

Foraminiferal Evidence of the Early Albian Moosebar/Clearwater Seaway in Mannville Group Strata, Fort à la Corne Kimberlite Field, East-Central Saskatchewan¹

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McNeil, D.H. and Zonneveld, J-P. (2004): Foraminiferal evidence of the Early Albian Moosebar/Clearwater Seaway in Mannville Group strata, Fort à la Corne kimberlite field, east-central Saskatchewan; in Summary of Investigations 2004, Volume 1, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2004-4.1, CD-ROM, Paper A-15, 9p.

Abstract

Microfossil analysis of nine samples from the 106 m thick Cantuar Formation in the Star 96-03 borehole, Fort à la Corne kimberlite field, east-central Saskatchewan, has resulted in the recognition of three distinct microfossil assemblages (A to C). Assemblage A, in the lower part of the Cantuar, consists of thecamoebians occurring below and above coaly strata and is characteristic of fresh- to brackish-water environments. Assemblage B, in the lower part of the middle Cantuar, comprises foraminifera of the latest Early Albian Verneuilinoides cummingensis Subzone, as well as pyritized diatoms, rare radiolarians, fish fragments, and transported megaspores, and is characteristic of marginal-marine environments. Assemblage C, in the upper part of the Cantuar, consists of megaspores (aquatic ferns and club moss from flood-plain lakes and swamps) that are either in situ or transported by aqueous means into estuarine and tidal-flat environments. The marginal-marine microfossil assemblage (B) is a significant record of the Early Albian Moosebar/Clearwater Seaway in east-central Saskatchewan and indicates close proximity to the southeastern limit of this boreal seaway.

The occurrence of the V. cummingensis Subzone (assemblage B) establishes a maximum age for kimberlite activity at the Star 96-03 site. The oldest kimberlite in the borehole is a 3 m thick, primary, pyroclastic, airfall deposit occurring at mid-Cantuar level, approximately 17 m above the microfossil zone.

Keywords: foraminifera, megaspores, thecamoebians, Albian, Cretaceous, Saskatchewan, Cantuar Formation, Mannville Group, Moosebar/Clearwater Sea, paleoenvironments, kimberlite.

1. Introduction

Benthic foraminifera, typical of the Early Albian Moosebar and Clearwater formations of Alberta, have been recovered from a narrow stratigraphic interval within the lower part of the Cantuar Formation in a single core sample from the Star Kimberlite Body, Fort à la Corne kimberlite field of east-central Saskatchewan.

Systematic studies of the geology of the Fort à la Corne kimberlite field have been ongoing since the discovery of the field in 1988 (Lehnert-Thiel *et al.*, 1992; Leckie *et al.*, 1997; Jellicoe, 1998; Zonneveld *et al.*, in press). Our current study of microfossils in the Mannville Group in the Star 96-03 borehole (Figure 1) is part of a larger study in which several hundred samples from boreholes across the Fort à la Corne area are being analyzed for microfossil and palynological content, primarily for the purpose of providing a temporal framework for kimberlite occurrences interstratified with Lower Colorado and Mannville strata. Preliminary results from cores of the Star Kimberlite Body were presented at the Saskatchewan Geological Survey's Open House 2003 in Saskatoon (McNeil *et al.*, 2003; Zonneveld *et al.*, 2003). McNeil and Gilboy (1999, 2000) also published preliminary information on the biostratigraphic framework of several cores from drill holes located to the southeast of the kimberlite field.

Although Cantuar strata in the Star 96-03 borehole are not sub-divided into members, there are numerous references in this paper to the regionally developed members of the Cantuar (in succession from oldest to youngest, the Dina, Cummings, Lloydminster, Rex, General Petroleum, Sparky, and Waseca members). Usage conforms to that of Christopher (2003) and is shown in Figure 2.

The foraminifera recovered from the Star 96-03 borehole are exclusively agglutinated and indicate shallow, marginal-marine conditions of sedimentation. Monotypic, high-density, trace fossil assemblages (e.g., *Gyrolithes*)

¹ Geological Survey of Canada Contribution Number 2003327.

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and sedimentary structures (inclined heterolithic stratification and herringbone ripples) in adjacent strata suggest that the microfossil assemblage probably developed in an estuarine environment. The foraminifera fall within the *Marginulinopsis collinsi/Verneuillinoidea cummingensis* Subzone of the *Gaudryina nanushukensis* Zone which is widely recognized in the Western Interior from south-central Alberta northward to the Arctic Ocean (Caldwell *et al.*, 1978). For the sake of brevity, the subzone can be referred to as the *V. cummingensis* Subzone in east-central Saskatchewan.

In addition to foraminifera, thecamoebians and megaspores also have been recovered from the Cantuar Formation. The thecamoebians occur in close proximity to coaly strata, and the megaspores, which originated in floodplain lakes or swamps, occur more widely in both terrestrial and marginal-marine sediments as a result of fluvial transportation.

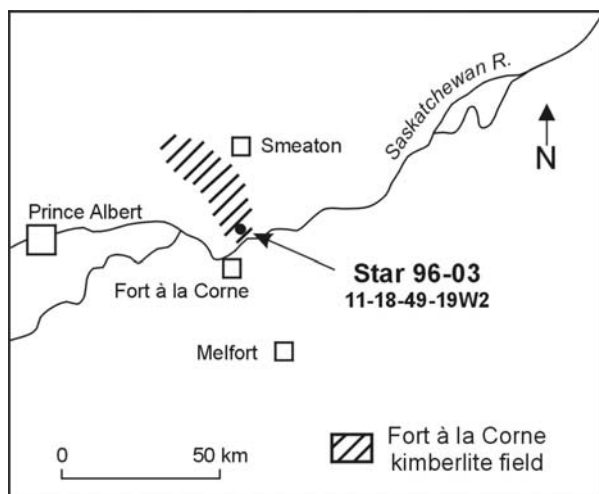


Figure 1 - Location of the Star 96-03 borehole (NAD83, 514860E, 5897870N).

AGE		STRATIGRAPHIC UNIT	
Early Cretaceous	Albian	Mannville Group	Pense Formation
			Waseca Member
			Sparky Member
			General Petroleum Member
			Rex Member
			Lloydminster Member
	Cummings Member		
Aptian			Dina Member

Figure 2 - Stratigraphic nomenclature and age of the Mannville Group in central Saskatchewan (from Christopher, 2003).

2. Regional Paleogeography

The paleogeography of the Early Albian seas in the interior of western Canada (Figure 3) have been well outlined by Jeletzky (1971) and Williams and Stelck (1975). This seaway extended southward from the Arctic and was the first of the Cretaceous marine incursions to reach the interior of North America. Jeletzky (1971) and Williams and Stelck (1975) referred primarily to the ammonite record as evidence for the timing and extent of the marine incursions, e.g., the distribution of *Subarcthoplites* and the latest Early Albian sea (Moosebar/Clearwater Sea). Caldwell *et al.* (1993) noted that the premiere reference section for the Albian in the Western Interior was that in the Peace River District of northeastern British Columbia where the molluscan and foraminiferal records are exceptionally well developed. The molluscan record of the Early Albian seaway has never been recognized eastward into the subsurface of Alberta and Saskatchewan, but marine strata have been known to exist within the widespread Mannville Group in



Figure 3 - Paleogeographic extent of the Early Albian Moosebar/Clearwater Sea in interior North America (modified after Jeletzky, 1971; Williams and Stelck, 1975; McLean and Wall, 1981; and Atkin, 1986).

Saskatchewan on the basis of foraminiferal occurrences (Fuglem, 1970; North and Caldwell, 1975a, 1975b; Atkin, 1986) and regional geological studies (Christopher, 1974, 1975, 1997, 2003).

McLean and Wall (1981) referred to this Early Albian boreal marine incursion as the Moosebar Sea. They indicated that the southernmost extent of the Moosebar Sea in Alberta (Figure 3) lay between 51° and 52°N. Christopher (1974, 1975, 2003) has reported foraminifera in Cummings equivalents of the Cantuar Formation as far south as the Maple Creek area of Saskatchewan (15-12-10-27W3), just south latitude 50°N. The most consistent foraminiferal records of the Moosebar Sea in Saskatchewan, however, occur to the north of the Duval/Saskatoon area (circa 52°N). A southern limit of the seaway at approximately this latitude is also supported by the existence of a pronounced erosional high forming a divide at 51°45'N (Maycock, 1967; Vigrass, 1977).

3. Previous Microfossil Studies

Nauss (1945, 1947) played a dual pioneering role in describing benthic foraminifera from core of the Mannville Well No. 1 (1-18-50-8W4) of the Vermilion area of east-central Alberta and in establishing stratigraphic members within the Mannville Formation. Eight foraminiferal species were described from the Cummings Member and made up an assemblage similar to that found in the Star 96-03 core of the present study. In the Lloydminster area, Fuglem (1970) presented an informal stratigraphic breakdown of the Mannville Formation, reporting foraminifera in most of the units (i.e., from the Cummings to the Waseca). Details of the foraminiferal distributions and identifications are sketchy in that report, but it is apparent that the foraminiferal assemblage from the Cummings Formation represented the strongest marine influence indicated by the mixed calcareous and agglutinated foraminifera, notably *Marginulinopsis collinsi*. North and Caldwell (1975a, 1975b) recognized an assemblage of benthic foraminifera low in the Mannville of west-central Saskatchewan (7-24-41-24W3), south of the Lloydminster area, and considered this occurrence to represent a marine shale tongue of the Cummings unit from east-central Alberta.

The most extensive studies of Early Albian foraminifera in western Canada were those by Mellon and Wall (1956), Stelck *et al.* (1956), and McLean and Wall (1981). In these publications, foraminifera from the well developed open-marine, molluscan-bearing Moosebar, Clearwater, and McMurray formations were described. Open-marine foraminiferal assemblages were characterized by the presence of both agglutinated and calcareous benthic foraminifera. McLean and Wall (1981) noted that the calcareous component of the assemblages was lost in the southern margins of the boreal flooding, i.e., in the central Foothills of Alberta and east-central Alberta.

In Saskatchewan, Atkin (1986) documented the occurrence of foraminifera in the Mannville Group and confirmed that the Early Albian sea transgressed at least as far west as Prince Albert and at least as far south as Saskatoon. He considered that the assemblage described by Nauss (1947) from the Cummings Member of the Vermilion area would likely equate with the Lloydminster shale of west-central Saskatchewan in the revised stratigraphic scheme of Vigrass (1977) and Orr *et al.* (1977). In the Choiceland No. 1 Choice (13-3-50-18W2) core, approximately 16 km northeast of the Star 96-03 borehole, Atkin (1986) recorded only one significant foraminiferal assemblage low in the core, at approximately 253 m (830 ft), well within the Dina Member (incompletely recovered) as picked by Christopher (2003). Atkin's (1986) records of sporadic occurrences of foraminifera higher in the Mannville of the Choiceland core are simple forms that could be interpreted as thecamoebians.

4. The Star 96-03 Core

The Star 96-03 borehole is situated on the north fringe of the Star Kimberlite Body at the southern end of the Fort à la Corne kimberlite field (Figure 1) and was drilled to a depth of 287 m. Kimberlitic airfall deposits form a significant part of the core from 108 to 179 m. The main body of kimberlite is overlain by sediments of the Westgate Formation and underlain by Mannville sediments. The Mannville sediments are present lower in the core and contain two thin kimberlite airfall deposits at 199 and 219 m (Figure 4). Twenty-two microfossil samples were collected over the length of the 96-03 core. Nine of the samples were from the Cantuar Formation, and these are reported on in this paper (Table 1).

The Cantuar Formation in Star 96-03 is approximately 106 m thick (Figure 4). The lower part consists of fine-grained, unconsolidated, fluvial channel sandstone with some low-angle, trough cross-stratification. Overlying this basal sandy unit (Dina Member) is a middle Cantuar succession of generally finer grained sediments consisting of shales, siltstones, and fine-grained sandstones apparently deposited in a delta-plain and estuarine complex. A 4 m thick kimberlite caps this middle part of the Cantuar Formation. It is a primary pyroclastic airfall unit deposited in a terrestrial environment (rootlets and immature paleosols in adjacent sediments) approximately 0.5 km north of the central Star Kimberlite Body (Zonneveld *et al.*, in press), and displays no evidence of reworking. In this core, five thin coal beds occur between 215 and 261 m, and root traces are present at several horizons (Figure 4). Sediments from the upper part of the Cantuar (above the kimberlite at 219 m) consist of fine-grained mudstone generally of estuarine and tidal-flat origin based on low diversity, high-density assemblages of diminutive trace fossils.

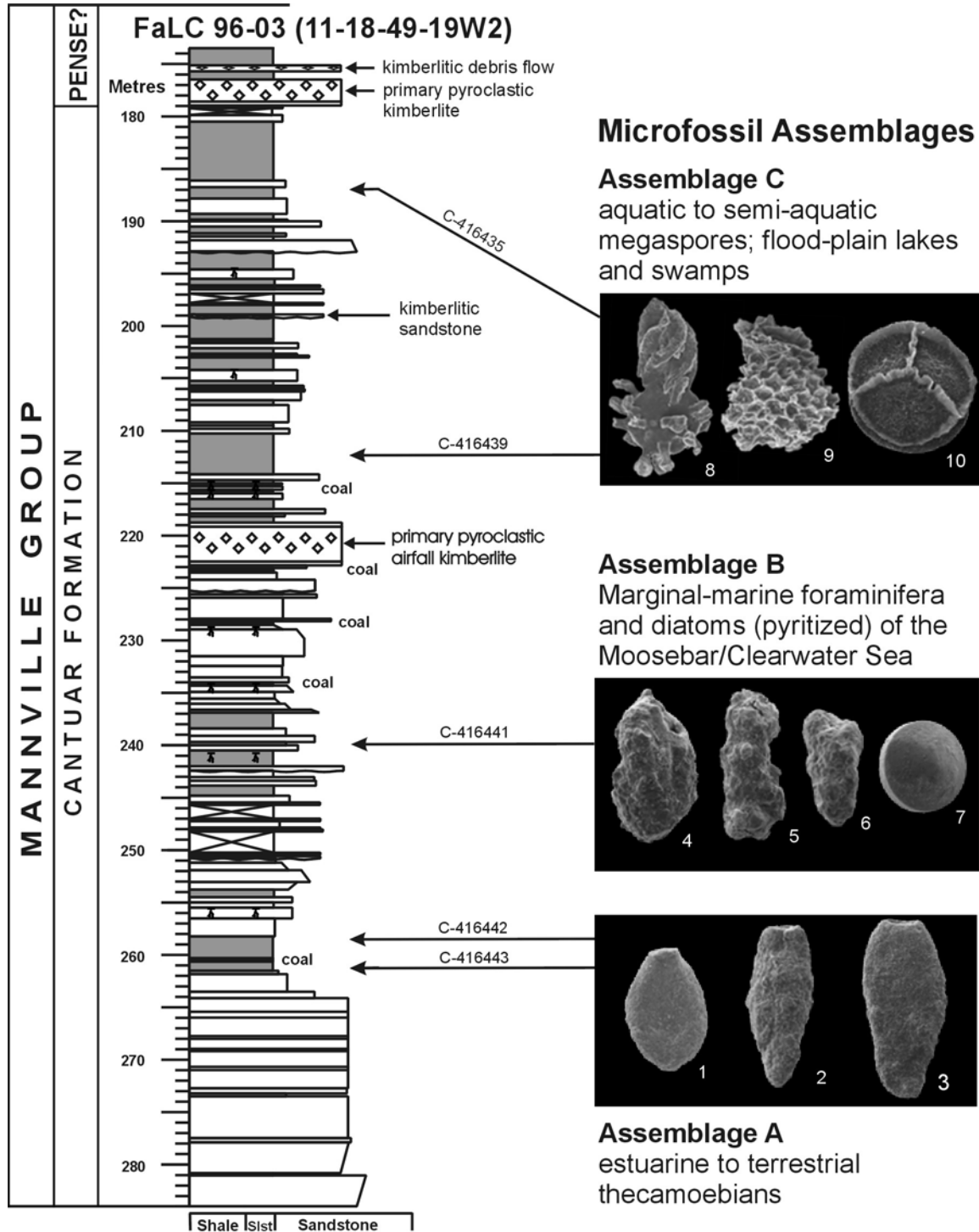


Figure 4 - Generalized lithological succession for the Mannville Group in the Star 96-03 core (11-18-49-19W2) with illustrations and interpreted paleoenvironments of three microfossil assemblages (A to C). See Table 1 for additional information on microfossil distributions and samples.

1) thecamoebian sp. 2 (x59, GSC 113740); 2) thecamoebian sp. 3 (x57, GSC 113741); 3) thecamoebian sp. 3 (x39, GSC 113742); 4) *Miliammina manitobensis* (x77, GSC 113743); 5) *Ammobaculites humei* (x59, GSC 113744); 6) *Verneuilinoides cummingensis* (x64, GSC 113745); 7) diatom sp. (pyritized) (x86, GSC 113746); 8) *Arcellites disciformis* (x44, GSC 113747); 9) *Arcellites incipiens* (x55, GSC 113748); and 10) *Minerisporites venustus* (x53, GSC 113749).

Table 1 - Plant and animal microfossils from the Cantuar Formation in the Star 96-03 kimberlite core (assemblage A: 258.5 and 261.5 m; assemblage B: 240.0 m; assemblage C: 187.0 and 212.5 m). Sample depths are in metres below Kelly bushing.

GSC Locality Number	C-416435	C-416436	C-416437	C-416438	C-416439	C-416440	C-416441	C-416442	C-416443
Metres below KB	187.0	191.2	200.4	209.5	212.5	218.5	240.0	258.5	261.5
PLANTS									
Prasinophytes (algal cysts)									
<i>Leiosphaeridia</i> sp.	1	-	-	-	-	-	-	-	-
<i>Leiosphaeridia</i> sp. (thin walled)	4	-	-	-	-	-	-	-	-
Diatoms									
diatom (pyritized) sp. 1	-	-	-	-	-	-	5	-	-
diatom (pyritized) sp. 2	-	-	-	-	-	-	1	-	-
Megaspores									
Aquatic ferns									
<i>Arcellites disciformis</i>	54	-	-	-	13	-	-	-	-
<i>Arcellites nudus</i>	5	-	-	-	1	-	-	-	-
<i>Arcellites incipiens</i>	-	-	-	-	13	-	20	-	-
<i>Arcellites</i> sp. (reticulate)	-	-	-	-	1	-	-	-	-
Lycopods (club moss)									
<i>Minerisporites marginatus</i>	4	-	-	-	-	-	-	-	-
<i>Minerisporites venustus</i>	2	-	-	-	35	-	15	-	-
<i>Minerisporites</i> ? sp.	-	-	-	-	-	-	-	1	-
Lycopods (incertae sedis)									
<i>Maexisporites soldanellus</i>	-	-	1	-	-	-	-	-	-
Seeds									
<i>Spermatites</i> sp.	1	-	-	-	1	-	-	-	-
Incertae Sedis									
<i>Dictyothylikos</i> sp.	-	-	-	-	-	-	1	-	-
Miscellaneous									
cuticle debris	++	-	-	-	+	-	-	-	-
coaly fragments	+	-	-	-	+	-	++	-	-
amber	-	-	-	-	-	-	+	-	-
ANIMALS									
Testate Amoeba ("Thecamoebians")									
thecamoebian sp. 1 (rounded)	-	-	-	-	-	-	-	26	6
thecamoebian sp. 2 (oval)	-	-	-	-	-	-	-	2	7
thecamoebian sp. 3 (elongate)	-	-	-	-	-	-	-	16	-
Foraminifera									
<i>Saccamina lathrami</i>	-	-	-	-	-	-	1	-	-
<i>Glomospira</i> sp.	-	-	-	-	-	-	2	-	-
<i>Miliammina manitobensis</i>	-	-	-	-	-	-	4	-	-
<i>Haplophragmoides</i> sp.	-	-	-	-	-	-	10	-	-
<i>Ammobaculites humei</i>	-	-	-	-	-	-	9	-	-
<i>Pseudobolivina</i> ? sp.	-	-	-	-	-	-	1	-	-
<i>Trochammina mcmurrayensis</i>	-	-	-	-	-	-	4	-	-
<i>Trochammina</i> sp. 1	-	-	-	-	-	-	4	-	-
<i>Trochammina</i> sp. 2	-	-	-	-	-	-	2	-	-
genus? (stout, multiserial)	-	-	-	-	-	-	2	-	-
<i>Uvigerinammina</i> sp.	-	-	-	-	-	-	1	-	-
<i>Verneuilinoides cummingensis</i>	-	-	-	-	-	-	36	-	-
<i>Gravellina</i> sp.	-	-	-	-	-	-	1	-	-
Radiolaria									
radiolarian sp.	-	-	-	-	-	-	1	-	-
Fish									
Teeth									
fish teeth	-	-	1	-	-	-	1	-	-
Bone fragments									
fish fragments	-	-	-	-	-	-	++	-	-

Note: numbers of specimens per 100 grams of sediment are indicated above; + = rare occurrences, ++ = common occurrences. Samples, microslides, and type specimens are stored at Geological Survey of Canada (Calgary). Samples are referenced by GSC locality numbers.

Nine samples were analyzed from the Cantuar Formation in Star 96-03, and three microfossil assemblages (A to C) are conspicuous in the samples (Table 1): assemblage A – thecamoebians from shales and siltstones in close proximity to coaly strata in the lower part of the core (258.5 and 261.5 m); assemblage B – a relatively well developed marine assemblage including diatoms, foraminifera, radiolarians (rare), and transported megaspores in siltstone (240.0 m) occurring a few metres above a *Glossifungites* surface and immediately below *Gyrolithes*-bearing sandstone; and assemblage C – aquatic to semi-aquatic, fern and club moss megaspores in the upper part of the Cantuar core (187.0 and 212.5 m).

5. Cantuar Microfossil Assemblages

a) Assemblage A

Two samples (258.5 and 261.5 m) from dark, organic-rich shales and siltstones have yielded simple, agglutinated, sack-shaped organisms identified as thecamoebians (also known as testate amoeba or arcellaceans), which constitute assemblage A. The fossil record for thecamoebians is poorly known because the test is weakly agglutinated and the vast majority of species are not preserved as fossils. In modern environments, however, thecamoebians occur prolifically in fresh-water environments, and some species tolerate brackish waters, typically marsh environments of the upper estuary. Three morphotypes are recognized in the Star 96-03 samples: spherical, oval, and elongate. Oval and elongate morphotypes are illustrated in Figure 4 (specimens 1, 2, and 3). The close proximity of these specimens to coaly strata compares closely to a classic coal cyclothem comprising terrestrial underclay, coal, and a brackish-water overclay in a lower delta-plain coastal environment. A lack of transported microfossils indicates a protected low-energy environment of deposition.

b) Assemblage B (Moosebar/Clearwater Sea Foraminifera)

Assemblage B was recovered from a glauconitic siltstone at 240.0 m in the Star 96-03 core. It is dominated by agglutinated foraminifera (Figure 4, specimens 4 to 6) associated with megaspores (moderately abundant), diatoms (Figure 4, specimen 7), radiolaria (rare), fish fragments, and coaly debris. The mixed marine and terrestrial assemblage clearly indicates a marginal-marine environment of deposition, and it seems most likely that the terrestrial indicators were fluviially transported from the southeast into shallow-marine water. Conversely, the open-marine indicators (radiolarians) were no doubt marine transported from the northwest into this shallow, marginal-marine environment. Although detailed sampling of individual beds was not undertaken, it appears from the lithological succession that this marine unit is thin (<5 m), and marine conditions of sedimentation were short lived.

The foraminifera of assemblage B (Table 1) are diagnostic of the late Early Albian *Verneulinoides cummingensis* Subzone, which, together with the *Marginulinopsis collinsi* Subzone, is developed widely from south-central Alberta and Saskatchewan northward to the Arctic (Caldwell *et al.*, 1993). McLean and Wall (1981) documented an essentially identical foraminiferal assemblage as being diagnostic of the southern marginal deposits of the boreal Moosebar Sea in Alberta. The presence of *V. cummingensis* in a narrow zone within the Mannville of the Fort à la Corne area indicates that this site was in close proximity to the southeastern limit of the Moosebar/Clearwater Sea and represents maximum marine transgression.

Species occurrences and abundances at the Star 96-03 locality are listed in Table 1. The assemblage is dominated by *Miliammina manitobensis*, *Haplophragmoides* sp., *Ammobaculites humei*, *Trochammina mcmurrayensis*, and *Verneulinoides cummingensis*, which together are characteristic of low-salinity, marginal-marine environments, including lagoons and estuaries. Estuarine conditions of sedimentation are indicated by the occurrence of a monotypic, high-density trace fossil assemblage consisting of the trace fossil *Gyrolithes* in the overlying sandstone beds at 239.5 m (Figure 5).

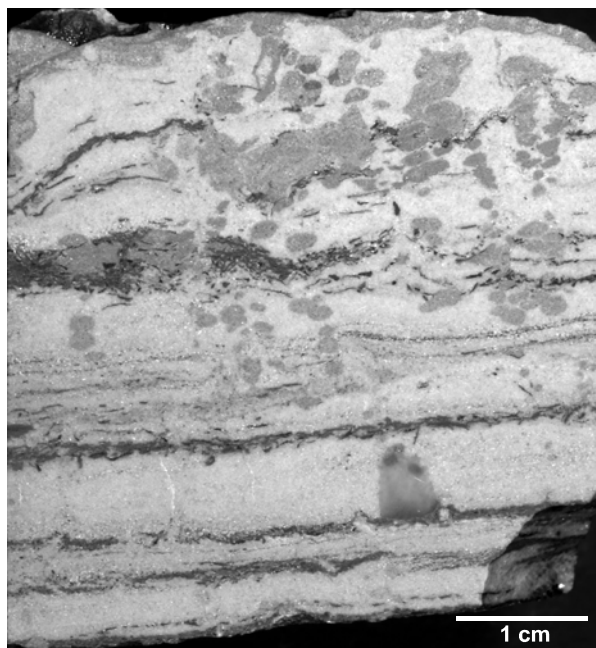


Figure 5 - Estuarine trace fossil *Gyrolithes* in fine-grained sandstone with carbonaceous laminae. Star 96-03, 239.5 m, C-441569.

The *Verneuilinoides cummingensis* Subzone extends westward toward the Lloydminster area where foraminifera are more abundant and occur at more numerous stratigraphic levels within the Cantuar Formation as indicated by Fuglem (1970), Vigrass (1977), Atkin (1986), and Christopher (2003). Their information indicates that the main foraminifera-bearing unit is the Lloydminster Member, and to a lesser extent the Cummings. Detailed correlations between east and west-central Saskatchewan are not attempted here, but initial observations indicate that assemblage B in Star 96-03 represents Lloydminster equivalents.

c) Assemblage C

Assemblage C consists predominantly of the megaspores *Arcellites* and *Minerisporites* (Figure 4, specimens 8 to 10) recovered from two samples (187.0 and 212.5 m) in the upper part of the Cantuar Formation (Table 1). Five other samples from the upper Cantuar were essentially barren of microfossils.

Kovach (1988) recognized *Arcellites* and *Minerisporites* as being particularly widespread in both terrestrial and marginal-marine facies. Both megaspores were considered to be from aquatic or semi-aquatic plants, and their wide dispersal interpreted as the result of aqueous transportation. The *in situ* habitat for *Arcellites* and *Minerisporites* was that of a flood-plain lake or swamp (Kovach, 1988).

Sedimentary structures and trace fossils indicate that the megaspores in the 212.5 m sample settled in bay-fill deposits or an abandoned meander deposit. Megaspores recovered from the 187.0 m sample were apparently deposited in an estuarine or tidal-flat environment (based on the nature of physical and biogenic bedforms) and, therefore, were likely transported.

6. Summary

Three discrete microfossil assemblages (A to C) have been recovered from the Cantuar Formation in the Star 96-03 kimberlite exploration borehole in the Fort à la Corne kimberlite field of east-central Saskatchewan. The lowermost assemblage (A) consists of thecamoebians that occur within a classic coal cyclothem above fluvial sandstones typical of the Dina Member. The second assemblage (B) notably contains marginal-marine foraminifera indicative of the Early Albian Moosebar/Clearwater Sea. The occurrence of this assemblage within a narrow stratigraphic interval bounded by estuarine, delta-plain, and terrestrial sediments indicates a paleogeographic position very near the southern and eastern limits of the Early Albian seaway. Regional microfossil distributions suggest correlation of assemblage B strata with the Lloydminster Member of the Cantuar Formation in west-central Saskatchewan. A third assemblage (C) consisting of aquatic megaspores occurs in the upper part of the Cantuar in sediments that were deposited in estuarine, tidal-flat, or delta-plain environments.

Thin (3 m thick), primary, airfall, pyroclastic kimberlites occur in the middle part of the Cantuar Formation in the Star 96-03 core. Their occurrence above the late Early *Verneuilinoides cummingensis* Subzone (assemblage B) places a maximum age limit on kimberlite activity preserved in this borehole. In the Star 96-03 core, the major kimberlite deposits occur in post-Cantuar strata, which are described in a separate report on the emplacement of the Star Kimberlite Body (Zonneveld *et al.*, in press).

7. Acknowledgments

Acknowledgment is extended to J. Dixon (Geological Survey of Canada, Calgary), A.R. Sweet (Geological Survey of Canada, Calgary), and D.R. Leckie (Nexen Incorporated) for review comments on this manuscript. The guidance of Art Sweet in identifying megaspore genera and species is especially appreciated. Shore Gold Incorporated of Saskatoon, Saskatchewan is gratefully acknowledged for allowing access to the Star 96-03 core and providing permission to publish results.

8. References

- Atkin, K.T.J. (1986): Foraminifers and other microfossils from the Early Cretaceous Mannville Group in Saskatchewan; unpubl. M.Sc. thesis, Univ. Sask., 89p.
- Caldwell, W.G.E., North, B.R., Stelck, C.R., and Wall, J.H. (1978): A foraminiferal zonal scheme for the Cretaceous System in the Interior Plains of Canada; *in* Stelck, C.R. and Chatterton, B.D.E. (eds.), *Western and Arctic Canadian Biostratigraphy*, Geol. Assoc. Canada, Spec. Pap. 18, p495-575.

- Caldwell, W.G.E., Diner, R., Eicher, D.L., Fowler, S.P., North, B.R., Stelck, C.R., and von Holdt, W.L. (1993): Foraminiferal biostratigraphy of Cretaceous marine cyclothem; *in* Caldwell, W.G.E. and Kauffman, E.G. (eds.), *Evolution of the Western Interior Basin*, Geol. Assoc. Canada, Spec. Pap. 39, p477-520.
- Christopher, J.E. (1974): The Upper Jurassic Vanguard and Lower Cretaceous Mannville Group of Southwestern Saskatchewan; *Sask. Dep. Miner. Resour., Rep.* 151, 349p.
- _____ (1975): The depositional setting of the Mannville Group (Lower Cretaceous) in southwestern Saskatchewan; *in* Caldwell, W.G.E. (ed.), *The Cretaceous System in the Western Interior of North America*, Geol. Assoc. Canada, Spec. Pap. 13, p523-552.
- _____ (1997): Evolution of the Lower Cretaceous Mannville sedimentary basin in Saskatchewan; *in* Pemberton, S.G. and James, D.P. (eds.), *Petroleum Geology of the Cretaceous Mannville Group, Western Canada*, Bull. Can. Petrol. Geol., Mem. 8, p191-210.
- _____ (2003): Jura-Cretaceous Success Formation and Lower Cretaceous Mannville Group of Saskatchewan; *Sask. Industry Resources, Rep.* 223, CD-ROM.
- Fuglem, M.O. (1970): Use of core in evaluation of productive sands, Lloydminster area; *in* Mesozoic Core Seminar, Paper No. 5, *Sask. Geol. Soc./Sask. Dep. Miner. Resour.*, 31p.
- Jellicoe, B.C., Robertshaw, P., Williamson, P., and Murphy, J. (1998): Summary of exploration activities and results for the Fort à la Corne diamond project, Saskatchewan; *in* Summary of Investigations 1998, Saskatchewan Geological Survey, *Sask. Energy Mines, Misc. Rep.* 98-4, p144-157.
- Jeletzky, J.A. (1971): Marine Cretaceous Biotic Provinces and Paleogeography of Western and Arctic Canada: Illustrated by a Detailed Study of Ammonites; *Geol. Surv. Can., Pap.* 70-22, 92p.
- Kovach, W.L. (1988): Quantitative palaeoecology of megaspores and other dispersed plant remains from the Cenomanian of Kansas, USA; *Cret. Resear.*, v9, p265-283.
- Leckie, D.A., Kjarsgaard, B.A., Bloch, J., McIntyre, D., McNeil, D., Stasiuk, L., and Heaman, L. (1997): Emplacement and re-working of diamond-bearing, crater facies kimberlite in Albian sediments of central Saskatchewan, Canada; *Geol. Soc. Amer. Bull.*, v109, p1000-1020.
- Lehnert-Theil, K., Loewer, R., Orr, R.G., and Robertshaw, P. (1992): Diamond-bearing kimberlites in Saskatchewan, Canada: The Fort à la Corne case history; *Explor. Mining Geol.*, v1, p391-403.
- Maycock, I.D. (1967): Mannville Group and Associated Lower Cretaceous Rocks in Southwestern Saskatchewan; *Sask. Dep. Miner. Resour., Rep.* 96, 108p.
- McLean, J.R. and Wall, J.H. (1981): The Early Cretaceous Moosebar Sea in Alberta; *Bull. Can. Petrol. Geol.*, v29, p334-377.
- McNeil, D.H. and Gilboy, C.F. (1999): High-resolution, Cretaceous biostratigraphic record from the Kennebec Crooked River and Leather River kimberlite cores, east-central Saskatchewan – preliminary report; *in* Summary of Investigations 1999, Volume 1, Saskatchewan Geological Survey, *Sask. Energy Mines, Misc. Rep.* 99-4.1, p41-44.
- _____ (2000): Cretaceous stratigraphy in four cores from the vicinity of the Fort à la Corne kimberlite field, east central Saskatchewan – preliminary results; *in* Summary of Investigations 2000, Volume 1, Saskatchewan Geological Survey, *Sask. Energy Mines, Misc. Rep.* 2000-4.1 p98-105.
- McNeil, D.H., Dolby, G., Zonneveld, J-P., and Kjarsgaard, B.A. (2003): A biostratigraphic transect across the Star Kimberlite Body of east-central Saskatchewan – preliminary results; *in* Saskatchewan Geological Survey, *Sask. Industry Resources, Open House 2003, Saskatoon, abstr. vol.*, p39.
- Mellon, G.B. and Wall, J.H. (1956): Geology of the McMurray Formation. Part 1. Foraminifera of the Upper McMurray and Basal Clearwater Formations; *Resear. Counc. Alta., Rep.* 72, 29p.
- Nauss, A.W. (1945): Cretaceous stratigraphy of Vermilion area, Alberta, Canada; *Amer. Assoc. Petrol. Geol.*, v29, p1605-1629.
- _____ (1947): Cretaceous microfossils of the Vermilion area, Alberta; *J. Paleont.*, v21, p329-343.

- North, B.R. and Caldwell, W.G.E. (1975a): Foraminiferal faunas in the Cretaceous System of Saskatchewan; *in* Caldwell, W.G.E. (ed.), *The Cretaceous System in the Western Interior of North America*, Geol. Assoc. Can., Spec. Pap. 13, p303-331.
- _____ (1975b): Illustrations of Canadian Fossils. Cretaceous Foraminifera from Saskatchewan and Manitoba; Geol. Surv. Can., Pap. 74-38, 35p.
- Orr, R.D., Johnston, J.R., and Manko, E.M. (1977): Lower Cretaceous geology and heavy-oil potential of the Lloydminster area; Bull. Can. Petrol. Geol., v25, p1187-1221.
- Stelck, C.R., Wall, J.H., Bahan, W.G., and Martin, L.J. (1956): Middle Albian Foraminifera from Athabasca and Peace River Drainage Areas of Western Canada; Resear. Counc. Alta., Rep. 75, 60p.
- Vigrass, L.W. (1977): Trapping of oil at intra-Mannville (Lower Cretaceous) disconformity in Lloydminster area, Alberta and Saskatchewan; Amer. Assoc. Petrol. Geol. Bull., v61, p1010-1028.
- Williams, G.D. and Stelck, C.R. (1975): Speculations on the Cretaceous palaeogeography of North America; *in* Caldwell, W.G.E. (ed.), *The Cretaceous System in the Western Interior of North America*, Geol. Assoc. Can., Spec. Pap., 13, p1-20.
- Zonneveld, J-P., McNeil, D.H., Kjarsgaard, B.A., and Harvey, S.E. (2003): Sedimentologic and stratigraphic constraints on emplacement of the Fort à la Corne kimberlites, east-central Saskatchewan; *in* Saskatchewan Geological Survey, Sask. Industry Resources, Open House 2003, Saskatoon, abstr. vol., p38.
- Zonneveld, J-P., Kjarsgaard, B.A., Harvey, S.E., Heaman, L.M., McNeil, D.H., and Marcia, K.Y. (in press): Sedimentologic and stratigraphic constraints on emplacement of the Star Kimberlite, east-central Saskatchewan; *Lithos*.