 0.17 mm. Figure 20; G.M.U.S. Pf 4518; length 0.56 mm; width 0.17 mm.

Remarks. Bathysiphon cf. B. brosgei differs from the types of the species in that the test commonly has non-parallel sides and lacks transverse growth constrictions.

Bathysiphon vitta Nauss, 1947

Description. Test unilocular, moderately large, elongate, tubular, compressed to flattened, generally wrinkled with regularly spaced transverse constrictions common; wall usually very finely agglutinated, without visible grains, smoothly finished; aperture at open ends of tube.

Remarks. Although the tests are generally very finely agglutinated, a few coarse-grained specimens have been recovered. The coarse-grained appearance may have resulted from sand-grains adhering to, or being pressed into, the
test during compaction and diagenesis.

SUBFAMILY HIPPOCREPINNINAE

**Hippocrepina** Parker, 1870

**Hippocrepina** sp. Crespin

Plate 1, figures 21-22

1963. *Sacculinella* sp. Crespin, p.22, pl.1, figs.21-22
1967. *Hippocrepina*? sp., Guliov, p.16, pl.1, fig.2
1975. *Brachysiphon* sp., North and Caldwell, pl.1, figs.2-3.
1981. *Hippocrepina* sp., McNeil and Caldwell, p.130, pl.9, figs.3-4

**Description.** Test unilocular, flattened, sac-shaped, with numerous transverse constrictions; wall finely agglutinated, without visible grains, smoothly finished; aperture large, terminal, elliptical, formed by a gentle constriction of wall.

**Figured specimens.** Figure 21; G.M.U.S. Pf 4519; length 1.87 mm; width 0.78 mm. Figure 22; G.M.U.S. Pf 4520; length 1.26 mm; width 0.56 mm.

**Hippocrepina barksdalei** Tappan

Plate 1, figures 13-15

1957. *Hyperamminoides barksdalei* Tappan, p.202, pl.65, figs.6-12
1962. *Hyperamminoides barksdalei* Tappan; Tappan, p.129, pl.29, figs.21-27
1981. *Hippocrepina barksdalei* Tappan; McLean and Wall, pl.8, figs.1-2
Description. Test unilocular, elongate, flattened, sac-like to tubular, without transverse constrictions; wall very finely agglutinated, without visible grains, smoothly finished; aperture terminal, elliptical, on short neck.

Figured specimens. Figure 13; G.M.U.S. Pf 4511; length 1.00 mm; width 0.30 mm. Figure 14; G.M.U.S. Pf 4512; length 0.50 mm; width 0.23 mm. Figure 15; G.M.U.S. Pf 4513; length 0.93 mm; width 0.34 mm.

FAMILY SACCAMMINIDAE

SUBFAMILY SACCAMMINAE

Saccammina Sars, 1869

Saccammina alexanderi Loeblich and Tappan

Plate 1, figures 16-17

1950. Proteonina alexanderi Loeblich and Tappan, p.5, pl.1, figs.1-2
1960. Saccammina alexanderi Loeblich and Tappan; Eicher, 1960, p.55, pl.3, figs.1-2
1963. Saccammina alexanderi Loeblich and Tappan; Crespin, p.20, pl.1, fig.10-12
1967. Saccammina cf. S. alexanderi Loeblich and Tappan; Guliov, p.16, pl.1, fig.3
1975. Saccammina alexanderi Loeblich and Tappan; North and Caldwell, pl.1, fig.4; pl.6, fig.6
1981. Saccammina alexanderi Loeblich and Tappan; McNeil and Caldwell, p.132, pl.9, fig.8

Description. Test unilocular, inflated, flask-shaped, with prominent neck; wall medium to coarsely agglutinated, with angular quartz grains visible,
smoothly to roughly finished; aperture terminal, rounded, at end of prominent neck.

**Figured specimens.** Figure 16; G.M.U.S. Pf 4514; length 0.89 mm; width 0.33 mm. Figure 17; G.M.U.S. Pf 4515; length 0.67 mm; width 0.30 mm.

*Saccammina lathrami* Tappan

Not Figured

1956. *Saccammina* sp., Stelck et al., p.31-32, pl.4, fig.11
1962. *Saccammina lathrami* Tappan; Tappan, p.129, pl.29, figs.9-12
1963. *Psammosphaera parva* Crespin, p. 20, pl.11, figs.4-9
1975. *Saccammina lathrami* Tappan; North and Caldwell, pl.1, fig.5; pl.6, fig.5
1981. *Saccammina* sp. A, McLean and Wall, pl.7, fig.1
1981. *Saccammina* cf. *S. lathrami* Tappan; McNeil and Caldwell, p.134, pl.9, fig.10

**Description.** Test unilocular, rounded to gently ovate in profile, flattened; wall very finely agglutinated, smoothly finished; aperture rounded to ovate, at end of short neck.

**Pelosina** Brady, 1879

*Pelosina* sp.

Not Figured

1975. *Pelosina* sp. North and Caldwell, pl. 6, fig.3
Description. Test unilocular, fusiform, thin-walled, flattened; wall very finely agglutinated, without visible grains; aperture small, at open ends of tube-like extensions at both ends.

SUBFAMILY DIFFUSILININAE

Thuramminoides Plummer, 1945

Thuramminoides spp.

Plate 1, figures 10-12

Remarks. Several specimens, unidentifiable as to species, are referred to this genus. They vary in size and are circular in outline and generally compressed. The wall is very finely agglutinated and lacks visible grains. No aperture is visible. Specimens of Saccammina lathrami Tappan in which the aperture has been obscured by preservation easily could be mistaken for Thuramminoides.

Figured specimens. Figure 10; G.M.U.S. Pf 4508; maximum diameter 0.54 mm. Figure 11; G.M.U.S. Pf 4509; maximum diameter 0.50 mm. Figure 12; G.M.U.S. Pf 4510; maximum diameter 0.35 mm.

FAMILY AMMODISCIDAE

SUBFAMILY AMMODISCINAE

Ammodiscus Reuss, 1862.
Ammodiscus anthosatus Guliov

Not Figured

1966. Ammodiscus anthosatus Guliov, p.142, pl.12, figs. 1-5
1975. Ammodiscus anthosatus Guliov; North and Caldwell, pl.1, fig.7
1981. Ammodiscus anthosatus Guliov; McNeil and Caldwell, p.134, pl.9, fig.12

Description. Test unilocular, disc-shaped, planispiral, evolute, usually with a broad shallow umbilicus; whorls closely appressed, four or five in number, proximal whorl obscure, last three whorls each divided into about four lobate tubular sections by constrictions of test wall; wall finely agglutinated, surface slightly rough; aperture a rounded opening at end of last volution.

SUPERFAMILY LITUOLACEA

FAMILY RZEHAKINIDAE

Miliammina Heron-Allen and Earland, 1930

Miliammina manitobensis Wickenden

Plate 1, figures 23-26

1932. Miliammina manitobensis Wickenden, p.90, pl.1, fig.11
1958. Miliammina sp. B, Stelck et al., p.30, pl.3, figs.17-20
1962. Miliammina manitobensis Wickenden; Tappan, p.160, pl.36, figs.12-18
1967. Miliammina cf. M. manitobensis Wickenden; Guliov, p.22, pl.3, fig.3
1975. Miliammina manitobensis Wickenden; North and
Caldwell, pl.1, figs. 12-14
1981. *Miliammina manitobensis* Wickenden; McLean and
Wall, pl.7, figs.2-3
1981. *Miliammina manitobensis* Wickenden; McNeil and
Caldwell, p.143, pl.10, figs.9-14

**Description.** Test elliptical, quinqueloculine; chambers tubular, commonly obscure; sutures indistinct, depressed; wall finely to very-finely agglutinated, commonly with visible quartz grains and moderately rough finish; aperture terminal, elliptical, toothless, at end of short neck in well preserved specimens.

**Figured specimens.** Figure 23; G.M.U.S. Pf 4521; length 0.76 mm; width 0.45 mm. Figure 24; G.M.U.S. Pf 4522; length 0.67 mm; width 0.38 mm. Figure 25; G.M.U.S. Pf 4523; length 0.83 mm; width 0.48 mm. Figure 26; G.M.U.S. Pf 4524; length 0.63 mm; width 0.37 mm.

**Miliammina sproulei** Nauss

Plate 1, figures 27-30

1956. *Miliammina sproulei* Nauss; Stelck et al., p.45, pl.5, figs.7-12
1975. *Miliammina sproulei* Nauss; North and Caldwell, pl.1, fig.15
1981. *Miliammina sproulei* Nauss; McLean and Wall, pl.7, figs.4-7

**Description.** Test elongate, approximately triangular in cross-section, quinqueloculine; chambers tubular,
sutures distinct, depressed; wall very finely agglutinated, without visible grains, smoothly finished; aperture terminal, rounded, toothless.

Figured specimens. Figure 27; G.M.U.S. Pf 4525; length 0.83 mm; width 0.28 mm. Figure 28; G.M.U.S. Pf 4526; length 0.83 mm; width 0.28 mm. Figure 29; G.M.U.S. Pf 4527; length 0.76 mm; width 0.30 mm. Figure 30; G.M.U.S. Pf 4528; length 0.89 mm; width 0.37 mm.

FAMILY LITUOLIDAE

SUBFAMILY HAPLOPHRAGMIDINAE

Haplophragmoides Cushman, 1910

Haplophragmoides gigas Cushman

Not Figured

1927. Haplophragmoides gigas Cushman, p.79-80, pl.1, fig.5
1947. Haplophragmoides gigas Cushman; Nauss, p.3338, pl.49, fig.8
1956. Haplophragmoides gigas Cushman; Stelck et al., p.35, pl.5, fig.1
1960. Haplophragmoides gigas Cushman; Eicher, p.58, pl.3, fig.16
1962. Haplophragmoides gigas Cushman; Tappan, p.134, pl.30, fig.15
1963. Haplophragmoides gigas Cushman; Crespin, p.31, pl.6, figs. 9-17
1967. Haplophragmoides gigas Cushman; Guliov, p.23, pl.4, fig.1
1975. Haplophragmoides gigas Cushman; North and Caldwell, pl.1, fig.19-20
1981. Haplophragmoides gigas Cushman; McNeil and Caldwell, p.147, pl.11, figs.4a, b, 5

Description. Test large, planispiral, involute, compressed, deeply umbilicate, commonly with umbilical
lobe; eight to twelve chambers in ultimate whorl; sutures sigmoidal, depressed; wall finely agglutinated, with visible quartz grains, smoothly finished; aperture a small, low, arched slit, equatorial, interiomarginal.

**Haplophragmoides kirki** Wickenden

Not Figured

1932. *Haplophragmoides kirki* Wickenden, p.85-86, pl.1, fig.1
1967. *Haplophragmoides kirki* Wickenden; Guliov, p.24, pl.4, fig.1
1975. *Haplophragmoides kirki* Wickenden; North and Caldwell, pl.6, fig.21
1981. *Haplophragmoides kirki* Wickenden; McNeil and Caldwell, p.152, pl.11, figs.10a, b

**Description.** Test small, planispiral, completely involute; chambers distinct, four or five in ultimate whorl; sutures distinct, weakly depressed, straight; wall finely agglutinated, with visible quartz grains, smoothly finished; aperture a low arched slit, equatorial, interiomarginal.

**Haplophragmoides linki** Nauss

Plate 1, figures 35-36; Plate 2, figure 1

1947. *Haplophragmoides linki* Nauss, p.339, pl.49, fig.7
1947. *Haplophragmoides gigas var. minor* Nauss, p.338, pl.49, fig.10

21
Description. Test involute, planispiral, deeply umbilicate, periphery broadly rounded; chambers distinct, six to eleven in ultimate whorl; sutures distinct, depressed, straight in uncrushed specimens, sigmoidal or straight in crushed specimens; wall finely agglutinated, with visible quartz grains, smoothly finished; aperture a low arched slit, equatorial, interiomarginal.

Figured specimens. Figure 35; G.M.U.S. Pf 4533; maximum diameter 0.52 mm. Figure 36; G.M.U.S. Pf 4534; maximum diameter 0.52 mm. Figure 1; G.M.U.S. Pf 4535; maximum diameter 1.13 mm.

Remarks. Haplophragmoides gigas var. minor Nauss is believed to be a variety of H. linki. The straight sutures of H. linki become contorted when crushed, thereby creating the apparent sigmoidal sutures that characterize H. gigas var. minor.
Recurvoides EARLAND, 1934

Recurvoides sp.

Plate 1, figures 31-34

Description. Test sub-spheroidal, streptospirally coiled; chambers distinct, eight to twelve in ultimate whorl, a few chambers of previous whorl visible on one side; sutures distinct, depressed; wall finely agglutinated, with visible quartz grains, smoothly finished; aperture, small, equatorial, interiomarginal.

Figured specimens. Figure 31; G.M.U.S. Pf 4529; maximum diameter 0.56 mm. Figure 32; G.M.U.S. Pf 4530; maximum diameter 0.52 mm. Figure 33; G.M.U.S. Pf 4531; maximum diameter 0.46 mm. Figure 34; G.M.U.S. Pf 4532; maximum diameter 0.50 mm.

SUBFAMILY LITUOLINAE

Ammobaculites Cushman, 1910

Ammobaculites euides Loeblich and Tappan

Plate 2, figures 22-23

1949. Ammobaculites euides Loeblich and Tappan, p.250, pl.46, fig.8
1967. Ammobaculites euides Guliov, p.26, pl.4, fig.5

Description. Test elongate, proximal portion planispiral involute, distal portion uniserial; chambers of coiled portion indistinct, chambers of uniserial portion distinct, approximately five, first uniserial
chamber of only slightly greater diameter than coiled portion; sutures indistinct, flush in coiled portion; wall finely agglutinated, with visible quartz grains, smoothly finished; aperture terminal, rounded.

Figured specimens. Figure 22; G.M.U.S. Pf 4556; length 2.26 mm; width 0.65 mm. Figure 23; G.M.U.S. Pf 4557; length 2.26 mm; width 0.61 mm.

Remarks. This species is distinguished from the genus Reophax by the sutures of the coiled portion being faintly visible and by the suture between the coiled and uniserial portions commonly being oblique to the test wall.

Ammobaculites fragmentarius Cushman

Plate 2, figures 19-21

1927. Ammobaculites fragmentarius Cushman, p.130, pl.1, fig.8
1956. Ammobaculites fragmentarius Cushman; Stelck et al., p.21, pl.5, fig.18
1962. Ammobaculites fragmentarius Cushman; Tappan, p.136, pl.32, figs. 8-11
1963. Ammobaculites fragmentarius Cushman; Crespin, p.39, pl.7, fig.15
1975. Ammobaculites fragmentarius Cushman; North and Caldwell, pl.2, figs.2-5
1981. Ammobaculites fragmentarius Cushman; McLean and Wall, pl.8, figs.9-10
1981. Ammobaculites fragmentarius Cushman; McNeil and Caldwell, p.158, pl.12, figs.6-7

Description. Test large to moderately large, elongate, proximal portion planispiral involute, distal
portion uniserial; chambers weakly inflated, increasing in size as added, three to five in coiled portion, three to seven (rarely as many as nine) in uniserial portion; sutures distinct, depressed; wall finely to coarsely agglutinated, with visible quartz grains, smoothly or roughly finished; aperture terminal, rounded.

Figured specimens. Figure 19; G.M.U.S. Pf 4553; length 1.17 mm; width 0.35 mm. Figure 20; G.M.U.S. Pf 4554; length 1.70 mm; width 0.65 mm. Figure 21; G.M.U.S. Pf 4555; length 2.17 mm; width 0.52 mm.

Ammobaculites janus Stelck and Wall

Plate 2, figures 17-18

1956. Ammobaculites janus Stelck and Wall, p.23, pl.4, figs.1-2

Description. Test elongate, proximal portion planispiral involute, distal portion uniserial; chambers weakly inflated, four or five in coiled portion, two or three in uniserial portion; sutures distinct, depressed; wall finely agglutinated, with visible quartz grains, smoothly finished; aperture terminal, rounded.

Figured specimens. Figure 17; G.M.U.S. Pf 4551; length 0.63 mm; width 0.24 mm. Figure 18; G.M.U.S. Pf 4552; length 0.76 mm; width 0.39 mm.

Remarks. Specimens found in the Cummings shale of the Dee Valley section differ from the type species in
that sutures are distinct and depressed.

**Ammobaculoides** Plummer, 1932.

*Ammobaculoides whitneyi* Cushman and Alexander

Plate 2, figures 24-25

1930. *Spiroplectammina whitneyi* Cushman and Alexander, p.8-9, pl.2, fig.12
1949. *Ammobaculoides whitneyi* Cushman and Alexander; Loeblich and Tappan, p.252, pl.47, figs.2-4
1956. *Ammobaculoides athabascensis*, Stelck et al., p.25, pl.5, fig.21
1960. *Ammobaculoides whitneyi* Cushman and Alexander; Eicher, p.65, pl.4, figs.12-14
1967. *Ammobaculoides whitneyi* Cushman and Alexander; Gulov, p.30, pl.5, figs.6-8
1975. *Ammobaculoides whitneyi* Cushman and Alexander; North and Caldwell, pl.2, fig.12
1981. *Ammobaculoides whitneyi* Cushman and Alexander; McNeill and Caldwell, p.160, pl.12, figs.11-12

**Description.** Test elongate, ellipsoidal in cross-section, sides near-parallel; chambers of proximal portion planispiral, involute, forming a moderately deep umbilicus, six to eight in ultimate whorl; chambers of distal portion moderately inflated, biserial, commonly becoming uniserial, two to six in biserial portion, one to three in uniserial portion if present; sutures distinct, depressed; wall finely agglutinated, with visible quartz grains, smoothly finished; aperture terminal, rounded.

**Figured specimens.** Figure 24; G.M.U.S. Pf 4558; length 1.30 mm; width 0.43 mm. Figure 25; G.M.U.S. Pf
Ammomarginulina Wiesner, 1931

*Ammomarginulina asperata* Guliov

Plate 2, figures 28-30

1966. *Ammomarginulina asperata* Guliov, p. 142-143, pl.12, figs.6-9
1981. *Ammomarginulina asperata* Guliov; McNeil and Caldwell, p.161, pl.12, fig.13

Description. Test large, proximal portion planispiral, involute, followed by poorly developed uniserial portion; umbilicus narrow and moderately depressed in inflated forms, broad and shallow in crushed specimens; chambers inflated, increasing markedly in size as added, five to seven in ultimate whorl of coiled portion, one to three in uniserial portion; sutures fairly distinct, depressed; wall coarse to medium grained, roughly finished; aperture terminal, rounded.

Figured specimens. Figure 28; G.M.U.S. Pf 4562; length 1.24 mm; width 1.07 mm. Figure 29; G.M.U.S. Pf 4563; length 1.80 mm; width 1.17 mm. Figure 30; G.M.U.S. Pf 4564; length 1.76 mm; width 1.35 mm.

Remarks. Where only a single uniserial chamber is developed, *A. asperata* can be distinguished from *Haplophragmoides* by the terminal position of the aperture.
Ammomarginulina sp.

Plate 2, figures 26-27

1967. Ammomarginulina sp., Guliov, p.32-34, pl.6, fig.3
1981. Ammomarginulina sp., McLean and Wall, pl.7, figs.14-15

Description. Test elongate, compressed, proximal portion planispiral involute, distal portion uniserial; chambers weakly inflated, increasing in size as added, three to five in ultimate whorl, two to four in uniserial portion, final chamber pyriform; sutures distinct, depressed, oblique to test margin; wall finely agglutinated, with visible quartz grains, smoothly finished; aperture terminal, elliptical.

Figured specimens. Figure 26; G.M.U.S. Pf 4560; length 1.08 mm; width 0.52 mm. Figure 27; G.M.U.S. Pf 4561; length 0.91 mm; width 0.57 mm.

Flabellammina Cushman, 1928

Flabellammina? sp. McLean and Wall

Plate 2, figures 31-34

1963. Reophax sp.C, Crespin, p.26, pl.4, figs.11-12
1967. Reophax sp., Guliov, p.19, pl.2, fig.3

Description. Test elongate, asymmetric-fusiform in outline, proximal stage appears coiled but difficult to
distinguish, distal portion uniserial; about four chambers in uniserial portion, increasing very markedly in size as added; sutures indistinct, depressed; wall coarsely agglutinated, very roughly finished, little cement; aperture terminal, rounded.

**Figured specimens.** Figure 31; G.M.U.S. Pf 4565; length 1.26 mm; width 0.57 mm. Figure 32; G.M.U.S. Pf 4566; length 1.65 mm; width 0.87 mm. Figure 33; G.M.U.S. Pf 4567; length 1.91; width 0.70. Figure 34; G.M.U.S. Pf 4568; length 1.96 mm; width 0.74 mm.

**Remarks.** The coarsely agglutinated wall and invariably crushed condition of the test obscures details necessary for confident assignment of this species to a genus. The proximal portion appears coiled, thereby favoring the genus *Flabellammina*. Chambers commonly appear chevron-shaped — likely a consequence of crushing. Originally, chambers were probably inflated with straight sutures. Whatever the genus to which this species belongs, it is distinct and readily identifiable.

**FAMILY TEXTULARIIDAE**

**SUBFAMILY PSEUDOBOLIVININAE**

*Pseudobolivina* Wiesner, 1931
Pseudobolivina variana Eicher

Plate 2, figures 2-5

1960. Bimonilina variana Eicher, p.67, pl.4, figs.15-19
1963. Bimonilina variana Eicher; Crespin, p.55, pl.14, fig.15-19
1981. Pseudobolivina variana Eicher; McNeil and Caldwell, p.166, pl.13, fig.3

Description. Test elongate, flattened, biserial throughout, tapering towards proximal end, particularly in microspheric forms; proloculus large and bulbous in megalospheric forms, small in microspheric forms; chambers strongly inflated in megalospheric forms, weakly inflated in microspheric forms, increasing in size as added in both; sutures distinct, depressed; wall finely agglutinated, without visible grains, smoothly finished; aperture a terminal slit with prominent lip.

Figured specimens. Figure 2; G.M.U.S. Pf 4536; length 1.22 mm; width 0.56 mm. Figure 3; G.M.U.S. Pf 4537; length 1.09 mm; width 0.50 mm. Figure 4; G.M.U.S. Pf 4538; length 0.87; width 0.53. Figure 5; G.M.U.S. Pf 4539; length 1.09 mm; width 0.50 mm.

FAMILY ATAXOPHRAGMIIDAE
SUBFAMILY VERNEUILININAE
Gaudryina d'Orbigny, 1839
**Gaudryina canadensis** Cushman

Plate 2, figures 11-16

1943. *Gaudryina canadensis* Cushman, p.27-28, pl.6, figs.7-8
1947. *Gaudryina hectori*, Nauss, p.335, pl.48, fig.6
1956. *Gaudryina hectori* Nauss; Stelck et al., p.32, pl.5, figs.14-15
1958. *Gaudryina hectori* Nauss; Stelck et al., p.26, pl.3, figs.23-24
1960. *Verneuilionoides hectori* Nauss; Eicher, p.68, pl.5, figs.3-4
1962. *Gaudryina canadensis* Cushman; Tappan, p.146, pl.35, figs.1-7
1967. *Gaudryina hectori* Nauss; Guliov, p.34, pl.7. fig.2
1975. *Gaudryina canadensis* Cushman; North and Caldwell, pl.3, figs.9-11
1981. *Gaudryina canadensis* Cushman; McNeil and Caldwell, p.176, pl.14, figs.10-11

**Description.** Test elongate, proximal one-third triserial, remainder biserial, biserial portion commonly twisted; chambers distinct, gradually increasing in size as added; sutures distinct, depressed; wall finely agglutinated, with visible quartz grains, smoothly finished; aperture a moderately high interiomarginal slit.

**Figured specimens.** Figure 11; G.M.U.S. Pf 4545; length 1.02 mm; width 0.39 mm. Figure 12; G.M.U.S. Pf 4546; length 0.91 mm; width 0.22 mm. Figure 13; G.M.U.S. Pf 4547; length 0.52 mm; width 0.20 mm. Figure 14; G.M.U.S. Pf 4548; length 0.46 mm; width 0.26 mm. Figure 15; G.M.U.S. Pf 4549; length 0.61 mm; width 0.22 mm. Figure 16; G.M.U.S. Pf 4550; length 0.80 mm; width
0.26 mm.

**Verneuilinoides** Loeblich and Tappan, 1949

**Verneuilinoides cummingensis** Nauss

Plate 2, figures 8-10

1947. *Verneuilina canadensis* Nauss, p.341, pl.49, fig.4
1975. *Verneuilinoides cummingensis* Nauss; North and Caldwell, pl.3, figs.4-5
1981. *Verneuilinoides cummingensis* Nauss; McLean and Wall, pl.7, figs.20-22

**Description.** Test elongate, cone-shaped, rounded in cross-section, triserial throughout; chambers inflated, increasing in size as added; sutures distinct, depressed; wall finely agglutinated, with visible quartz grains, smoothly finished; aperture a high, arched interiomarginal slit.

**Figured specimens.** Figure 8; G.M.U.S. Pf 4542; length 0.59 mm; width 0.33 mm. Figure 9; G.M.U.S. Pf 4543; length 0.67 mm; width 0.37 mm. Figure 10; G.M.U.S. Pf 4544; length 0.72 mm; width 0.33 mm.

**Verneuilina** d'Orbigny, 1839

**Verneuilina canadensis** Cushman

Plate 2, figures 6-7

1927. *Verneuilina canadensis* Cushman, p.131, pl.1, fig.10
1975. *Verneuilina canadensis* Cushman; North and Caldwell, pl.3, fig.6
1981. *Verneuilina canadensis* Cushman; McNeil and Caldwell, p.175, pl.14, fig.3

**Description.** Test small, pyramidal, triangular in cross-section, triserial throughout; chambers weakly inflated, increasing in size as added; wall finely agglutinated, with visible grains, smoothly finished; aperture an arched interiomarginal slit.

**Figured specimens.** Figure 6; G.M.U.S. Pf 4540; length 0.59 mm; width 0.28 mm. Figure 7; G.M.U.S. Pf 4541; length 0.56 mm; width 0.27 mm.

**SUBORDER ROTALIINA**

**SUPERFAMILY NODOSARIACEA**

**FAMILY NODOSARIIDAE**

**SUBFAMILY NODOSARIINAE**

*Marginulinopsis* d'Orbigny, 1826.

*Marginulinopsis collinsi* Mellon and Wall

**Not Figured**

1956. *Marginulinopsis collinsi* Mellon and Wall, p.20, pl.2, figs.1-4
1958. *Marginulinopsis collinsi* Mellon and Wall; Stelck et al., p.44, pl.3, figs.19-20
1962. *Marginulinopsis collinsi* Mellon and Wall; Tappan, p.167, pl.43, figs.1-4

**Description.** Test ovate in cross-section, proximal portion planispiral involute, distal portion uniserial; costae raised, running from last one or two chambers of coiled portion to about one-quarter way up the terminal
chamber, nine to twelve in number, uninterrupted by sutures; chambers distinct, five or six in ultimate whorl of coiled portion, three in uniserial portion, last three becoming weakly inflated; sutures distinct, depressed in uniserial portion; wall calcareous, perforate; aperture radiate, at outer angle.

SUBFAMILY LIGULININAE

_Lingulina_ d'Orbigny, 1826.

_Lingulina rediviva_ Berthelin

Not Figured

1880. **Lingulina rediviva** Berthelin, p.65, pl.4, fig.7
1962. **Lingulina rediviva** Berthelin; Tappan, p.172, pl.44, fig.22

Description. Test narrow, elongate, uniserial, gently tapering proximally; chambers increasing markedly in size as added in proximal portion, gradually increasing in size as added in distal portions, as many as five in number, all closely appressed with considerable overlap; sutures straight, horizontal, flush; wall calcareous, finely perforate, smoothly finished; aperture a terminal slit.

FAMILY POLYMORPHINIDAE

SUBFAMILY POLYMORPHININAE

_Globulina_ d'Orbigny, 1839.
Globulina lacrima canadensis Mellon and Wall

Not Figured

1956. Globulina lacrima canadensis Mellon and Wall, p.16, pl.2, fig.6
1958. Globulina lacrima canadensis Mellon and Wall; Stelck et al., p.32, pl.3, figs.13-14
1962. Globulina lacrima canadensis Mellon and Wall; Tappan, p.183, pl.47, figs.18-19

Description. Test small, ovate in outline, circular in cross-section, base broadly rounded, apertural end slightly produced; chambers few, increasing markedly in size as added, strongly overlapping; sutures oblique, flush, commonly obscure; wall calcareous, finely perforate, smoothly finished; aperture terminal, slit-like.

SUBPHYLUM CILIOPHORA

CLASS CILIATEA

SUBORDER TINTINNINA

FAMILY CODONELLIDAE Kent, 1882.

Dicloeopella Eicher, 1965

Dicloeopella borealis Eicher

Plate 1, figures 3-9

1965. Dicloeopella borealis Eicher, p.454, pl.1, figs.1-6

Description. Lorica cup-shaped, one to one and one-half oral diameters in length (crushed specimens),
constricted to form two closely spaced collars at top; wall very finely agglutinated with smooth finish; aperture formed by a minor constriction of the wall at end of lorica.

Figured specimens.
Figure 3; G.M.U.S. Pc 1; length 0.24 mm; width 0.15 mm.
Figure 4; G.M.U.S. Pc 2; length 0.22 mm; width 0.20 mm.
Figure 5; G.M.U.S. Pc 3; length 0.22 mm; width 0.18 mm.
Figure 6; G.M.U.S. Pc 4; length 0.18 mm; width 0.18 mm.
Figure 7; G.M.U.S. Pc 5; length 0.22 mm; width 0.18 mm.
Figure 8; G.M.U.S. Pc 6; length 0.20 mm; width 0.20 mm.
Figure 9; G.M.U.S. Pc 7; length 0.21 mm; width 0.17 mm.

III. INTERPRETATION

III.1 Biostratigraphy

Although the Mannville Group of Saskatchewan contains a sufficient number and variety of foraminifers for paleoenvironmental analyses, there is a limit to the extent to which they may be used for biostratigraphic analyses. The Lloydminster shale contains an assemblage of foraminifers that may be identified in terms of the zonal scheme of Caldwell et al. (1978). The foraminifers Marginulinopsis collinsi Mellon and Wall, Globulina lacrima Ruess, Ammobaculites fragmentarius Cushman (≡A. humei Nauss...
and *A. petilus* Eicher), *Gaudryina canadensis* Cushman, *Haplophragmoides linki* Nauss (=*H. linki minor* Nauss), *Miliammina manitobensis* Wickenden, *M. sproulei* Nauss, *Verneuilinoides cummingensis* Nauss, and *Saccammina alexanderi* Loeblich and Tappan indicate that the Lloydminster shale falls within the *Marginulinopsis collinsi*-*Verneuilinoides cummingensis* Subzone of the *Gaudryina nanushukensis* Zone. This subzone is present also in the Clearwater Formation of the Fort McMurray area, the upper Wilrich, Falher, and Notikewin Members of the Spirit River Formation in the Peace River district, and the Moosebar Formation of the Rocky Mountain foothills (Caldwell et al., 1978, p. 507). The subzone contains a *Marginulinopsis collinsi* and a *Verneuilinoides cummingensis* biocacies; the former, dominated by calcareous foraminifers, represents a more off-shore, open-sea environment, whereas the latter, dominated by agglutinated foraminifers, denotes a more restricted, nearshore environment (ibid., p. 507). The assemblage of the Lloydminster shale clearly is dominated by agglutinated species (Figures 3 and 4).

Faunal elements now regarded as characteristic of the *Marginulinopsis collinsi*-*Verneuilinoides cummingensis* Subzone have been described from the Vermilion area by Nauss (1945, 1947) in what he defined as the Cummings member. The similarities between the fauna found by Nauss
and that now recovered from the Lloydminster shale (figs. 3 and 4) suggests that these units are one and the same. It follows, therefore, that what is now accepted to be the Cummings formation is not the same as the Cummings member defined by Nauss.

The *Haplophragmoides gigas* Zone (Caldwell et al., 1978, p. 511) is clearly recognizable in the Joli Fou Formation, above the Mannville Group, by the presence of *Haplophragmoides gigas* Cushman, *H. linki* Nauss, *Ammomarginulina asperata* Guliov, *Ammodiscus anthosatus* Guliov, *Ammobaculites fragmentarius* Cushman, *Ammobaculoides whitneyi* Cushman and Alexander, *Gaudryina canadensis* Cushman, and *Miliammina manitobensis* Wickenden. Divisions of the Mannville Group lying above the Lloydminster shale and below the Joli Fou Formation also contain foraminifers, but neither the assemblage as a whole nor any individual species allow them to be related unequivocally to the zonal elements of Caldwell et al (1978). That the Joli Fou Formation rests unconformably on the Mannville Group and that those subzones above the *Marginulinopsis collinsi-Verneuilinoides cummingensis* Subzone and below the *Haplophragmoides gigas* Zone are unknown south of northwestern Alberta suggests that the entire Mannville Group above the Lloydminster shale also falls within the *Marginulinopsis collinsi-Verneuilinoides cummingensis* Subzone. Below the Lloydminster shale, the Cummings
formation in the Lloydminster area is marine, and therefore sediments of this formation must have been deposited in the Clearwater sea. Hence this formation too must correlate with the Clearwater Formation and be part of the Marginulinopsis collinsi-VerneuIinoides cummingsensis Subzone. The Dina formation is non-marine and has not been dated reliably.

Similarities in faunal distribution between the Paradise Hill and Dee Valley sections suggest that, although depauperate, some foraminiferal suites of the Mannville Group may be sufficiently distinct to permit biostratigraphic correlation at least locally. The Lloydminster shale is noted for the relative diversity of its foraminifers and for the relative abundance of Flabellammina? sp. McLean and Wall and Pseudobolivina variana Eicher. The G.P. shale is characterized by a less diverse suite with relatively abundant Ammobaculoides sp. and Ammomarginulina sp. A diversity of foraminifers similar to that of the G.P. shale is present in the Cummings shale of the Dee Valley section but is absent from the Paradise Hill section where much of the core through the Cummings formation was not recovered. In the Dee Valley section, the Cummings suite is rendered distinct by a comparative abundance of Ammobaculites janus Stelck and Wall.

The Marginulinopsis collinsi-VerneuIinoides
cummingensis Zone is late Early Albian in age (Caldwell and North, 1984, p. 62). Thus if the entire Mannville Group in the Lloydminster area and adjacent parts of Alberta and Saskatchewan falls within this zone, the group will be of late Early Albian age. The Haplophragmoides gigas Zone is of early Late Albian age (ibid.), which is then the age of the Joli Fou Formation above the Mannville Group. The unconformity on top of the Mannville Group then may mark a hiatus corresponding at minimum to all of Middle Albian time.

III.2 Transgressive–Regressive Sequences

Inundation by the Clearwater Sea in the Early Albian Epoch resulted in a transgressive-regressive sequence of notable paleogeographic importance in the northern half of the Western Interior Basin. Detailed examination of that sequence reveals evidence of numerous, smaller, transgressive-regressive sequences within this larger sequence. Cant (1984) recognized eight transgressive-regressive sequences in the Spirit River Formation of west-central Alberta, and numerous transgressive-regressive sequences also have been recognized in the Mannville Group of the Lloydminster area (e.g. Vigrass, 1977; MacCallum, 1979; Wilson, 1984). Although there is general agreement that smaller-scale transgressive-regressive sequences are present in the Mannville Group and that they correspond approximately to the stratigraphic divisions, there is
dispute as to the number of smaller-scale transgressive-regressive sequences present. Paleontology provides good evidence of the more major of these sequences but rather controversial evidence of the more minor. The more minor sequences should be better developed to the northwest, the direction from which the sea entered the Lloydminster area, and paleontological studies of the Mannville Group to the northwest well could resolve without ambiguity the number of transgressive-regressive sequences in the Lloydminster area.

The Dina formation is of fluvial origin and fills irregularities in the pre-Cretaceous eroded surface (Dunning et al., 1980, p. 137; Christopher, 1980, p. 17-19). This formation, therefore, does not record a transgressive-regressive sequence.

III.2.1 The Cummings Formation

In the studied sections, the lowest occurrence of foraminifers is near the base of the Cummings formation (622.25-624.25 m depth in the Paradise Hill section; 572-573 m depth in the Dee Valley section). Few foraminifers are found between this level and that of the Cummings coal, which is near the top of the formation. Between these levels, however, the abundance of megaspores increases, which suggests increasingly marginal-marine to non-marine environments of deposition. Hence, these deposits, ranging
Figure 3. Distribution chart of the foraminifera and other microfossils in the Paradise Hill cored section.
Figure 4. Distribution chart of the foraminifers and other microfossils in the Dee Valley cored section.
from at least the base of the Cummings shale to the base of the Cummings coal, probably record a transgression and regression.

III.2.2 The Lloydminster Formation

A low-diversity fauna of unilocular foraminifers was recovered from the Cummings coal and associated sediments in the Paradise Hill and Dee Valley sections, in which the coal is closer to being a carbonaceous shale. Number of specimens, complexity of test, and diversity of species increase up-section into the Lloydminster shale, thereby suggesting a transgressive sequence. Number of specimens, complexity of test, and diversity of species decrease, and the fossil assemblage becomes dominated by megaspores between the top of the Lloydminster shale and the base of the Rex formation (figs. 3 and 4), suggesting a regressive sequence. Paleontological data support the interpretation of the Lloydminster formation as a transgressive-regressive sequence by Viggrass (1977, p. 1012), Orr et al. (1977, p. 1195), and Wilson (1984, p. 126), who based their conclusions largely on sedimentological studies of core and on geophysical-log characteristics.

III.2.3 The Rex Formation

Sedimentological studies of core and studies of geophysical logs have resulted in the Rex formation being interpreted as a transgressive-regressive sequence (Orr et
al., 1977, p. 1195; Vigrass, 1977, p. 1012; Wilson, 1984, p. 126). Paleontological evidence is consistent with such an interpretation. A moderately diverse assemblage of multilocular foraminifers was recovered from the shales near the base of the formation. Upper beds of the formation were found to be barren of fossils in the sections studied (figs. 3 and 4), but a discontinuously distributed coal seam at the top of the Rex formation provides evidence of subaerial exposure (Vigrass, 1977, p. 1014; Wilson, 1984, p. 126).

III.2.4 The General Petroleums (G.P.) and Sparky Formations

Studies of cores and geophysical logs have resulted in numerous interpretations of environments of deposition and geological history of the G.P. and Sparky formations. The latter, in particular, has been a subject of dispute. Sandstone bodies within the Sparky have been interpreted as off-shore bars (Robson, 1980, p. 185-186), near-shore tidal deposits (Fuglem, 1970, p. 8-10), and wave-generated structures (Haidl, 1984, p. 185; Hulten and Smith, 1984, p. 439). The numbers of megaspores and the numbers and low diversity of foraminifers in mudstones and shales adjacent to these sandstones support a nearshore environment of deposition.

The G.P. and the Sparky formation have been interpreted as representing one, two, or six identifiable, transgressive-regressive sequences on the basis of core and
log studies (Vigrass, 1977, p. 1012-1013; MacCallum, 1979, p. 228; Smith, 1984, p. 423; and Wilson, 1984, p. 126). Paleontological data do little to resolve the problem. The high number and relative diversity of foraminifers in the G.P. shale point to a significant marine transgression and the lower number and reduced diversity in the overlying section to the top of the Sparky formation point to overall marine regression. Sporadic distribution of foraminifers and megaspores in the overlying section suggests that the overall regression may not have been continuous and regular but rather pulsatory. The irregular distribution of a coal seam at the top of the G.P. formation (Wilson, 1984) provides evidence of subaerial exposure at this time and, hence, the occurrence of foraminifers in the Sparky formation likely resulted from a second marine transgression.

III.2.5 The Waseca, McLaren, and Colony Formations

The Waseca, McLaren, and Colony formations contain the most difficult rocks to interpret in the entire Mannville Group. Their origin has been interpreted as fluvial (Putnam, 1980, p. 213), mixed marine and non-marine (Orr et al., 1977, p. 1195), and nearshore (Lorsong, 1980b, p. 261). Paleogeographic events in the history of late Mannville deposition are, therefore, poorly understood. In the Paradise Hill and Dee Valley sections, foraminifers
have been found at three stratigraphic levels in the upper Mannville -- approximately at the base of the Waseca, the base of the McLaren, and the top of the McLaren. This implies that three separate transgressive-regressive sequences are present within the upper Mannville Group.

III.3 Paleoenvironments

III.3.1 Fossils of the Mannville Group

Fossils found in the Mannville Group of the Lloydminster area include the entire or fragmentary remains of foraminifers, ostracods, radiolarians, molluscs, echinoderms, diatoms, megaspores, and fishes. Of these, the foraminifers and megaspores are the most common and most useful in paleoenvironmental reconstruction. Brief remarks on the other groups are, nonetheless, warranted. Calcareous fossils are rare and when found are commonly replaced by pyrite or other iron-rich minerals.

Unidentified ostracod carapaces were recovered mainly from the Paradise Hill core (fig. 3), where they are most common in the upper Lloydminster formation and rare about the middle of the Rex formation and in the lower Joli Fou Formation. All of these ostracods occur in association with foraminifers and were probably themselves marine dwellers.

Species of four distinct types of radiolarians were recovered from the Paradise Hill core (fig. 3) where they are restricted to the upper-middle and upper Mannville
Group (base of the Sparky formation, base of the Waseca formation, top of the McLaren formation, and upper Colony formation). Although radiolarians are never common, their occurrences are extremely important because generally these organisms are reliable indicators of open-marine conditions and they are present in that part of the Mannville succession in which the presence of foraminifers is diminished. The association of radiolarians with sparse assemblages of unilocular and simple multilocular agglutinated foraminifers and with the tintinnid *Dicloeoella borealis* is both reassuring and surprising — reassuring in that pronounced marine influence at the levels of the radiolarian occurrences is confirmed and there is no need to suspect that the radiolarians may have been derived; surprising in that the foraminifer-tintinnid associations would suggest marginal-marine conditions, quite possibly with waters of reduced salinity. The possibility exists that the limited number of radiolarian tests may have been transported for short distances and washed into the marginal-marine zone.

Among invertebrate megafossils, molluscs are most common in the Mannville Group, although their presence is revealed mainly by shell fragments, including the calcite prisms of bivalve (inoceramid) shells. Fragmentary molluscan remains were recovered from every formation of the Mannville Group, except the Dina formation, and from
the overlying Joli Fou Formation in the combined cores of the Dee Valley, Paradise Hill, and Choiceland sections (figs. 3, 4, and 5). The great majority of the fragmentary molluscan remains occur in association with marine foraminifers; hence most of the molluscs were probably marine species. A few occurrences in association with megaspores but without the association of other marine organisms leaves open the possibility that some of the molluscan fragments may have been derived from terrestrial forms. A 10 cm-thick bed of calcite-cemented mudstone beneath the G.P. shale in the Dee Valley section contains the best-preserved bivalves. Distinctive organic fragments recovered from the Lloydminster shale of the Paradise Hill section in association with a diverse foraminiferal assemblage betray the presence of the odd echinoderm in the Clearwater Sea at Lloydminster.

A few diatom tests also were recovered from the Lloydminster shale of the Paradise Hill section (fig. 3), which is of interest in that siliceous tests of marine diatoms are present mainly in Upper Cretaceous and post-Cretaceous rocks. These marine plants have a large surface area per unit weight and, as a result, they can be carried great distances by ocean currents, winds, birds, and fish (Lohman, 1957, p. 1059), and thus should only be used for paleoenvironmental reconstruction when their numbers are high.
Among the vertebrates, the teeth and scales and other fragmentary remains of fishes are present in every formation of the Mannville Group, except the Dina formation, and they are also present in the Joli Fou Formation above the Mannville Group (figs. 3, 4, and 5). Tiny fish fragments are recurrent microfossils throughout the Mannville section of the combined Dee Valley and Paradise Hill sections. With only a few exceptions, the fish remains occur in association with marine foraminifers; hence the fish fauna represented almost certainly is largely or wholly marine.

High concentrations of megaspores are most likely to occur in marginal-marine to non-marine environments, and previous studies of marine to non-marine transitional sections, with alternating marine and non-marine deposits, in the Cretaceous rocks of western Canada have exposed a prevailing inverse relationship between concentrations of foraminifers and ostracods on the one hand and of megaspores and other palynomorphs on the other (see, for example, Hills and Levinson, 1975). Several different groups of plants which lived in marginal-marine to non-marine environments along the edge of the Clearwater Sea are represented by their megaspores in rocks of the Mannville Group. The Marsileales and Salviniales are, respectively, rooted and free-floating heterosporous ferns, restricted to low-energy environments such as lakes and
ponds (Taylor, 1981, p. 273-274). They are represented in the Mannville flora by their megaspores, *Ricinospora* and *Arcellites*, respectively. Heterosporous lycopsids are represented in the same flora by *Erlansonisporites*, *Horstisporites*, *Minerisporites*, *Paxillitriletes*, and *Verrutriletes* of the selaginellacean and isotacean orders. Extant lycopsids are found in a wide variety of environments, including deserts, but are most common in moist environments, such as coastal swamps (Tyron and Tyron, 1982, p. 818, 829; Raven et al., 1981, p. 323).

The common foraminifers of the Mannville Group are among the best indicators of paleoenvironments. With the exception of the allogromiids, which have chitinous tests and a low potential for preservation, foraminifers are exclusively marine. Some of them, however, can tolerate low salinities, and many of the species recovered from the Mannville Group are believed to have lived in brackish-water environments.

The general relationship that prevails between species diversity and environmental stability is useful in interpreting the Mannville foraminifers. As among most benthic marine invertebrates, diversity tends to increase from marginal-marine to off-shore environments (Emery and Stevenson, 1957, p. 693; Bandy and Arnal, 1960, p. 1922; Hazel, 1975, p. 740-743), and this trend may continue even to the abyssal depths (Hessler and Sanders, 1967; Buzas...
and Gibson, 1969). The principal causes of low-diversity faunas seem to be: 1) 'new' environments, in which the number of species is increasing, 2) 'severe' environments, which are nearly abiotic and may become completely abiotic with a small change in the environment, and 3) 'unpredictable' environments, in which environmental conditions (e.g. energy levels, food supply, and salinity) are not readily predictable from day to day or year to year (Slobodkin and Sanders, 1969, p. 83). Preservation, a fourth factor, also must be considered when dealing with fossil assemblages. The predictability of a marine environment is largely dependant on proximity to shore, water depth, and efficiency of circulation. Atmospheric perturbations, such as storms, daily and seasonal variations in moisture balance (evaporation vs. precipitation), and changes of sea-level, will affect the energy regime, temperature, turbidity, and salinity. Atmospheric perturbations will have their greatest effect in shallow-water, near-shore environments, whereas deep-water, off-shore environments will be buffered from such effects by the greater mass of water and better circulation. The relationship between diversity and environment can be useful in interpreting ancient environments from fossil assemblages. The more normal the marine environment, the greater the diversity of foraminifers (Murray, 1973, p. 239).
A second general ecological relationship useful in interpreting the Mannville foraminiferal assemblages is that, as waters become increasingly brackish, there is greater reduction of species in groups which have a calcareous skeleton than in groups which lack a calcareous skeleton (Remane and Schlieper, 1971, p. 18). Hence, it is not surprising that the Textulariina-Rotaliina-Miliolina ratio of a foraminiferal assemblage is sensitive to salinity. Textulariinids have agglutinated tests; rotaliinids have hyaline-calcareous tests; miliolinids have porcellaneous-calcareous tests. The miliolinids are extremely sensitive to salinity; they cannot maintain their pseudopodial reticulum at salinities less than 32 per mille (Murray, 1973, p. 229). The availability of calcium carbonate is closely related to carbon dioxide content, salinity, and temperature of the waters. Warm, hypersaline waters have a ready source of calcium carbonate and favour foraminiferal faunas dominated by miliolinids; cool, hyposaline waters favour populations dominated by textulariinids; and normal marine waters are most commonly dominated by rotaliinids (Greiner, 1974). Although temperature and salinity are the most common causes of differing concentrations and solubilities of calcium carbonate, they are not the only ones — availability of calcium ions, pH, availability of oxygen, hydrostatic pressure, and depth of the photic zone (for
foraminifers with symbiotic algae) also may be important in determining the availability of calcium carbonate. The lack of miliolinids, the paucity of rotaliinids, and the relatively common presence of textulariinids in the Mannville Group of the Lloydminster area suggests that the Clearwater sea was brackish. Restriction of rotaliinids to the Lloydminster shale points to this unit representing the closest approximation to open-marine conditions in the history of deposition of the Mannville sediments in the area -- an interpretation that is strengthened by echinoderm fragments having been recovered only from the same unit.

A third ecological relationship observed among modern foraminifers that may be used in paleoenvironmental interpretations of the Mannville foraminiferal faunas is restricted to the textulariinids. In modern environments, textulariinids of simple form generally are found in nearshore waters and those of more complex form in off-shore waters (Bandy, 1960, p. 8; Haynes, 1982, p. 93). Both of these workers regarded taxa such as Saccammina, Reophax, Ammobaculites, Haplophragmoides, Milimmina, and Trochammina as simple forms. With the exception of Saccammina, however, these multilocular textulariinids count among the more complex forms found in the Mannville Group. Truly complex forms, in the sense of Bandy or Haynes, are absent from the Mannville Group. Be that as it
may, within certain units of the Mannville Group it is possible to recognize gradations or shifts of the textulariinid assemblages from simple unilocular types to more complex multilocular types. The former are interpreted to denote marginal-marine environments, the latter more off-shore environments — an interpretation that is supported by the tendency for the unilocular foraminifers to occur in close association with megaspores in the studied sections (figs. 3 and 4).

The tintinnid *Dicloeopella borealis* Elcher also occurs in close association with a unilocular textulariinid assemblage and with megaspores. This tintinnid was first described from the Late Albian Thermopolis Shale of Wyoming, where it was interpreted to have lived in a marginal-marine environment (Eicher, 1965, p. 452).

Keeping these major ecological relationships in mind, the paleoenvironments that prevailed during deposition of Mannville sediments in the Lloydminster and adjacent areas may be readily assessed from the distribution charts of the principal sections studied (figs. 3, 4, and 5). The complementary proportionality of foraminifers and megaspores is readily apparent in general from the opposing histograms. A diverse assemblage of foraminifers, including calcareous walled and multilocular agglutinated-walled species, with relatively high numbers of specimens and with megaspores absent or in relatively low numbers, is
Figure 5. Distribution chart of the foraminifers and other microfossils in the Choiceland cored section.
LEGEND refer to Dee Valley section
taken as evidence of strong marine influence, as for example in the uppermost Cummings and Lloydminster formations of the Dee Valley section or the Lloydminster formation of the Paradise Hill section. The common occurrence of several different kinds of megaspores, with an absence of foraminifers, is taken as evidence of prevailing terrestrial conditions, as for example in parts of the middle Mannville Group (undifferentiated as to formations) in the Choiceland section or through most of the middle to upper Cummings formation in the Paradise Hill section. When a fairly diverse assemblage of foraminifers, including multilocular agglutinated species, is present in reasonable numbers of specimens and is complemented by a relatively low number of different kinds of megaspores, the environment is taken as having been off-shore marginal-marine, as for example in the lower part of the G.P. formation in the Dee Valley section. And finally, when different kinds of megaspores are strongly represented numerically and complemented by a sparse foraminiferal assemblage composed wholly of, or dominated by, unilocular agglutinated forms, the prevailing environment is interpreted as having been near-shore marginal-marine, as for example the undifferentiated Mannville Group of the Choiceland section between 170 and 190 m depth. These interpretations are recognized to be generalizations, but they are supported by the kinds of sediments, sedimentary
structures, and other fossils found in the rocks occupying the various intervals sampled.

III.3.2 Geographic Variations in the Fauna and Character of the Mannville Group

Two main trends are evident in the foraminiferal fauna of the Clearwater Sea that occupied the southern Interior Plains region in the Early Albian: 1) the diversity of foraminifers decreases to the south-southeast, and 2) calcareous foraminifers are an important and sizable constituent of northern and western faunas but a trivial component of eastern and southeastern faunas (figures 7 and 8). The former trend is better developed and there is less departure from it along the line from the Athabasca River valley to Duval sections than from the Beaverdam to Fall Creek sections in the Rocky Mountain Foothills. This probably results from conflicting influences stemming from proximity of the western line of sections to the western shoreline. In general, the reduced diversity of foraminifers to the south and southeast suggests increasingly unpredictable environments (sensu Slobodkin and Sanders, 1969) in these directions, probably arising from shallower water depths, reduced circulation with the open ocean, and the kinds of sediments being deposited.

The reduction in the number of calcareous foraminiferal elements from the Athabasca River section southeast to the Duval section points to reduced
Figure 6. Map showing the distribution of sections through the Mannville Group and equivalents in Alberta and Saskatchewan from which foraminifers and other microfossils have been recovered. Alberta sections are mostly those studied by McLean and Wall (1981), but also includes the Athabasca River valley section studied by North and Caldwell (unpublished). Saskatchewan sections are those studied for this thesis. Combination of all sections provides the data base for the generalized paleoenvironmental reconstructions.
Figure 7. Graphical representation of the different kinds of foraminifers and ostracods (to generic level) present in the Mannville and equivalent rocks of Alberta and Saskatchewan.
<table>
<thead>
<tr>
<th>Section</th>
<th>Faunal Elements</th>
<th>Foraminifers</th>
<th>Ostracods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall Creek</td>
<td>Gap Lake</td>
<td>Wapiabi Creek</td>
<td>Chungo Creek</td>
</tr>
<tr>
<td>Foothills</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sask.</td>
<td>Athabasca River</td>
<td>Paradise Hill</td>
<td>Dee Valley</td>
</tr>
</tbody>
</table>

- **MAXIMUM ABUNDANCE GREATER THAN THREE SPECIMENS IN A SINGLE SAMPLE**
- **MAXIMUM ABUNDANCE OF ONE TO THREE SPECIMENS IN A SINGLE SAMPLE**
Figure 8. Graphical representation of the different kinds of foraminifers and ostracods (to specific level) present in the Mannville and equivalent rocks of Alberta and Saskatchewan.
<table>
<thead>
<tr>
<th>SECTION</th>
<th>FORAMINIFERS</th>
<th>OSTRACODS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CALCAREOUS</td>
<td>MULTICULAR AGGLUTINATED</td>
</tr>
<tr>
<td>FOOTHILLS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FALL CREEK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GAP LAKE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WAPIABI CREEK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHUNGO CREEK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RUBY CREEK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MACKENZIE CREEK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CADOMIN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LITTLE BERLAND RIVER 70-02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LITTLE BERLAND 70-07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOUTH BERLAND RIVER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VICTOR LAKE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MALCOLM CREEK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GUSTAVS FLATS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEAVERDAM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SASK.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATHABASCA RIVER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PARADISE HILL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEE VALLEY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHOICELAND</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DUVAL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- ☐ MAXIMUM ABUNDANCE GREATER THAN THREE SPECIMENS IN A SINGLE SAMPLE
- ☐ MAXIMUM ABUNDANCE OF ONE TO THREE SPECIMENS IN A SINGLE SAMPLE
concentrations of calcium carbonate in the seawater, likely resulting from the sea becoming increasingly brackish. The comparatively high proportion of calcareous taxa (all rotaliinids) in the foothills also points to higher concentrations of calcium carbonate, perhaps resulting from the western part of the sea being of more normal marine salinity due to better circulation with the ocean.

More enigmatic differences between east and west include the common occurrence of calcareous skeletons of megafossils and Chara-like fossils in Mannville-equivalent rocks of the Rocky Mountain foothills and the paucity of these fossils in Saskatchewan. Chara, a freshwater algae, favors hard, calcium-rich waters (Prescott, 1970, p. 18). Genera related to this algae are found in the non-marine Gladstone Formation (McLean and Wall, 1981, their table 2). Calcareous skeletons of megafossils are common in the Gladstone and Moosebar formations of the foothills (McLean and Wall, 1981, p. 347, 354; Taylor and Walker, 1984, p. 702-704). Whole skeletons of megafossils are rare in Saskatchewan but microscopic fragments of these skeletons have been found, including the needle-like prisms of the outer layer of bivalve shells, and indicate that molluscs were more common in the Clearwater Sea than the distribution of megafossils themselves would suggest. Moreover, these shell fragments together with the preservation of pyritized tests of calcareous foraminifers.
and ostracod carapaces replaced by iron oxides indicate that dissolution of calcareous shell material must have occurred, likely at or near the sediment-water interface.

Sandstones of Mannville-equivalent rocks in the foothills have a small but notable proportion of limestone and dolomite grains, attesting to erosion of Paleozoic carbonates in the nearby Cordillera (Mellon, 1967, p. 162-164). Grains of carbonate have not been recorded in significant quantities from the Mannville Group of Saskatchewan (Smith et al., 1984, p. 153). Thus paleotopographic highs, consisting of Paleozoic carbonates and protruding through parts of the Mannville Group, were not being actively eroded and any sands derived from the rising Cordillera were barren of carbonate grains possibly due to these grains having been dissolved or otherwise destroyed.

III.4 Paleogeography

Within the southern part of the Western Interior basin of Canada, the gradual reduction and eventual loss of marine fossils in the Clearwater and equivalent formations to the south-southeast points to the Clearwater sea having invaded the region from the north-northwest. There is no evidence of a southern sea entering what is now the Prairie Provinces until later in Cretaceous time, certainly not before the time of deposition of the Joli Fou sediments when seas transgressing into the Western Interior basin
from north and south eventually coalesced to form a continuous strait between what is now the Beaufort sea and the Gulf of Mexico (Caldwell, 1984, p. 191-192). Mapping the maximum geographic extent of the Clearwater sea is hampered by the decreasing occurrences of foraminifers to the south-southeast (figs. 7 and 8). This trend is due to the attenuation of marine deposits to the south-southeast and probably also to increasingly restricted marine, or progressively more brackish close to the southeastern shores. Extrapolation of this trend in species diversity indicates the possibility of the Clearwater sea having become too restricted (brackish) to support a marine fauna in its most landward extensions to the southeast.

III.4.1 The Western Margin

Unequivocally marine faunas in the Moosebar Formation (essentially equivalent to the Clearwater Formation) have been described from the Beaverdam to Fall Creek sections in the foothills (McLean and Wall, 1981, fig. 1, table 2). The most southerly certain occurrence of a marine fauna is in the Fall Creek section (ibid., p. 367). A more enigmatic fossil assemblage has been reported farther south in the Elbow River section, near Calgary. The fauna consists of a poorly preserved specimen of the brackish-water ostracod Cytherida bonaccordensis Loranger(?), two specimens of the brackish-water ostracod
Orthonotacythere(?) sp., eight specimens of fresh-water ostracods, and "three arenaceous entities bearing superficial resemblance to some foraminifera, but lacking definite features for assignment to this order" (Taylor and Walker, 1984, p. 707-708). The Moosebar Formation of the Elbow River section has been interpreted as having been deposited in a large brackish-to fresh-water coastal lake (Taylor and Walker, 1984, p. 708-709).

III.4.2 The Southern Margin

Paleontologic and sedimentologic evidence suggested a restricted marine, high energy, wave-dominated environment of deposition for the Glaucocitic Sandstone of the Mannville Group in the Suffield Heavy Oil Pilot Project (Tilley and Longstaffe, 1984, p. 1005, 1009). Hence, it is probable that the sea extended this far south (fig. 9).

In southwestern Saskatchewan, throughout the region north and northeast of the city of Swift Current, parts of the Cantuar Formation have been interpreted as being marine in origin on the basis of sedimentary structures, the presence of glauconite, and rare fossils (Christopher, 1975, p. 544).

Evidence has not been found of a marine influence in southeastern Saskatchewan. A few highly enigmatic structures that possibly could be simple, unilocular, agglutinated foraminifers were recovered from the Steelman section (fig. 9). These tubular agglutinated structures do
Figure 9. Map of the inferred limits of the Clearwater sea in Alberta and Saskatchewan.
not resemble any foraminifers found in other studied sections; they could also be thecamoebians or burrows.

A single pulse of the Clearwater sea is recognized in Cantuar Formation of south-central Saskatchewan, near Saskatoon. The foraminifers Hippocrepina barksdalei Tappan, Saccammina lathrami Tappan, and Bathysiphon cf. B. brosgei Tappan, and the tintinnid Dicloeopella borealis Eicher were recovered between 538.6 and 541.7 m depth in the Duval section. Foraminifers also were recovered from the Pense Formation in the Duval section and these occurrences are discussed more fully in the following section.

III.4.3 The Eastern Margin of the Clearwater Sea

The distribution of foraminifers and megafossils indicates that the Clearwater sea repeatedly encroached as far east as Choiceland in east-central Saskatchewan (figs. 5 and 9). The species present are insufficient for detailed correlation to the Lloydminster area. The maximum eastward extent of the Clearwater sea remains unknown in detail, but the possible limits, based on known occurrences of marine microfossils, have been reconstructed in figure 9.

IV. A NOTE ON THE PENSE FORMATION

The Pense Formation of southern Saskatchewan lies above the Cantuar Formation and below the Joli Fou
Formation. The Joli Fou was deposited as an offshore mud whereas the Cantuar consists of mixed sandstones, mudstones, and shales deposited largely in a non-marine setting. The Pense Formation has been interpreted as a transgressive marine deposit by Maycock (1967, p. 46) and Price and Ball (1973, p. 22) and as four progradational marine sequences by Christopher (1974, p. 98). As proposed by Christopher, the Pense sea was an early pulse of the Kiowa-Skull Creek sea -- the Gulf coastal counterpart of the Boreal Joli Fou sea. Regardless of whether the Pense sediments are transgressive or regressive (progradational) in origin, they are the products of deposition in an early phase of the Joli Fou sea. It may be claimed, therefore, that the Pense Formation belongs with the Joli Fou Formation in the Colorado Group and should be excluded from the Mannville Group.

The contact between the Cantuar and Pense formations may be either sharp or disturbed and gradational (Maycock, 1967, p. 47-48). The presence of a gradational contact may indicate that the Mannville-Colorado contact lies within the uppermost Cantuar Formation in places, but on a regional basis, Christopher (1980, p. 20) described the pre-Pense unconformity as planing the Cantuar Formation to its base over the Punnichy Arch of southern Saskatchewan, thus emphasizing the magnitude of this
unconformity.

The Pense–Joli Fou contact varies from sharp and erosional to transitional (Maycock, 1967, p. 31, 32, 34, 48; Price and Ball, 1971, p. 20). Coarse-grained quartz sands, with the grains commonly reaching granule size, and phosphatic sands or phosphate-enriched sand lenticles may occur near the contact (Maycock, 1967, p. 34), perhaps resulting from submarine erosion as the earliest Joli Fou sea advanced. Oddly enough, although both coarse- and fine-grained sands may be present, no medium-grained sands are to be found in the contact zone (Maycock, 1967, p. 34). This upper contact of the Pense Formation is expressed inconsistently, but is probably disconformable regionally.

Plant fragments have been described from the Cantuar Marker Bed of southwestern Saskatchewan, which consists of a heterogeneous mixture of grey sand and shale and marks the boundary between the Cantuar and Pense formations (Cummings and Francis, 1957, p. 68 and 72). Fish teeth and vertebrae and rare plant remains were reported from the Pense Formation by Maycock (1967, p. 31). In the present study, fragments of the waxy layers of plants, fish remains, foraminifers, and tintinnids have been recovered from the Pense Formation in the Calderbank and Duval sections (figs. 10 and 11).

The basal portion of the Pense Formation in both the
Calderbank and Duval sections consists of black carbonaceous shale which yielded moderate numbers of the tintinnid *Dicloeopella borealis* Eicher, a few simple tubular agglutinated structures which may be foraminifers or burrows, and fragments of the waxy layers of plants (1015.5 to 1021.5 m depth in the Calderbank section; 484.0 to 485.7 m depth in the Duval section). These waxy layers are probably from the cuticle and would be expected only from terrestrial plants. The tintinnids provide evidence of a marine setting. Hence, the carbonaceous sediments probably were deposited in a marginal-marine environment, possibly a lagoon or coastal swamp.

In the studied sections, beds above the basal carbonaceous shale consist largely of bioturbated, flaser- and lenticular-bedded mudstones and sandstones interbedded with thick beds of fine-grained sandstone (998.2 to 1015.5 m depth in the Calderbank section; 478.2 to 484 m depth in the Duval section). The flaser- and lenticular-bedded sediments are poorly fossiliferous but yield a few unilocular foraminifers, fish teeth, and small tubular burrows. Flaser- and lenticular-bedding are produced in environments in which there is alternation between high- and low-energy conditions and in which both sand and mud are available for deposition. These criteria are met in many different environments, but the preferred environments are subtidal and intertidal (Reineck and Singh, 1973, p.
Figure 10. Distribution chart of the microfossils recovered from the Pense Formation in the Calderbank cored section.
C.D.R. CALDERBANK
(13-28-19-7W3M)

JOLI FOU Fm.

PENSE Fm.

CANTUAR Fm.

LEGEND: Refer to Dee Valley section.
Figure 11. Distribution chart of the microfossils recovered from the Pense Formation in the Duval cored section.
DUVAL CORPORATION PILOTHOLE
(6-18-36-6W3M)

LEGEND: Refer to Dee Valley section.
101). Given that the flaser- and lenticular-bedded sediments of the Pense Formation were deposited in an intertidal to shoreface environment, it is likely that major sandstones within this facies accumulated as nearshore bars (barrier or shoreface), tidal channel fills, and beaches.

The upwards transition from coastal swamp or lagoonal deposits of the basal shale into intertidal or shoreface deposits points to the Pense Formation being a transgressive marine sequence. As such, it must have been deposited in the early Joli Fou sea and mark the initiation of deposition of the Colorado Group.

V. PRINCIPAL CONCLUSIONS

(a) The basal Cretaceous Mannville Group in the Lloydminster area of the Alberta-Saskatchewan borderland and in adjoining areas of Saskatchewan contains, as microfossils, between twenty-five and thirty species of foraminifers, many fewer species of radiolarians, ostracods, diatoms, and megaspores, and the fragmentary remains of molluscs, echinoderms, and fishes.

(b) The foraminifers, dominantly agglutinated but some calcareous, are most common in the lower middle part of the Mannville Group (above the Dina formation) and diminish in number and variety in the upper part of the group. The foraminifers suggest that the entire
Mannville Group (above the Dina formation) lies within the Marginulinopsis collinsi-Verneuilinoides cummingensis Assemblage Zone and is, therefore, of Early Albian age.

(c) The foraminifers provide indisputable evidence of the recurrence of marine beds essentially throughout the Mannville Group and of a much higher proportion of the Mannville sediments having been deposited in marine and marginal-marine environments than hitherto believed.

(d) Alternation of beds containing foraminifers and lacking, or containing relatively few, megaspores with beds containing relatively high numbers of different kinds of megaspores and lacking foraminifers suggests alternation of marine and non-marine conditions of deposition during accumulation of Mannville sediments. This alternation is interpreted to have resulted from transgressive-regressive cycles of sedimentation in the Clearwater sea. The most open-marine conditions were established fairly early in the history of Mannville sedimentation, when deposits of the upper Cummings and Lloydminster formations were laid down.

(e) Foraminifer-bearing marine beds may prove to be the most reliable for correlation of the heterogeneous sequence of terrigenous clastic sediments that compose the Mannville Group. The most marine foraminifer-
bearing beds may be used as marker beds and thereby increase confidence in the identification of formations.

(f) Reduction in the overall diversity of the foraminifers and reduction in the proportion of calcareous-walled foraminifers from north and west to south and east across the Clearwater marine gulf suggests that waters of more normal marine salinity prevailed in the north and west whereas more brackish waters prevailed to the south and east.

(g) The presence of foraminifers in the Mannville sediments indicates that the extent of the Clearwater sea, vaguely defined on the eastern side of the gulf, now may be carried with certainty as far east as Choiceland and as far south as Saskatoon in Saskatchewan.

(h) The Pense Formation, the higher of the two formations that compose the Mannville Group across most of southern Saskatchewan, is interpreted as a transgressive marine sequence deposited during the earliest marine invasion of the Late Albian Joli Fou sea. As such, the Pense Formation should be excluded from the Mannville Group and linked with the Joli Fou Formation as the basal deposits of the Colorado Group.
IV REFERENCES CITED


1960. Cretaceous Spinney Hill Sand in west-


XVII, pt. 4, p. 142-143.


LORSONG, J.A. 1980. Geometry of nearshore sand bodies in the upper Mannville Group, Celtic field, Saskatchewan. In L.S. Beck, J.E. Christopher, and D.M. Kent (Eds.), Lloydminster and Beyond: Geology of Mannville Hydrocarbon Reserves, Saskatchewan Geological Society, Special Publication 5, p. 236-
268.


SMITH, S.R. 1984. The Lower Cretaceous Sparky formation, Aberfeldy steamflood pilot project, Saskatchewan; a wave-dominated delta? In D.F. Stott and D.J. Glass (Eds.), The Mesozoic of Middle North America, Canadian Society of Petroleum Geologists, Memoir 9, p. 413-430


8, p. 1004-1023.


Figures 1 and 2: Unidentified Diatoms. Lloydminster Shale; Paradise Hill section, 579.2 to 580.5 m-depth.

Figures 3 to 14: Dicloeopella borealis Eicher.
3, 4, 5. McLaren formation; Paradise Hill section, 462.5 to 464.0 m-depth.
6, 7, 8. Waseca formation; Paradise Hill section, 507.0 to 508.5 m-depth.
9. Sparky formation; Paradise Hill section, 520.5 to 522.0 m-depth.

Figures 10 to 12: Thuramminoides spp.
10. McLaren formation; Paradise Hill section, 462.5 to 464.0 m-depth.
11. McLaren formation; Paradise Hill section, 478.75 to 481.0 m-depth.
12. Sparky formation; Paradise Hill section, 525.0 to 526.5 m-depth.

Figures 13 to 15: Hippocrepina barksdalei Tappan
13. McLaren formation; Paradise Hill section, 473.5 to 475.0 m-depth.
14. Sparky formation; Paradise Hill section, 525.0 to 526.5 m-depth.
15. Middle Mannville Group; Choiceland section, 191.5 to 193.1 m-depth.

Figures 16 and 17: Saccammina alexanderi Loeblich and Tappan. Waseca formation; Paradise Hill section, 496.75 to 499.75 m-depth.

Figures 18 to 20: Bathysiphon cf. B. Brosgei Tappan. Middle Mannville Group; Choiceland section, 191.5 to 193.1 m-depth.

Figures 21 to 22: Brachysiphon sp. Crespin. Lloydminster formation; Paradise Hill section, 574.0 to 575.3 m-depth.

Figures 23 to 26: Miliammina manitobensis Wickenden.
23. Sparky formation; Paradise Hill section, 525.0 to 526.5 m-depth.
24. G.P. formation; Dee Valley section, 491.0 to 492.5 m-depth.
25 - 26. G.P. formation, Paradise Hill section, 538.5 to 540.0 m-depth.

Figures 27 to 30: Miliammina sproulei Nauss. Lloydminster formation; Paradise Hill section, 571.0 to 572.5 m-depth.

Figures 31 to 34: Recurvoides sp.
31. Crushed specimen -- Waseca formation; Paradise Hill section, 496.75 to 499.75 m-depth.
32 to 34. Lloydminster formation; Paradise Hill section, 573.3 to 577.9 m-depth.

Figures 35 and 36: Haplophragmoides linki Nauss
35. Sparky formation; Paradise Hill section, 522.5 to 524.0 m-depth.
36. Lloydminster formation; Paradise Hill section, 575.3 to 576.6 m-depth.
Figure 1: Haplophragmoides linki Nauss. Waseca formation; Paradise Hill section, 496.75 to 499.75 m-depth.

Figures 2 to 5: Pseudobolivina variana Eicher. Lloydminster formation; Paradise Hill section, 576.6 to 577.9 m-depth.

Figures 6 and 7: Verneuilinina canadensis Cushman. Lloydminster formation; Paradise Hill section, 569.5 to 572.0 m-depth.

Figures 8 to 10: Verneuilinoides canadensis Nauss.
8 - 9. Lloydminster formation; Dee Valley section, 522.5 to 524.0 m-depth.
10. Lloydminster formation; Paradise Hill section, 571.0 to 573.0 m-depth.

Figures 11 to 16: Gaudryina canadensis Cushman.
11 - 14. Lloydminster formation; Dee Valley section, 521.0 to 524.0 m-depth.
15 - 16. Lloydminster formation; Paradise Hill section, 571.0 to 574.0 m-depth.

Figures 17 and 18: Ammobaculites janus Stelck and Wall. Cummings formation; Dee Valley section, 572.0 to 573.0 m-depth.

MAGNIFICATION: X 23

Figures 19 to 21: Ammobaculites fragmentarius Cushman. Joli Fou Formation; Choiceland section, 158.3 to 159.2 m-depth.

Figures 22 and 23: Ammobaculites euides Loeblich and Tappan. Joli Fou Formation; Choiceland section, 158.3 to 159.2 m-depth.

Figures 24 and 25: Ammobaculoides whitneyi Cushman and Alexander. Joli Fou Formation; Choiceland section, 158.3 to 159.2 m-depth.

Figures 26 and 27: Ammomarginulina sp. G.P. formation; Paradise Hill section, 538.5 to 540.0 m-depth.

Figures 28 to 30: Ammomarginulina asperata Guliov. Joli Fou formation; Choiceland section, 156.8 to 158.3 m-depth.

Figures 31 to 34: Flabellammina? sp. Lloydminster formation; Paradise Hill section, 574.0 to 590.0 m-depth.