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**A MULTIDISCIPLINARY SUBSURFACE STUDY
OF THE ALBIAN BOW ISLAND AND WESTGATE FORMATIONS
IN SOUTHWESTERN ALBERTA, CANADA**

Olga Vorobieva

A thesis presented to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science

Department of Earth Sciences, College of Natural Sciences
Carleton University
Ottawa-Carleton Geoscience Centre

December 2000

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**A MULTIDISCIPLINARY SUBSURFACE STUDY OF THE ALBIAN
BOW ISLAND AND WESTGATE FORMATIONS IN
SOUTHWESTERN ALBERTA, CANADA**

Submitted by Olga Vorobieva, B.Sc.
in partial fulfillment of the requirements for the degree of
Master of Science

Thesis Supervisor: Claudia Schröder-Adams

Chair, Department of Earth Sciences: George Dix

Carleton University
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December 2000

Abstract

The Lower Cretaceous Bow Island Formation in southwestern Alberta contains significant gas reserves with production concentrated within its upper part. Despite extensive well penetration, coring and abundant petrophysical data, published information on the Bow Island sediments is limited. This multidisciplinary study of the Bow Island and Westgate formations integrates micropaleontological, sedimentological, petrophysical and geochemical data.

Following Cox (1993) the Bow Island Formation in southwestern Alberta can be subdivided into three informal lithostratigraphic units: the Lower Bow Island, the Middle Bow Island and the Upper Bow Island. Basinward prograding shelf-shoreface sediments of the Lower Bow Island and coastal-plain sediments of the Middle Bow Island represent deposits of the highstand systems. The boundary between the Middle Bow Island and the Upper Bow Island represents a combined sequence boundary/transgressive reworking surface and is characterized as a type 2 sequence boundary. Marginal-marine sediments of the Upper Bow Island represent deposits of the transgressive systems tract. Several drops in relative sea-level during an overall transgression were recorded as transgressive lag deposits within the shoreface and offshore-shoreface facies associations on the east, and as valley incisions on the west that later were filled by deposits of the estuarine and lagoonal-estuarine facies associations during subsequent sea-level rise. Basal shales of the overlying Westgate Formation represent a major flooding event of the transgression that started at the base of the Upper Bow Island.

The Lower Bow Island and the Middle Bow Island are correlative to the parasequences of the regional Viking Formation, while the Upper Bow Island is correlated with the upper part of the Viking Formation. The sequence boundary between the Middle and the Upper Bow Island possibly is time equivalent to the sequence boundary within the Viking Formation.

Foraminiferal assemblages from the Upper Bow Island and the Westgate formations are assigned to the *Miliammina manitobensis* Zone, in most cases to its *Verneuilina canadensis* Subzone; however, some faunal elements of the *Haplophragmoides gigas* Zone are also present. Fluctuations of the paleoecological conditions within the shallow sea caused extreme vertical and lateral variations of foraminiferal abundance, diversity and composition. Many faunal elements of the *Miliammina manitobensis* and *Haplophragmoides gigas* zones are facies controlled. Restricted lagoonal settings are characterized by low diverse foraminiferal assemblages, whereas well oxygenated shoreface environments contain abundant foraminifera of increased diversity. The Westgate Formation is remarkably poor in benthic foraminifera in southwestern Alberta compared to more distal regions of the Western Interior basin. This is explained by a possible freshwater lid caused by river runoff resulting in water stratification and subsequent depletion in bottom-water oxygen.

Sediments of both the Bow Island and Westgate formations show low TOC and HI values and are not likely to be a source of a hydrocarbon generation.

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Introduction

The area of study is situated in southwestern Alberta (fig. 1) in close vicinity to the Blood Indian Reserve and stretches from Range 19W4 to 28W4 and from Township 6 to 13. This research covers the stratigraphic interval from the top of the Upper Mannville Group to the base of the Fish Scales Formation, which includes the Bow Island and the Westgate formations.

For decades the petroleum industry has had an interest in the Lower Cretaceous Bow Island Formation due to its hydrocarbon reserves in excess of 600×10^9 cubic feet (BCF) (Cox, 1993). The formation is known mainly as a gas producer with production concentrated within its upper part. In spite of the extensive exploration of this interval published material about the depositional environments, stratigraphic relationships, and biostratigraphic framework of the Bow Island Formation is limited. This multidisciplinary study is the first to examine the Bow Island Formation for its micropaleontological content, integrated with sedimentological, petrophysical and geochemical data.

The main objectives are: 1) to produce the biostratigraphic framework for the upper Bow Island and Westgate formations, using foraminiferal data; 2) to understand facies relationships of certain agglutinated foraminiferal species; 3) to recognize different depositional environments within the study interval; 4) to study the geometry of the Westgate Formation and the lithostratigraphic units, comprising the Bow Island Formation; 5) to understand the depositional history of the Bow Island and Westgate formations in southwestern Alberta, and to determine the relative sea-level fluctuations during the late Albian time; 6) to develop a sequence stratigraphic framework for the Bow Island - Westgate interval.

Figure 1. Location map with major tectonic elements (modified after Leckie and Smith, 1992).

Data Set and Methods

The study area is located in southwestern Alberta, covering the area from 6-18W4 to 14-28W4 (fig. 2). Sedimentological description and interpretation was performed on 8 cores with 139 samples being taken for Rock-Eval pyrolysis and 146 samples being examined for the micropaleontological content. A total of 740 wireline well-logs were examined within the study area. Outcrops of the Bow Island Formation are not known in southern Alberta.

Sedimentology

Sedimentological analysis was based on detailed lithological core descriptions, which include visual characteristics of sediments in terms of composition, grain size, texture, sedimentary structures, degree of bioturbation, and fossil content (see Appendix 1). Selection of cores was primarily based on their location, length, and recovered interval with the desirable upper boundary of the Bow Island Formation. Core data is concentrated within the upper part of the Bow Island Formation and the Westgate Formation.

Micropaleontology

Micropaleontological analysis was based on core samples, taken at regular intervals of half to one meter, depending on lithological boundaries, unusual characteristics of sediments, or critical intervals. Samples for micropaleontological analysis were prepared according to the method described by Then and Dougherty (1983). Foraminifera were picked from the sand-size fraction (>63µm). Volumes of picked residues varied with foraminiferal abundance, therefore a fully quantitative analysis was not possible. Moderate to poor preservation of foraminifera did not always allow identification to species level. The foraminiferal fauna represented by agglutinated, benthic species, and approximate estimation of the abundance of fish remains, algal cysts and bivalve shell prisms are listed in

Figure 2. Base map showing locations of cores, wells and selected cross-sections.

Appendix 2.

Scanning electron micrographs of most identified foraminiferal species were done on a JOEL 6400 scanning electron microscope (SEM) at Carleton University Research Facility for Electron Microscopy. Foraminiferal images are presented on Plates 1 to 4.

Petrophysics

15 principal wireline well-log cross-sections running east-west and north-south were constructed within the study area using the digital database from International Datashare Corporation (iDc), Calgary. East-west cross-sections were running through every Township, while north-south oriented ones were constructed for every second Range. Additionally numerous short wireline well-log cross-sections with different orientations were made for a better understanding of complicated geometries of the Westgate and Bow Island formations, integrating almost all well-logs available within the study area. Well control varies within the study area and is denser within the gas fields such as Blood and Keho (south-central and north-eastern parts of the study area respectively) and is scarce in the south-western part of the study area. Usually gamma-ray, resistivity, and sonic logs were available for correlations.

Structural maps of the top of the Bow Island and Westgate formations, and an isopach map of the Westgate Formation have been constructed within the study area based on petrophysical well-log analysis of all available well-logs of the study interval. Maps were produced partly by the computer contouring program of Geooffice from International Datashare Corporation (iDc) and partly by hand to enhance some details ignored by the computer.

Geochemistry

Rock-Eval pyrolysis was performed at the Geological Survey of Canada, Calgary, using standard methods laid out in Espitalié et al. (1985). It provides information about the amount of organic carbon, source of organic material in

sediments and its state of maturity, and in combination with micropaleontological and sedimentological data will support interpretations of the depositional history of the study area. For each sample the following parameters have been measured: Total Organic Carbon (TOC), Hydrogen Index (HI), Oxygen Index (OI), Tmax, and petroleum potential (S_1 , S_2 , S_3). Organic geochemical data are listed in Appendix 3.

Regional Geology

Geological Setting

The Western Canada Sedimentary Basin (WCSB) is an asymmetrical basin with high rates of subsidence on its western limit. The basin extends from the eastern flanks of the Rocky Mountains to the stable interior platform in western Ontario, and from the Arctic Ocean to the southern international border with the United States, where it becomes the Western Interior Basin. It is a thin wedge of supracrustal rocks, that tapers northeastward, covering the Precambrian crystalline basement of the North American craton (Price, 1994).

The tectonic and stratigraphic history of the WCSB is closely related to the origin and evolution of the Canadian Cordillera (Price, 1994), which can be divided into three major stages (Porter et al., 1982). The main collisions of plates, which caused rapid subsidence of the foreland basin and building of the Rocky Mountains, took place during the second stage (Early Jurassic - Late Cretaceous) and played an important role in the development of the WCSB. This tectonic activity provided a source of sediments, a gradient to transport sediments and a basin for deposition (Leckie and Reinson, 1993). Late Jurassic and Cretaceous clastic wedges were deposited in a developing basin.

During Cretaceous sea-level fluctuations, western North America flooded to various extents, forming at times of sea-level highstand a connection between the Tethyan Sea to the South and the Boreal Sea to the North. Six major regional transgressive/regressive cycles, representing the combined effects of eustasy, basin tectonics, and sediment supply patterns (Kauffman and Caldwell, 1993), are recognized within the WCSB (Sloss, 1963). The Bow Island Formation was deposited at the top of the lower Zuni sequence, which corresponds with the regressive phase of the Albian Kiowa-Skull Creek Marine Cycle, followed by a

transgressive phase of the Greenhorn Cycle (late Albian - middle Turonian) (Kauffman, 1977; Caldwell, 1984). The Kiowa-Skull Creek and early Greenhorn cycles are expressed in the deposits of Joli Fou, Bow Island and Westgate formations. Marine fauna of the Joli Fou Formation indicates evidence of the first connection between the Tethys and the Boreal seas (Caldwell, 1984).

Southern Alberta is characterized by several major structural elements that have had an influence on the Cretaceous deposition in the WCSB (fig. 1). The Rocky Mountain (Foreland) Belt, stretching along the southwest boundary of the province with British Columbia, forms the southern part of the Canadian Cordilleran fold-thrust belt. In southern Alberta the northwest trending Sweetgrass Arch was a positive structural feature during Laramide Orogeny and possibly during the Jurassic. In the earliest Cretaceous the arch became active and caused the development of the broad uplands with the drainage system radiating northwestward and northeastward (Christopher, 1984). In early Jurassic and late Cretaceous times this arch separated the Williston basin, located in Saskatchewan, Montana and North Dakota, from the Alberta Basin. The Peace River Arch in northwestern Alberta, uplifted during Cambrian, started to subside in late Devonian, and became a basin (Leckie and Smith, 1992). By the middle to late Albian the arch started to rise and became a positive-relief feature during the latest Cretaceous and Tertiary times (Williams, 1958).

Regional Stratigraphic Nomenclature

The term "Bow Island Formation" first appeared in 1908 to name a subsurface unit of sandstones and mudstones, drilled by Canadian Pacific Railroad northwest of Bow Island, Alberta (Glass, 1990). The stratigraphic relationships of the Bow Island Formation and its equivalents in northeastern British Columbia,

Alberta, Saskatchewan and northwestern United States have been studied for many years (fig. 3).

In **southwestern Alberta** sediments of the Bow Island Formation lie at the base of the Lower Colorado Group. It unconformably overlies the Mannville Group with local appearances of Basal Colorado Sands and marine shales of the Joli Fou Formation. The Joli Fou Formation becomes distinctive in eastward and northward directions, where it loses its sand component (Tizzard and Lebrekmo, 1975; Leckie et al., 1994). The Bow Island Formation is overlain by transgressive marine shales of the Westgate Formation (Bloch et al., 1993). In southwestern Alberta, Cox (1993) subdivided the Bow Island Formation into three informal lithostratigraphic units (Lower Bow Island, Middle Bow Island and Upper Bow Island) that can be correlated over an extensive area.

In the **Southern Alberta Foothills**, where the shales of the Joli Fou Formation are missing, the Bow Island Formation merges with the Mannville Group to form the Blairmore Group (Leckie and Reinson, 1993). Conglomeratic beds of the Mill Creek Formation within the Upper Blairmore Group are believed to be a lateral equivalents of the Bow Island Formation (Melon, 1967; Leckie et al., 1994). Based on paleontological data, Stelck (1958) suggested that the Viking Formation, which is an equivalent of the Bow Island Formation, was deposited between Upper and Lower Blairmore of the Southern Foothills and between Mountain Park and Blackstone formations of the Central Foothills during the erosional hiatus.

The relationship between the Bow Island Formation and the Viking Formation in **central Alberta** and **southern Saskatchewan** is not clearly understood (Reinson et al., 1994). In southern Saskatchewan Leckie et al. (1994) and Reinson et al. (1994) show the Viking and Joli Fou formations stratigraphically slightly lower than the Bow Island/Viking and Joli Fou formations

Figure 3. Stratigraphic nomenclature for the Bow Island Formation and equivalent units, and enclosing strata (1 - after Reinson et al., 1994; 2 - after Bloch et al., 1993; 3 - after MacEachern et al., 1998; 4 - after McNeil and Caldwell, 1981; 5 - after Lopez, 1995; 6 - after Dolson et al., 1991). Absolute age after Obradovich (1993).

in central and southern Alberta. Schröder-Adams et al. (1996) and McEachern et al. (1998) place Viking and Joli Fou formations in both central Alberta and southern Saskatchewan at the same level. In southern Alberta the Viking Formation was correlated with the lower part of the Bow Island Formation (Caldwell et al., 1978, fig. 4). Some authors consider the Bow Island Formation as a stratigraphically equivalent to both Joli Fou and Viking formations (Glaister, 1959; Cox, 1993; Reinson et al., 1994). The Joli Fou Formation loses its shaly character towards the southwest by becoming sandy and silty, and together with the Viking Formation passes laterally into the Bow Island Formation (Leckie and Reinson, 1993; Leckie et al., 1994). This transition occurs in the southwest corner of the Suffield area (between Townships 19 and 26 and Ranges 1 and 16 west of the 4th Meridian) northeast from the study area (Tizzard and Lebrekmo, 1975). However, there is no formal biostratigraphic framework created for the Bow Island Formation, that can give a precise correlation with the Viking Formation and the underlying Joli Fou Formation.

In **northwestern Alberta** correlations of the late Albian strata have been a subject of discussions for many years. Workman (1959) and Smith et al. (1984) believed that the Harmon Member within the Peace River Formation is an equivalent of the Joli Fou Formation, whereas Stelck (1958) and Jackson (1984) dated it slightly older. The Viking Formation was correlated with both Paddy and Cadotte members by Workman (1959), but is shown as a stratigraphic equivalent only to the Paddy Member by Stelck (1958). Koke and Stelck (1984) and Stelck and Leckie (1990). Foraminiferal assemblages from the Cadotte Member are of middle Albian age (Stelck and Koke, 1987), while the Viking Formation is dated as the late Albian.

In **northeastern British Columbia** the upper part of the Boulder Creek Formation correlates with Joli Fou and Viking formations (Stelck and Koke, 1987; Leckie et al., 1994). In **northeastern Alberta** and **Manitoba** Reinson et al. (1994) correlate the Bow Island Formation with the Pelican Formation and Newcastle Member of the Ashville Formation respectively.

In **Montana** the lower part of the Blackleaf Formation is equivalent to the Bow Island Formation (Glaister, 1959; Glass, 1990; Lopez, 1995). According to McGookey (1972) and Dolson et al. (1991) the Vaughn-Bow Island Sandstone within the Blackleaf Formation is correlative to the Bow Island Formation, while the Taft Hill Member is an equivalent of the Joli Fou shales (fig. 3). On the stratigraphic cross-section in southern Alberta Lang and McGugan (1988) plotted the electric-log marker of the top of the Bow Island Sand within the Bootlegger Member. In **Wyoming** the Muddy Sandstone and Thermopolis-Skull Creek Shale are the equivalents to the Viking and Joli Fou formations (McGookey et al., 1972; Dolson et al., 1991).

The shales of the Westgate Formation in southern and central Alberta and southern Saskatchewan are stratigraphically equivalent to the lower part of the Shaftesbury Formation in the northwestern Alberta plains and foothills (Warren and Stelck, 1969; Stelck and Leckie, 1990; Bloch et al., 1993), part of the Hasler Formation in northeastern British Columbia (Stelck and Leckie, 1990), the Colorado Shale of southern Saskatchewan (Reinson et al., 1994), the Westgate Member of the Ashville Formation of Manitoba (McNeil and Caldwell, 1981) and the Mowry Shale in Montana and North Dakota (McGookey et al., 1972).

Age and Foraminiferal Biostratigraphy

For western Canada Caldwell et al. (1978) established three foraminiferal zones within the Albian stage: the *Gaudryina nanushukensis* Zone, *Haplophragmoides gigas* Zone, and *Miliammina manitobensis* Zone. Correlations with molluscan zones (Stelck and Koke, 1987; Caldwell et al., 1993) place the *Gaudryina nanushukensis* Zone within the early to middle Albian, the *Haplophragmoides gigas* Zone within the early late Albian, and the *Miliammina manitobensis* Zone within the late late Albian (fig. 4). In northeastern British Columbia these three Albian foraminiferal zones have their fullest expression and can be subdivided into a number of subzones - six within

REFERENCE		Stelck and Koke (1987)	Stelck (1991) Caldwell et al. (1993)	Stelck and Leckie (1990) Caldwell et al. (1978)	Mattison and Wall (1993) Caldwell et al. (1978)	Caldwell et al. (1978)
STAGE	SUBSTAGE	MOLLUSCAN ZONES	NORTHEASTERN BRITISH COLUMBIA	NORTHWESTERN ALBERTA	NORTHEASTERN ALBERTA	CENTRAL ALBERTA
ALBIAN	UPPER	Neogastropiles macleodensis	Haplophragmium swarzeni / Bulbophragmium swarzeni	Haplophragmium swarzeni		
		Neogastropiles americanus				
		Neogastropiles maydeni		Haplophragmoides positis goodrichi		
		Neogastropiles cornutus				
		Neogastropiles haasi				
		Inoceramus comancheanus	Vermulina canadensis	Vermulina canadensis	Vermulina canadensis	
			Reophax troyeri			
			Trochammina unialensis			
			Trochammina depressa			
			Reophax tundraensis			
			Haplophragmoides gigas phaseolus			
			Haplophragmoides gigas gigas			
MIDDLE		Haplophragmoides uniorbis				
	Stelkiceras lardensis	Ammobaculites wenonahae				
		Ammobaculites sp.	Ammobaculites sp.			
LOWER		Haplophragmoides multiplex	Haplophragmoides multiplex			
		Marginulinopsis collinsi - Vermulinoides cunningensis	Marginulinopsis collinsi - Vermulinoides cunningensis	Marginulinopsis collinsi - Vermulinoides cunningensis	Marginulinopsis collinsi - Vermulinoides cunningensis	Marginulinopsis collinsi - Vermulinoides cunningensis
		Trochammina mcnamayensis	Trochammina mcnamayensis	Trochammina mcnamayensis	Trochammina mcnamayensis	
		Rectobolivina sp.				

Figure 4. Foraminiferal zones and subzones and their correlation with molluscan zones within the upper Albian Substage (Modified after Strick and Schroder-Adams, 1999).

the *Gaudryina nanushukensis* Zone (Caldwell et al., 1978), seven within the *Haplophragmoides gigas* Zone (Stelck and Koke, 1987; Stelck, 1991), and three within the *Miliammina manitobensis* Zone (Caldwell et al., 1978) (fig. 4). Only *Haplophragmoides gigas gigas* and *H. gigas phaseolus* subzones of the *Haplophragmoides gigas* Zone and the *Verneuulina canadensis* Subzone of the *Miliammina manitobensis* Zone are known outside northeastern British Columbia. Even though not all subzones can be recognized within the entire Western Interior Sedimentary Basin, "...they offer a window through which may be seen, with greater or lesser degrees of clarity, the complete Albian history of much of the southern Interior Plains of Canada" (Caldwell et al., 1993, p. 491).

The Bow Island Formation in southern Alberta has not been analyzed for its micropaleontological content, while its stratigraphic equivalents were studied for many years. Foraminiferal assemblages of the Viking Formation in central Alberta, which is the most closely located stratigraphic equivalent of the Bow Island Formation (see previous chapter), place the formation above the occurrence of *Haplophragmoides gigas gigas* and below the *Miliammina manitobensis* Zone (Nauss, 1945, 1947; Bullock, 1950). Caldwell et al. (1978) also placed the Viking Sandstone between *Haplophragmoides gigas* Zone (the Joli Fou Shale) and *Miliammina manitobensis* Zone (shales above the Viking Sand and below the base of the Fish Scale Formation). In central Alberta Stritch and Schröder-Adams (1999) recovered faunal components of both *Haplophragmoides gigas* Zone and *Miliammina manitobensis* Zone from the Viking Formation. In the Willesden Green area, Joffre, and Garrington oil fields of south-central Alberta, and Eureka oil field in west-central Saskatchewan the Viking Formation is underlain by strata of the *Haplophragmoides gigas* Zone and overlain by sediments of the *Miliammina manitobensis* Zone with the position of the faunal boundary within the Viking Formation being somewhat uncertain (Boreen and Walker, 1991; Downing and Walker, 1988; Davies and Walker, 1993; Pozzobon and Walker, 1990; Stritch and Schröder-Adams, 1999). Shales overlying the Viking Formation in the

Caroline area, west-central Alberta, carry foraminiferal assemblages that belong to the *Verneuilina canadensis* Subzone of the *Miliammina manitobensis* Zone (Leckie and Reinson, 1993). In east-central Alberta shales of the Joli Fou Formation contain fauna of the *Haplophragmoides gigas* Zone (Mattison and Wall, 1993), while the *Miliammina manitobensis* Zone is recognized within the Lloydminster shale just above the Viking Formation (Tizzard and Lebrekmo, 1975).

In the Central Alberta Foothills the *Miliammina manitobensis* Zone has been recognized from the basal part of the Sunkay Member of the Blackstone Formation (Wall, 1967).

In southern Saskatchewan within the Skull Creek Member (Joli Fou equivalent) of the Ashville Formation Gulio (1967) recognized *Ammomarginulina asperata* and *Miliammina sproulei* subzones of the *Haplophragmoides gigas* Zone. Later North and Caldwell (1975) considered these subzones as their subzones IIa and IIb respectively within the zone II. In the Manitoba Escarpment the *Haplophragmoides gigas* Zone spans from the disconformable top of the Swan River Formation through the Skull Creek Member and subsequent Newcastle Member of the Ashville Formation with the lower *Ammomarginulina asperata* Subzone occupying the lowermost part of the Skull Creek Member (McNeil, 1984). The Skull Creek and Newcastle members are considered to be the Joli Fou and Viking equivalents respectively (McNeil, 1984).

In northeastern Alberta along the Athabaska River the *Haplophragmoides gigas* Zone is related to shales of the Joli Fou Formation (Wickenden, 1949; Bahan, 1951; Stelck et al., 1956).

In the Monkman area, northeastern British Columbia, the Boulder Creek Formation, non-marine equivalent of the Joli Fou and Viking formations (see previous chapter), is underlain by the Hulcross Formation that carries foraminifera from the *Haplophragmoides multiplum* Subzone of the *Gaudryina namushukensis* Zone. The Boulder Creek Formation is overlain by the Hasler Formation with the fauna of the *Trochammina depressa* Subzone of the

Haplophragmoides gigas Zone and contains multiple depositional hiatuses (Stelck and Leckie, 1990b). In the Peace River area, northeastern British Columbia, in the lower part of the Hasler Shale of the Fort St. John Group Koke and Stelck (1984, 1985) described the *Ammobaculites wenonahae* Subzone of the *Gaudryina nanushukensis* Zone from the lowermost sediments, overlain by the sediments that carry Joli Fou fauna of the *Haplophragmoides gigas* Zone. Stelck and Koke (1987) recognized the *Reophax tundraensis* Subzone of the *Haplophragmoides gigas* Zone within the “Viking” marker bed in the middle portion of the Hasler Shale, which they correlated in whole or in part with the Viking Formation and with the lower part of the Bow Island Formation in southern Alberta. The uppermost portion of the Hasler Shale, Goodrich Sandstone, and the basal portion of the Cruiser Shale below the Fish-Scale Marker Bed carry fauna of the *Miliammina manitobensis* Zone (Sutherland and Stelck, 1972; Caldwell et al., 1993).

The *Miliammina manitobensis* Zone was also described from northeastern British Columbia from the upper parts of the Hasler and the Buckinghorse formations (Stelck, 1975), lower part of the Sully Shale (Stelck and Hedinger, 1983), and in northeastern Alberta, Peace River town from the base of the Shaftesbury Formation (Nielsen, 1950; Stritch and Schröder-Adams, 1999). In northwestern Alberta, Goodfare, the upper part of the Paddy Member of the Peace River Formation and the lower part of the Shaftesbury Formation contain the foraminiferal assemblages of the *Verneuilina canadensis* Subzone of the *Miliammina manitobensis* Zone (Stelck and Leckie, 1990a).

In northern Montana the Bootlegger Member of the Blackleaf Formation (see fig. 3) contains fauna from the *Miliammina manitobensis* Zone, while the stratigraphic position of the Taft Hill Member is not well defined and its faunas are locally assigned to the *Gaudryina nanushukensis*, *Haplophragmoides gigas*, or *Miliammina manitobensis* zones (Lang and McGugan, 1988). In Wyoming within the uppermost part of the Thermopolis Shale (equivalent of the Joli Fou Formation) below the Muddy Sandstone (equivalent of the Bow Island Formation) Eicher (1960) determined *Verneulinoides kansasensis* and

Ammobaculites euides biofacies that correspond to the *Haplophragmoides gigas* Zone. Foraminiferal assemblages from the Shell Creek Shale above the Muddy Sandstone and below the Mowry Shale reported by Eicher and the *Miliammina manitobensis* Zone of the northeastern British Columbia have numerous features (Stelck, 1975).

Radiometric dating of the bentonite within the Viking Formation to the northeast of the study area showed that the age of the Viking Formation is believed to be about 100 m.y. (Tizzard and Lebrekmo, 1975).

Bow Island Subdivision and Definition of the Correlation Surfaces in Well-logs

The study covers the stratigraphic interval from the top of the Upper Mannville Group to the base of the Fish Scales Formation, which consists of Bow Island and Westgate formations.

As suggested by Glaiser (1959) the name "Bow Island Formation" is applied to a succession of interbedded sandstones and mudstones lying between non-marine to marginal-marine sediments of the Upper Mannville Group and the top of the first sandstone below the Fish Scale Zone. In the study area the Bow Island Formation can be subdivided into three distinct lithostratigraphic units including the Lower Bow Island, the Middle Bow Island, and the Upper Bow Island (Cox, 1993; Reinson et al., 1994). The Westgate Formation occupies the shaly interval between the top of the Bow Island Formation and the base of the Fish Scale Formation (Bloch et al., 1993, 1999). Four wireline logs have been chosen within the study area to show typical Bow Island and Westgate successions for the northern, southern, western and eastern parts of the study area and to define the major correlative surfaces (Fig. 5). The base of the Fish Scales Formation, an easily recognizable surface within the study area, was chosen as a datum.

The Lower Bow Island directly overlies sediments of the Upper Mannville Group. It consists of several stacked funnel-shaped gamma-ray signatures, more distinctive in the southwestern part of the study area. Although sediments of the Lower Bow Island have not been observed within cores of this study, this type of a petrophysical profile often reflects coarsening-upward mudstone and sandstone sequences within the shelf-shoreface environments (Hein et al., 1986; Reinson et al., 1988; Cox, 1993; Reinson et al., 1994; Burton and Walker, 1999). The lower boundary of this unit represents the lower boundary of the Bow Island Formation and is characterized by the beginning

Figure 5. Typical well patterns of subdivisions of the Bow Island Formation within the study area. The base of the Fish Scales Formation used as a datum. (UMG - Upper Mannville Group; LBI - the Lower Bow Island; MBI - the Middle Bow Island; UBI - the Upper Bow Island; W - the Westgate Formation; FScF - the Fish Scales Formation). GR - gamma-ray well-log, AC - sonic well-log, ILD - resistivity well-log.

of coarsening-upward sequences, higher gamma-ray values, and lower resistivity values in comparison with more sandy sediments of the Upper Mannville Group. In southwestern Alberta this boundary is difficult to define due to the absence of the Joli Fou shale, which forms a distinctive log marker above the sediments of the Upper Mannville Group in deeper parts of the basin in eastward and northward directions. In the northwestern part of the study area more sandprone coarsening-upward sequences lose the distinct funnel-shaped gamma-ray profile and towards the Rocky Mountain foothills the Lower Bow Island grades vertically and laterally into the Upper Mannville Group to form the Blairmore Group in the foothills (Glass, 1990; Leckie and Reinson, 1993). The occasional development of the Basal Colorado Sandstone between the Bow Island Formation and the Upper Mannville Group also causes difficulties in placing the lower boundary of the Bow Island Formation. The upper boundary of the Lower Bow Island is picked on top of the last coarsening-upward sequence. It is an easily recognizable boundary except in those areas where coarsening-upward sequences are poorly developed. In this situation the boundary was picked at the base of the highly radioactive non-marine deposits of the Middle Bow Island.

The Middle Bow Island is characterized by high radioactive mudstone and sandstone deposits. According to core data this coastal-plain unit is predominantly composed of paleosols and can be easily recognized within the study area due to its low resistivity values and characteristic nervous gamma-ray curve with peaks of very high reading. The boundary between the Lower and Middle Bow Island units has been described above. Both the Lower Bow Island coarsening-upward sequences and the Middle Bow Island coastal-plain deposits become sandier towards the northwest, and cannot be differentiated anymore. The upper boundary is defined by an increase of gamma-ray and decrease of resistivity values, and often by the beginning of the coarsening upward sequence (at the base) of the Upper Bow Island.

The Upper Bow Island consists of interbedded marginal-marine mudstones and sandstones. Upward increase in the sand component is reflected

in rapid changes of gamma-ray and resistivity values. Occasional appearance of blocky gamma-ray log characters reflects channel sediments. The upper boundary of the Upper Bow Island coincides with the upper boundary of the Bow Island Formation. It is characterized by a sudden increase of gamma-ray and decrease of resistivity values of the overlying shales of the Westgate Formation. Both, cores and well-logs show appearance of relatively thin sandstone or conglomeratic beds within the shales overlying the Bow Island Formation. Core data shows the distinct difference between often well bioturbated Bow Island sediments and poorly bioturbated black shales at the base of the Westgate Formation. In these situations placement of the upper boundary on top of the first sandstone below the Fish Scale Zone (see the beginning of this chapter) could not be used and the boundary is defined as the first appearance of the clean shale above the sandy sediments of the Bow Island Formation. Resistivity curves can be very useful in such problematic situations.

The Westgate Formation typically comprises finely interbedded mudstone and siltstone laminae and is characterized on well-logs by relatively uniform high gamma-ray and low resistivity responses. The boundary between Bow Island and Westgate formations has been described above. The boundary between Westgate and Fish Scales formations, commonly known as the Base of Fish Scales, is a relatively easy pick and is expressed in a sharp increase of gamma-ray and resistivity responses. Such increase of values can be explained by the high content of radioactive fish remains and other bioclastic material within the sediments of the Fish Scales Formation. Towards the foothills the shales of the Westgate Formation become thinner and sandier and at the most westerly study area the Fish Scales Formation directly overlies Bow Island sediments.

Stratigraphic Cross-Sections

Two cross-sections oriented from north-west to south-east (strike orientation) and from south-west to north-east (dip orientation) have been

chosen to show the geometry of the Westgate Formation and subdivisions within the Bow Island Formation (figs. 6, 7). Usually gamma-ray and resistivity logs, and in few cases sonic logs, were used for correlations. The readily recognizable base of the Fish Scales Formation has been chosen as a datum.

The northwest - southeast stratigraphic cross-section (fig. 6) runs from 16-2-15-26W4 to 14-26-6-19W4. The Upper Mannville Group shows a variety of gamma-ray signatures ranging from nervous at 16-2-15-26W4 to blocky at 6-34-10-22W4, reflecting different depositional environments within this unit. According to the gamma-ray logs sediments of the Upper Mannville Group usually are more sandprone than the overlying sediments of the Lower Bow Island. The contact between the Upper Mannville and the Lower Bow Island is fairly clear throughout the cross-section. The thickness of the Lower Bow Island changes from 112.5 m in the southeast and central part of the cross-section to 83 m in the northwest. Stacked funnel-shaped gamma-ray signatures of the Lower Bow Island are very clear in the southeast (14-26-6-19W4). Towards the northwest its coarsening-upward sequences become sandier and start to lose their characteristic pattern until they become indistinguishable from the Middle Bow Island. While the thickness of the Lower Bow Island decreases, the Middle Bow Island becomes thicker from 15.75 m to 54 m. Such changes of well-log signatures and thickness can reflect facies transition from non-marine flood-plain deposits of the Middle Bow Island into time-equivalent shoreface deposits of the Lower Bow Island (Reinson et al., 1994).

The Upper Bow Island shows a noticeable decrease in thickness in northwest direction from 22.5 m to about 6 m. Various gamma-ray signatures such as stacked funnel-shaped, blocky or irregular suggest lithologies of irregular interbedded sandstones and mudstones with an overall tendency of coarsening upward. In all wells the upper boundary of the Upper Bow Island is marked by a negative pick on the gamma-ray logs which reflects transgressive lag deposits as also seen in cores. The Westgate Formation is about 11 m thick and insignificantly changes its thickness only at the northwestern end of the

Figure 6. Regional northwest - southeast cross-section. The base of the Fish Scales Formation served as a datum.
 GR - gamma-ray well-log (API), AC - sonic well-log ($\mu\text{sec/m}$), ILD - resistivity well-log (Ohm).

cross-section. Westgate shaly sediments are generally coarsening upwards and become sandier towards the northwest.

The southwest - northeast stratigraphic cross-section stretches from 6-16-6-22W4 to 17-1-10-19W4 (fig. 7). The Upper Mannville Group has well-log characteristics similar to those described in the northwest-southeast stratigraphic cross-section. On the gamma-ray profile stacked funnel-shaped signatures with occasional appearance of a blocky signature mainly characterize the Lower Bow Island. Blocky signature might represent the channelized deposition such as tidal-channel fill (Reinson et al., 1988). Well-logs indicate that sediments are more sandprone in the southwest with increasing of the shale dominance towards the northeast. The thickness of the Lower Bow Island slightly thickens towards the northeast from 112 m to 134.5 m. The coastal plain deposits of the Middle Bow Island are easily recognizable within the cross-section due to the characteristic nervous gamma-ray signature. Its lower boundary can be clearly defined on both gamma-ray and resistivity well-logs. This lithostratigraphic unit also thins from 31 m to 20 m in northeastern direction. The thickness of about 17 m of the Upper Bow Island remains to be consistent and thins only at the northeast end of the cross-section (14-22-9-19W4 and 17-1-10-19W4). The gamma-ray profile shows various signatures within the unit. Well 6-16-6-22W4 contains the only core in the south-central part of the study area (Blood gas field) that penetrates through the entire Upper Bow Island unit. The blocky gamma-ray log character reflects channelized deposition, which is typical for the Upper Bow Island in this area. The contact between Bow Island and Westgate formations is sharp within the entire cross-section. Most dramatic thickness changes can be observed within the Westgate Formation, which pinches out towards the southwest, decreasing its thickness from 21.5 m to 2 m. Cross-sections show the increase of the sand component within the Westgate Formation and all subdivisions of the Bow Island Formation northwestward and southwestward respectively, reflecting closer proximity to the sediment source.

Figure 7. Regional southwest - northeast cross-section. The base of the Fish Scales Formation served as a datum. GR - gamma-ray well-log (API), AC - sonic well-log ($\mu\text{sec/m}$), ILD - resistivity well-log (Ohm).

Structure and Isopach Maps

For a better overview of the present day structure and subsurface geometry of Bow Island and Westgate formations, structural maps of the top of Bow Island and Westgate formations and an isopach map of the Westgate Formation have been constructed within the study area.

The *structural map of the top of the Bow Island Formation* (fig. 8) indicates a structural high located in the southeastern corner of the map that represents the southwestern flank of the northwestward trending Sweetgrass (Bow Island) Arch (Leckie and Smith, 1992). Several ridges with northward and northwestward orientation radiate from this high and are believed to be part of the arch. In the western part of the map the formation surface is dipping towards west-southwest. Dipping direction gradually changes and in the eastern part of the study area becomes northwest oriented. The dip angle decreases towards the east moving away from the eastern limb of the Alberta syncline (see fig. 1).

Similar features can be seen on the *structural map of the Westgate Formation* (fig. 9). Northward and northwestward stretching ridges are slightly smoother. On both structural maps change of the dip orientation is caused by the influence of the Sweetgrass Arch.

The *isopach map of the Westgate Formation* (fig. 10) demonstrates thinning of the unit from 28 m in the northeast of the study area to 0 m in the west. Thinning of the formation generally happens in southwest direction and is believed to be perpendicular to the direction of the paleoshoreline at Westgate time. The northeastern corner of the map shows a complicated geometry of the unit. As it was mentioned before there is a significant variation in well control within the study area. Therefore the northeastern part of the map with a high density of well-logs per Township might reflect a more detailed and realistic picture of the Westgate geometry in comparison with areas of scarce petrophysical data such as southern, central, and western parts. Also the occasional appearance of a blocky massive sandstone at the top of the Bow

Figure 8. Structural map of the Bow Island Formation. Structural depth from mean sea-level (MSL) in meters.

Figure 9. Structural map of the Westgate Formation. Structural depth from mean sea-level (MSL) in meters.

Figure 10. Isopach map of the Westgate Formation. Thickness in meters.

Island Formation in this area (13-21W4 and 13-20W4) causes a sudden decrease of Westgate thickness probably due to low sandstone compaction (fig. 11). These sandstone bodies have a linear geometry with northeastward orientation, and might represent a channelized deposition. Bow Island has never been cored within this area, therefore it is difficult to determine their nature. Anomalous thinning of the Westgate Formation in 6-22W4 is oriented northward and might be a result of low compaction of Bow Island sediments. Local thinning of the interval in 9-20W4, 11-21W4, 12-25W4, and 12-26W4 show an elongated linear geometry of southeastward orientation. In general thickness of the Westgate Formation depends on the topographic surface of the top of the Bow Island Formation, the nature of the Westgate transgression, and the nature of the lowstand event at the time of Fish Scales Formation (Leckie et al., 2000).

Figure 11. Anomalies in the thickness of the Westgate Formation . The base of the Fish Scales Formation used as a datum. (UBI - the Upper Bow Island; W - the Westgate Formation; FScF - the Fish Scales Formation). GR - gamma-ray well-log (API), AC - sonic well-log ($\mu\text{sec/m}$), ILD - resistivity well-log (Ohm).

Interpretation of the Facies Associations

In order to understand the depositional history of the Bow Island Formation eight cores have been examined for their lithological, geochemical and micropaleontological contents. Each core was first described on a bed-by-bed basis. Combination of sedimentological, micropaleontological and geochemical data allowed then grouping of separate beds into facies and later into the facies associations. In this chapter facies associations within each core will be described and discussed in terms of the depositional environment. Detailed description of facies for each core can be found in Appendix 1.

6-32-13-27W4

This core contains twelve different facies that represent three facies associations: the coastal-plain facies association (the Middle Bow Island), the lagoonal-estuarine facies association (the Upper Bow Island), and the offshore-lower shoreface facies association (the Westgate and the Fish Scales formations) (fig. 12).

The coastal-plain facies association is represented by massive gray to green pedified muddy siltstones of Facies 1, brownish gray to gray pedified silty mudstones of Facies 2 and muddy Facies 3. Numerous features suggest that sediments of facies 1 and 2 represent development of paleosols within the floodplain. Gray and greenish gray coloration of siltstones and mudstones (Facies 1) together with vertical root-traces, infilled with mud can characterize poorly drained and poorly aerated soils with reducing conditions (Leckie and Foscolos, 1986; Wright, 1989). Brownish color of Facies 2 possibly is a result of oxidation of ferrous iron minerals such as pyrite during times of exposure. Color alternation indicates fluctuations of the water table position. Very fine- and medium-grained sharp-based sandstone beds can represent occasional channel deposition on the river floodplain. Slickenslide surfaces within Facies 2 have a pedogenic nature and were formed as a result of either gravitation

Figure 12. Core 6-32-13-27W4.

Legend

Fish remains or scales
Shell debris layer
Shell fragment
Bioturbation	slight moderate intensive
Coal fragment
Roots
Fine parallel lamination
Parallel lamination
Low angled parallel lamination (hummocky)
Normal graded fine lamination
Normal graded bedding
Ripples	symmetrical asymmetrical
High angle cross bedding
Lenticular bedding
Double mud drapes
Shrinkage cracks
Syneresis cracks

Lithology

Bentonite
Conglomerate
Sand
Siltstone
Shale
Interbedding with shale
Pyrite
Siderite	Sid
Mud clast
Pebbles

Trace Fossils

<i>Terebellina</i>
<i>Skolithos</i>
<i>Zoophycos</i>
<i>Teichichnus</i>
<i>Planolites</i>
<i>Chondrites</i>
<i>Thalassinoides</i>
Escape structure
<i>Siphonites</i>
<i>Ophiomorpha</i>
<i>Arenicolites</i>
<i>Diplocraterion</i>
<i>Cylindrichnus</i>

Figure 13. Legend

compaction (Leckie and Foscolos, 1986) or due to repeated swelling and shrinkage of the clays during dry and wet periods (Cox, 1993). Retalack (1988) named soils containing pedogenic slickensides *Vertisols*. Absence of foraminifera supports the terrigenous nature of these deposits.

Deposition of interbedded silty mudstone and coal of the Facies 3 represent a flooding event of the coastal plain. Coal might be formed in swampy or marshy environment of a coastal plain where organic material was fast buried before oxidation could take place. Another possible environment for the deposition of Facies 3 is a low-energy central part of the protected estuary or lagoon where the organic material can be brought by river from the river floodplain. Absence of bioturbation indicates stressed benthic conditions. Possibly Facies 3 represents the transition between the coastal-plain facies association and the lagoonal-estuarine facies association.

The base of the lagoonal-estuarine facies association is represented by Facies 4. Deposition of sharp-based parallel- to high angle cross-laminated nonbioturbated fine sandstone took place within a high-energy environment with a possible marine influence (presence of a Radiolarian test).

Fine-grained sandstone beds with dark gray silty mudstone wavy laminae of Facies 5 indicate a variable energy regime within the environment. The syneresis cracks that were observed in this facies were formed through the sediment dewatering processes that are common within the environments of unstable salinity. Presence of bioturbation indicates the reduction of the stress for benthic organisms and possibly an increase of the marine influence, although conditions are still inhospitable for foraminifera. Such conditions can be observed within an estuarine environment.

Medium-grained sharp-based sandstones of Facies 7 contain characteristic features of strong current action within a high energy environment, such as predominance of high-angle cross-bedding, presence of mud rip-up clasts and chert pebbles, and dominance of vertical burrows (Reinson et al., 1988; Leckie, 1986). Preservation of rip-up clasts indicates a short distance of sediment transportation by currents from the nearby low-

energy environments. Mudstone and siltstone laminae represent the low energy periods during deposition. Absence of foraminifera can indicate stressed benthic environment caused by high sedimentation rate, high-energy regime and/or salinity fluctuations. In the core Facies 7 is located between estuarine sediments of Facies 6 (see interpretation below). It leads to a conclusion that the deposition of Facies 7 most likely took place within the tidally influenced environment and possibly represents a migration of the small bed forms of the tidal channel within the estuary (sandstone deposition) with occasional pauses in migration (deposition of mudstone laminae).

Intensively bioturbated interbedded fine-grained sandstone, siltstone and mudstone beds and laminae of Facies 6 were deposited within the environment with very variable energy conditions. Intensive bioturbation presented by low diverse trace-fossil assemblage dominated by *Terebellina*, *Planolites*, *Teichichnus* with overall reduced size of the biogenic structures is characteristic of stressful environments with reduction and/or fluctuation in water salinity (MacEachern and Pemberton, 1994; Zaitlin et al., 1995; MacEachern et al., 1999). A low abundant and low diverse foraminiferal assemblage was recovered within Facies 6, also reflecting marine influence within a stressed benthic environment. Medium-grained sandstone beds with occasional presence of mud rip-up clasts have similar characteristics with Facies 7 (see above) and can represent small channel deposits. Such conditions can be observed within estuarine environments.

Facies 8 consists of the same lithology as Facies 6, but in contrast shows the significant reduction in bioturbation intensity. Deposition of Facies 8 took place in a low energy environment (mudstone deposition) with subordinate storm events (deposition of sharp-based, well-sorted, parallel laminated sandstone). Low intensity and diversity of trace fossils dominated by *Planolites* and *Teichichnus* together with a poor foraminiferal assemblage indicate stressed benthic conditions such as oxygen deficiency or salinity anomalies. Facies 8, closely associated with Facies 6, represents deposits of the central part

of an estuarine during periods of reduced salinity, probably caused by river discharge.

Facies 9 possibly represents a more sandy and more bioturbated form of Facies 8 and also has similarities with Facies 6. Trace fossils are abundant but low in diversity showing stressed bottom conditions with reduction and/or fluctuation in water salinity. The poor foraminiferal assemblage indicates environmental stress. Increase of bioturbation intensity and diversity in comparison with Facies 8, presence of syneresis cracks and double mud drapes together with sedimentary structures such as parallel to lenticular bedding, parallel and rarely ripple cross-lamination, soft sediment deformation (load structures) suggest a tidally influenced brackish water environment with a variable energy regime and more stable salinity. Such conditions can be observed near the estuarine mouth.

Poor sediment sorting in Facies 10, trough cross-bedding and mud rip-up clasts are indicators of traction currents and short sediment transportation (Reinson et al., 1988; Leckie, 1986). Absence of bioturbation and foraminifera shows stressed benthic conditions, probably due to the high rate of sediment deposition and high energy regime under tidal influence. Similar facies have been interpreted as tidal-channel facies within an estuary (Reinson et al., 1988), and as deposits of offshore tidal currents (Leckie, 1986). Based on association with estuarine facies 3 – 9 in this core Facies 10 supports the interpretation by Reinson et al. (1988).

The offshore-lower shoreface facies association is represented by Facies 11–13 reflecting open marine environments. Deposition of pebbly sandstone of Facies 11 represents thin transgressive lag deposits developed during the rise of the Mowry Sea. Similar lag deposits were described from the Viking Formation in Central Alberta (Hein et al., 1986; Leckie, 1986; Reinson et al., 1983, 1988; Downing and Walker, 1988; Boreen and Walker, 1991) and the Bow Island Formation of Southern Alberta (Cox, 1993).

Facies 12 represents sediments of the Westgate Formation. Laminated mudstone and sharp-based siltstone/very fine-grained sandstone indicate quiet

environmental conditions with evidence of current action (asymmetrical ripple cross-stratification) and distal or low-intensity storm events (parallel and graded lamination). The low diversity and low abundance of foraminifera together with no to slight bioturbation indicates oxygen deficiency or other factors of stressed environment in this part of the Mowry Sea. Relative abundance and diversity of foraminifera at the lower part of Facies 12 can be explained by increase of nutrients washed out by the rising sea from previously terrestrial environments. Amounts of *Inoceramus* prisms, diatoms, and algal cysts are increasing in comparison with previously described facies indicating establishment of marine conditions. Deposition of Facies 12 took place within a transgressive offshore-lower shoreface environment. This most western core was possibly close to fresh water input resulting in water column stratification and subsequent bottom oxygen depletion.

Fine-grained sediments of Facies 13 represent deposits of the Fish Scales Formation and have numerous sedimentological characteristics of the Westgate sediments. Based on lithology and sedimentary structures deposition took place in an overall quiet environment (see interpretation of the Westgate sediments), although the increase of the sand component could be related to slight shallowing of the sea. Absence of bioturbation and foraminifera probably reflect oxygen depletion within the depositional environments, which has been also recorded by Schröder-Adams et al. (1996) and Leckie et al. (1992).

Geochemistry. Rock-Eval pyrolysis of paleosols (facies 1 and 2) shows extremely low values of TOC (0.05 - 0.41 wt%) and HI (0 mgHC/gTOC – 57 mgHC/gTOC) indicating that almost no organic material was preserved due to the high oxidation and/or bacterial activity. Extremely high values of TOC (7.8 wt%) and HI (230 mgHC/gTOC) in Facies 3 together with abundant coal laminae demonstrate an environment with high potential to preserve the organic material.

Samples from the lagoon-estuarine facies association (facies 4 - 10) show variations in TOC values between 0.04 wt% and 1.6 wt% and HI values between 59 mgHC/gTOC and 166 mgHC/gTOC, with lowest values

corresponding to the sandstone facies. Values are higher than those described from the coastal plain association and indicate various depositional complexes within the lagoon/estuarine environment.

TOC and HI data from the offshore-lower shoreface facies association (facies 12 and 13) in general show higher volumes than recorded from the lagoon – estuarine facies association. Reduction in numbers of benthic organisms corresponds with increased preservation of organic matter. Particularly high TOC and HI values in Facies 13 (up to 3.15 wt% and 395 mgHC/gTOC respectively) are believed to be a result of the oxygen depletion.

6-15-9-24W4

Six different facies of the core 6-15-9-24W4 were grouped into the coastal-plain facies association of the Middle Bow Island and the lagoonal-estuarine facies association of the Upper Bow Island (fig. 14).

The coastal-plain facies association of the Middle Bow Island is represented by massive gray to green pedified muddy siltstone of Facies 1 and dark gray pedified silty mudstone of the Facies 2. Lithological and sedimentological characteristics of these sediments are typical for paleosols, developing within wet conditions of the floodplain with unstable position of the water table (see coastal-plain facies association in core 6-32-13-27W4). The original depositional environment of the sediments is difficult to determine due to the lack of visible primary sedimentary structures. Cracks within Facies 2 are interpreted as shrinkage cracks that can be an indicator of desiccation of exposed soils. Brecciated mudclasts can be formed during flooding periods of the floodplain. Absence of foraminifera also supports the terrigenous nature of these deposits.

The lagoonal-estuarine facies association is represented by four facies that were deposited within variable depositional environments. Deposition of nonbioturbated to slightly bioturbated interlaminated mudstone and siltstone of Facies 3 took place within a low energy environment with periods of increased

Agglutinated	.				
Gaudryna canadensis	.				
Miliammina awunensis					
Miliammina manitobensis	.				
Vermeulinoides perplexus	.				
Total amount of foraminifera	3	1	5		
pyrite concretions	.	.	.	.	.
petrified plant material	.	.	.	.	.
amber	.	.	.	.	.
fish remains	.	.	.	.	.
algal cysts	.	.	.	.	.
shell fragments	.	.	.	.	.

trace fossils
congl.
sand

energy regime with predominance of unidirectional currents (sandstone deposition). The trace-fossil suite displays strong evidence of stressful benthic conditions. Cracks within the mudstone and sandstone beds were interpreted as desiccation cracks formed during aerial exposure of the sediments. Basal mudstone breccia represents a revinement surface formed during flooding of the coastal plain. No foraminifera have been recorded within this facies. The sandstone content increases upward and Facies 3 gradually passes into more sandy Facies 4 indicating an increase in energy.

Facies 4 consists of interbedded fine-grained sandstone and mudstone beds with sedimentary structures varying from wavy subparallel cross-bedding to occasional high-angle cross-bedding, demonstrating energy fluctuations. Presence of syneresis cracks, mud rip-up clasts and double mud drapes are common within the subtidal environments of unstable salinity. Absence of bioturbation indicates high stressed conditions, that can be caused by fluctuations in salinity or energy, or variations in substrate consistency. No foraminifera have been recorded within Facies 4. Characteristics of this unit can be observed in tidal channel sediments within brackish water environment. However, no sharp erosional base was observed. Gradual transition from the low energy environment of Facies 3 into the higher energy environment of Facies 4 together with upward energy reduction within Facies 4 can represent a migration of a sand body such as a sand bar within the estuarine.

Well bioturbated muddy sediments at the base of Facies 5 represent deposition within a quiet well oxygenated environment that allows benthic organisms to rework the substrate. The sharp base of this facies and presence of coarse chert grains indicates a flooding event within the estuarine environment. The poor foraminiferal assemblage shows marine influence, although the few foraminiferal specimens might be allochthonous and be brought into the environment by tidal currents, or during storms. Interbedded mudstone and sharp-based fine-grained sandstone indicate quiet, protected environmental conditions with signs of both current and wave action (combined-flow ripples). Graded laminae noticed within sandstone beds usually indicate waning flows

typical for the storm-current deposits (Tucker, 1995). Occurrence of multiple-graded bedding is usually the result of pulses in current. Deposition of the sandstone beds took place during the increase of energy regime that may correspond with fair-weather or weak storm events. Sporadic distribution of the slight to moderate bioturbation indicates a stress benthic environment caused possibly by salinity fluctuations within an estuarine environment. Only few foraminiferal specimens recovered from Facies 5 confirm stressed benthic conditions for marine fauna. Deposition of Facies 5 took place within a fair-weather lagoon or the estuarine central basin. Reinson et al. (1988) interpreted similar sediments as an estuary bay-fill facies that consists of alternated mudstones and sandstones with trace-fossil assemblages indicating a stressed benthic environment. Characteristics of the estuarine central basin as described by Zaitlin et al. (1995) also resembles Facies 5.

Fine- to medium-grained sandstones of Facies 6 demonstrate a variety of sedimentary structures from low angle cross-bedding to trough cross-bedding and parallel bedding. Sedimentary structures together with the presence of mudstone laminae indicate large energy fluctuations with an overall increase in energy towards the top. Low levels of bioturbation and absence of foraminifera suggest a stressed benthic environment caused either by salinity fluctuations or more likely high-energy regime with high rates of sediment deposition. Mud rip-up clasts, petrified plant material and double mud drapes observed throughout the interval are characteristic of tidally influenced environments. Facies 6 is interpreted as tidal channel fill within an estuarine environment.

Geochemistry. Samples from the coastal-plain facies association (facies 1 and 2) show extremely low values of TOC (0.01 wt%– 0.16 wt%) and HI (0 mgHC/gTOC – 8 mgHC/gTOC) that indicates a very low preservation potential of organic matter due to high oxidation and/or bacterial activity. Absence of foraminifera also supports the terrigenous nature of these deposits.

Increase of the TOC and HI values is observed within the lagoonal-estuarine facies association. In facies 3 and 4 TOC and HI values vary from 1.68 wt% to 1.13 wt% and 82 mgHC/gTOC to 36 mgHC/gTOC respectively.

with higher concentration of organic matter within Facies 3. Facies 5 shows an overall upward increase of values (0.93 wt% - 2.6 wt% and 65 mgHC/gTOC – 181 mgHC/gTOC). In Facies 6 TOC and HI values vary (0.08 wt%- 1.26 wt% and 27 mgHC/gTOC – 181 mgHC/gTOC) with lowest values at the top of the facies where sediments become more sandy.

11-33-11-26W4

Two facies associations were defined within the core 11-33-11-26W4 (fig. 15): the shoreface facies association, represented by facies 1 to 5 (the Upper Bow Island), and the offshore-lower shoreface facies associations, represented by Facies 6 to Facies 8 (the Westgate and the Fish Scales formations).

The shoreface facies association. Intensively bioturbated silty mudstones and muddy siltstones with very fine- to fine-grained sandstone beds of Facies 1a and Facies 1b were deposited within a low to moderate energy regime. Uniform distribution of the diverse and abundant *Cruziana* ichnofacies together with a relatively diverse foraminiferal assemblage supports a healthy marine origin of these facies. Slow continuous sediment deposition under the moderate energy allowed benthic communities to thoroughly rework the substrate (MacEachern and Pemberton, 1992; Pemberton and MacEachern, 1997). Sandstone beds of these facies with sharp erosional bases, low-angle, wavy cross-lamination represent distal storm deposition with short-term changes in flow conditions (presence of reactivation surfaces). Deposition of Facies 1a took place within the weakly storm-influenced upper offshore to lower shoreface environment. Sandy Facies 1b was interpreted as the lower shoreface deposits with progressive shallowing. More distinct trace fossils may indicate environments with higher sedimentation rates (Bockelie and Howard, 1984). Similar deposits were described from the Viking Formation by Leckie (1986), Downing and Walker (1988), Boreen and Walker (1999), and MacEachern et al. (1992, 1998, 1999).

[illegible]

	13	17	9	-	21	30	15	10	16	13	8	3	1	4	2
<i>Miliammina</i> spp	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Reophax</i> spp	.	○	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Reophax cf. pepperensis</i>	.														
<i>Saccammina alexanderi</i>	○													.	
<i>Uvigerinammina manitobensis</i>	○														
<i>Ammobaculites fragmentarius</i>		.		.	.	.	.	.	.	.	.	.	.		
<i>Bathysiphon</i> spp.		.		.	.	.	.	.	.	.	.	.	.		
<i>Gaudryina</i> spp.		.	○	.	○	.	.	.	.	.	.	.	.	.	
<i>Gaudryina canadensis</i>	○	○	○	.	○	●	.	○	○	.	.	.	.	.	
<i>Miliammina inflata</i>	.	.		.	.	.	.	.	.	.	.	.	.		
<i>Miliammina ischnia</i>	○	○		.	.	.	.	.	.	.	.	.	.	.	
<i>Verneuilinoides</i> spp.	.	.	.	.	.	○	.	.	.	.	.	.	.	.	
<i>Verneuilinoides cf. perplexus</i>	.	.	.	.	○	.	.	.	.	.	.	.	.	.	
<i>Miliammina manitobensis</i>		.	.	.	.	.	.	.	.	.	.	.	.	.	○
<i>Trochammina</i> spp.		.	.	.	.	.	.	.	.	.	.	.	.	.	
<i>Gaudryina irenensis</i>			○	.	○			○	○	.	.	.	.	.	
<i>Gaudryina tailleuri</i>			.	.	.			.	.						
<i>Verneulina canadensis</i>				.	○										
<i>Verneuilinoides borealis</i>			.	.	.	○		.	.	.	.	.	.	.	
<i>Miliammina awunensis</i>			.	.	.	.		.	.						
<i>Reophax troyeri</i>				.	○							.	.	.	
<i>Textularia topogrukensis</i>				.	.	.							.	.	
<i>Reophax sikanniensis</i>						.									
<i>Pseudobolivina varians</i>				.	.			.	.						
<i>Trochammina rutherfordi</i>				.	.			.	.						
<i>Bathysiphon brosgel</i>								.	.						
<i>Ammobaculites petilus</i>								.	.						
Total amount of foraminifera	13	17	9	-	21	30	15	10	16	13	8	3	1	4	2
petrified plant material		○			.	○	.	○	○		.	○			
shell fragment					○	.		○	○	.				○	
Inoceramus prisms										.	.	●			
fish remains										.	.	●	■	●	○

<i>Verneuilina canadensis</i>	<i>Verneuilinoides borealis</i>	<i>Miliammina avunensis</i>	<i>Reophax troyeri</i>	<i>Textularia topogorukensis</i>	<i>Reophax sikanniensis</i>	<i>Pseudobolivina variata</i>	<i>Trochammina rutherfordi</i>	<i>Bathysiphon brosgel</i>	<i>Ammobaculites petilus</i>	Total amount of foraminifera	petrified plant material	shell fragment	<i>Inoceramus</i> prisms	fish remains	pyrite concretions	diatoms	algal cysts
										2		○		○			
										9				●			
										1			■	■			
										3	○						
										3	○		●	○			•
										3			•	•	●	○	•
										8	•				○	•	•
										13		•	•	●	•	•	
	•							•	•	16	○		•	•	○	○	
	•									10		○		•	○	•	
										9		○					
										15	•						
	○	•								30	○	•					
○	•									21	•	○					
										6							
										17	○					○	
										13							

- present (for species)
- single
- few (2-5)
- some (6-10)
- common (11-20)
- abundant (21-50)
- nch (>50)

Facies 1a and 1b are separated by Facies 2 that consists of bioturbated sandstone and silty mudstone with pebbles at the base and a conglomeratic layer at the top. The trace-fossil assemblage probably represents mixed *Skolithos* - *Cruziana* ichnofacies. Foraminifera indicate a stressed benthic environment. Facies 2 indicates presence of high energy and is interpreted as transgressive lag deposits that were formed by reworking of lowstand deposits by the following transgression.

Increase of the sand component in Facies 3 and especially in Facies 5 with increase in thickness of storm sandstone beds characterize an increase in energy within the storm influenced depositional environments. Ichnofauna is represented by the diverse assemblage of relatively large trace-fossils which are characteristic of a fully marine environments. Slight dominance of *Terebellina* in Facies 3 and *Thalassinoides* and *Planolites* in Facies 5, reduced bioturbation intensity indicate some environmental stress that can be related to an increase in sedimentation rate and energy fluctuations. Deposition of facies 3 and 5 took place within the lower shoreface environment (probably its upper part) at or near fair-weather wave base.

Facies 4 consists of slightly bioturbated, interlaminated mudstone and silty very fine-grained sandstone reflecting a low energy environment with stressed bottom conditions such as an oxygen deficiency, high amount of suspended sediment in the water column or salinity fluctuations. Presence of pyrite concretions and pyritic sandstone laminae confirm oxygen depletion.

Facies within the Westgate and Fish Scales formations characterize the offshore-lower shoreface facies association. The thin conglomerate of Facies 6 represents a transgressive lag deposit developed during the rise of the Mowry Sea (see Facies 11 in core 6-32-13-27W4) and is common at the top of the Bow Island formation in contact with overlying Westgate shales.

Facies 7 represents sediments of the Westgate Formation. It contains similar sedimentological and lithological characteristics of the Westgate shales described in core 6-32-13-27W4 (Facies 12) and characterizes deposition within a lower offshore or shelf environment. Slight upward coarsening is seen

throughout the Westgate Formation and can represent basinward progradation of sediments. Foraminiferal and trace-fossil assemblages show a fairly small diversity and abundance with increasing amounts of *Inoceramus* prisms, diatoms, and algal cysts indicating stress within the marine environment. A short pulse of increased abundance and diversity in the lower part of Facies 7 can be caused by an increase of nutrients washed out by a rising sea.

Fine sediments of Facies 8 represent deposits of the Fish Scales Formation and resemble Westgate sediments. Deposition took place in an overall quiet environment (see interpretation of the Westgate sediments). Absence of bioturbation and lack of foraminifera probably reflect bottom oxygen deficiency.

Geochemistry. The shoreface facies association (facies 1 - 2) is characterized by relatively uniform TOC values (0.54 wt% - 1.11 wt%) with a slight increase within sandstones of facies 3 and 5 (1.20 wt% and 1.00 wt% respectively). HI values vary from 127 mgHC/gTOC to 80 mgHC/gTOC, with increasing values within muddy beds of the overall sandy facies 3 and 5 and at the base of Facies 1 (see fig. 15).

While TOC values from Facies 7 of the offshore-lower shoreface facies association do not differ from those of the shoreface facies association, HI data shows higher values (124 mgHC/gTOC –202 mgHC/gTOC). In Facies 8 both TOC and HI values are high (up to 4.56 wt % and 481 mgHC/gTOC respectively).

6-16-6-22W4

The core 6-16-6-22W4 (fig. 16) can be subdivided into two facies associations: the estuarine channel facies association (Facies 1 to 4 of the Upper Bow Island) and the offshore – lower shoreface facies association (Facies 5 to 8 of the Westgate and the Fish Scales formations).

The estuarine channel facies association. Presence of high-angle cross-bedded conglomeratic sandstone beds in current ripple cross-stratified sandy Facies 1 indicate strong current action. Rarely observed trace fossils of

Well	6-16-6-22W4
Logged	January 21, 1997
Core intervals	970-988.25 988.25-1005.5 m
Samples	25
# of cores	2
Core name	Gulf Mohawk Blood

Appl. Interval	Reophax spp. (?)	Uvigerinammina manitobensis	Ammobaculites spp.	Ammobaculites cf. tyrrelli	Ammobaculites cf. wenonahae	Bathysiphon spp.	Bathysiphon broggeri	Gaudryina spp.	Miliammina spp.	Miliammina manitobensis	Textularia spp. (?)	Hippocrepina spp.	Ammobaculites tyrrelli	Ammobaculites fragmentarius	Ammobaculoides whitneyi
970-988.25															
988.25-1005.5															

Figure 16. Core 6-16-6-22W4.

- present (for species)
- single
- few (2-5)
- ◐ some (8-10)
- common (11-20)
- abundant (21-50)
- ⬛ rich (>50)

Skolithos and *Ophiomorpha* and a very poor foraminiferal assemblage characterize a stressed benthic environment as the result of high sedimentation rates and/or freshening of the water during fluvial discharge.

Facies 1 is overlain by fining upward wavy interbedded mudstones and sandstones of Facies 2 that indicate a slight decrease in energy regime. Local presence of syneresis cracks in thin mud layers supports a possible fresh water influence. The trace-fossil assemblage within the sandstone contains escape structures of *Skolithos* and *Ophiomorpha* (rare), while ichnofauna of the mudstone laminae is represented by deposit feeding structures of *Planolites* and *Teichichnus*. Such distribution of biogenic structures is characteristic of stresses imposed by episodic deposition, variations of sedimentation rate and variable substrate consistency. An upward increase in frequency of double mud drapes together with improving foraminiferal and trace-fossil abundance and diversity reflect an increase of the tidal influence and therefore marine influence within the depositional environment.

Complexity of the sedimentary structures and lithological characteristics of the sandstone deposits of Facies 3 are characteristic of an environment with variable energy regime and tidal influence (presence of double mud drapes). Trace-fossil assemblages continue to reflect a stressed benthic environment supported by a single appearance of foraminifera.

Poorly sorted, clast-supported massive conglomerates of Facies 4 were deposited within an extremely high energy regime and can be found in a number of depositional environments such as fluvial, deltaic, tidal inlet and beach environments. This erosional-based unit was probably deposited within a channel. Absence of sedimentary structures make further interpretation difficult. No trace-fossils or foraminifera were found within Facies 4.

Facies succession within the estuarine channel facies association can characterize a shift from higher energy possible more fluvial influenced environment (Facies 1) to lower energy more tidally influenced environment (Facies 2) and back to a high energy environments of facies 3 and 4. Two possible scenarios can be discussed. In the first scenario facies succession

represents a transgressive estuarine deposits with proximal facies progressively passing into more distal ones. In this situation Facies 1 can represent bay-head delta deposits, overlain by central basin sediments of Facies 2, in close vicinity to the sediment source; the channelized deposits of Facies 3 cut into Facies 2 and are overlain by Facies 4, representing either a main tidal-channel entrance or barrier deposits. This model corresponds with segment 2 of a three-folded longitudinal subdivision proposed for incised-valleys (Dalrymple et al., 1992; Zaitlin et al., 1994; Zaitlin et al., 1995). In the other scenario estuarine facies are prograding basinward. In this case Facies 1 can correspond with a flood-tidal delta. Facies 2 and 3 can be still within the central basin, while the conglomerates of the Facies 4 would be interpreted as fluvial deposits. To determine the correct model mapping of different facies is required.

The offshore-lower shoreface facies association.

The thin well sorted conglomerate of Facies 5 is believed to represent a transgressive lag formed as the result of reworking of the coarse-grained deposits of Facies 4 during the rise of the Mowry Sea. Similar lags were described in cores 6-32-13-27W4 and 11-33-11-26W4 and are common at the top of the Bow Island Formation at the contact with overlying Westgate shales.

In this core the Westgate Formation is only 2 m thick and is represented by nonbioturbated to slightly bioturbated fissile black mudstone of Facies 6. Scarce foraminifera and trace-fossils indicate stressful benthic conditions.

Facies 7 represents the Fish Scales Formation and is characterized by abundant bioclastic material, which can be responsible for the increase in gamma-ray values. Rare trace-fossils and only two foraminiferal fragments, recovered from the uppermost sample, indicate stressful bottom conditions.

Laminated mudstone and sharp-based siltstones/very fine-grained sandstones of Facies 8 were deposited within overall quiet environmental conditions with evidence of current action (asymmetrical ripple cross-stratification) and distal or low-intensity storm events (parallel and graded lamination). Relatively abundant foraminiferal assemblages within the few samples and an upward increase of the bioturbation indicate reduced stress

within benthic communities. Water column stratification, causing dysoxic bottom conditions in the lower Fish Scales Formation (Facies 7) was further up within the formation disturbed by an increased energy regime resulting in Facies 8.

The Westgate (Facies 6) and the lower Fish Scales (Facies 7) formations represent an offshore depositional environment, while the upper Fish Scales Formation (Facies 8) represent the lower shoreface, indicating shallowing of the sea.

Geochemistry. TOC and HI values vary throughout the estuarine channel facies association. TOC values vary from 0.06 wt% and 0.04 wt% in coarse facies 3, 4 and 1 up to 2.28 wt% in muddy Facies 2. HI values vary from 12 mgHC/gTOC to 162 mgHC/gOC.

Within the offshore-lower shoreface facies association Facies 6 demonstrates TOC and HI values of 1.64 wt% to 1.48 wt% and 142 mgHC/gTOC – 120 mgHC/gTOC respectively. In Facies 8 TOC and HI values remain to be high and decrease only at the top.

11-17-10-21W4

A total of seven facies were described within the core 11-17-10-21W4 and were grouped into the lagoonal-estuarine facies association of the Upper Bow Island and the offshore facies association of the Westgate formations (fig. 17).

The lagoonal-estuarine facies association consists of three coarsening upward successions (facies 1 and 2, facies 1 and 3, facies 4 and 5) that are separated by flooding surfaces.

Change from homogenous sandy siltstone of Facies 1 to very fine- to fine-grained sandstone with rare wavy mudstone laminae of Facies 2 (first coarsening upward succession) or intensively bioturbated very fine- grained silty sandstone to moderately bioturbated fine-grained sandstone of Facies 3 (second coarsening upward succession) demonstrates an upward increase in

Agglutinated
Verniculioides spp.
Annolium spp.
Annobaculites spp.
Annobaculites fragmentarius
Annobaculites tyrelli
Gaudryna spp.
Gaudryna canadensis
Gaudryna irenensis
Gaudryna cf. nanushukensis
Millammina spp.
Millammina inflata
Millammina ischnia

21. trace fossils

[illegible]

<i>Ammonobaculites cf. fragmentarius</i>	
<i>Trochammina gatesensis</i>	
<i>Trochammina cf. umiatensis</i>	
<i>Reophax tundraensis</i>	
<i>Gravellina chamneyi</i>	
<i>Hyperammina spp.</i>	
<i>Psammimolopella subcirculatis</i>	
<i>Ammodiscus spp.</i>	
<i>Ammodiscus klowensis</i>	
<i>Trochammina rainwateri</i>	
Total amount of foraminifera	
petrified plant material	
<i>Inoceramus</i> prisms	
fish remains	
shell fragments	
algal cysts	
pyrite concretions	
amber	
diatoms	

- exist (for species)
- single
- few (2-5)
- some (6-10)
- common (11-20)
- abundant (21-50)
- ✱ nch (>50)

TOC
(mgHC/gTOC)

0 0.5 1 1.5 2 2.5 3 3.5

HI
(wt%)

0 40 80 120 160 200

energy regime. Reduced diversity of the trace-fossil assemblage in Facies 1 dominated by *Planolites*, *Terebellina*, and *Teichichnus* indicates an environmental stress that can be related to salinity and energy fluctuations and an increase of the sedimentation rate. High intensity of bioturbation accompanied with low diversity of species is typical for brackish water settings (Seilacher, 1967; Zaitlin et al., 1995). Occasional appearance of *Skolithos* escape structures within sandstone beds corresponds with deposition during the small-scale storm events. An increase of the sandstone content in facies 2 and 3 parallels changes in dominant ichnogenera from deposit feeding structures such as *Planolites* and *Teichichnus* to escape (dwelling) structures of *Skolithos*, *Arenicolites*, *Ophiomorpha* and *Diplocraterion* in response to increased episodes of rapid deposition. Facies 1, 2 and 3 show inhospitable conditions for the benthic foraminifera. In Facies 2 wavy mudstone laminae with sharp contacts may suggest tidal influence, although other characteristic evidences of tidal activity are absent. Combination of double mud drapes together with thin wavy mudstone laminae in Facies 3 can be considered as an unequivocal indication of a tidal action. Deposition of facies 1, 2 and 3 more likely took place within a restricted estuarine or lagoon environment with fluctuations of the energy regime and salinity. An increase of the sandstone content indicates a shift infacies towards the sediment source such as bay head delta of estuary mouth.

The third coarsening upward succession (facies 4 and 5) also shows energy fluctuations during an overall increase of the energy regime within the depositional environment. Combined flow ripples in Facies 4 indicate presence of both current and wave action. Hummocky cross-stratified (HCS) sandstone beds in Facies 5 have storm origin. Thin mudstone laminae and occasional double mud drapes can indicate a tidal activity within the depositional environment, although preservation of HCS usually is typical for the environments with a weak tidal activity (Walker and Plint, 1992). An upward increase of the energy regime reflects on the bioturbation intensity, which changes from moderate-intense (Facies 4) to nonexistent-slight (Facies 5).

Trace-fossil assemblages of Facies 4 have similar characteristics to those described from facies 2 and 3, and demonstrates a stressed benthic community. Episodic storm bed deposition rather than salinity fluctuations is responsible for absence of the bioturbation in most of the sandstone beds in Facies 5. Relatively abundant and diverse foraminifera occur in the lower part of Facies 4 and therefore indicate a strong marine influence within the depositional environment at that level.

Deposition of all three shallowing upward successions within the lagoonal-estuarine facies association probably took place during an overall transgression when more distal facies of an estuary overlies the proximal ones (retrograding parasequences). This conclusion is based mainly on the presence of the relatively diverse and abundant foraminiferal assemblage in a third coarsening upward succession and the character of the trace-fossil assemblage. During the transgression the rising sea exceeded the height of the barrier that separated the lagoon from the shoreface setting spreading marine waters and marine fauna into a previously restricted environmental setting.

The Westgate Formation is characterized by the offshore facies association. Facies 6 consists of fine parallel laminated mudstone with few widely spaced poorly sorted matrix-supported thin conglomerate horizons. This facies represents a transgressive lag deposit developed during the rise of the Mowry Sea. Foraminiferal assemblages collected from shaly interbeds are abundant and diverse indicating that phases of reworking were interrupted by times with normal marine conditions.

Facies 7 consists of sediments typical for the Westgate Formation. Laminated mudstone and sharp-based siltstone/very fine-grained sandstone indicate quiet environmental conditions with evidence of current action (asymmetrical ripple cross-stratification) and distal or low-intensity storm events (parallel and graded lamination). Such sediments are characteristic of offshore environments. Foraminiferal assemblages from the lower part of Facies 7 (samples 13 and 14) are the most abundant within the core and reflect maximum flooding. The assemblage of sample 14 consists of abundant very

small fine-grained foraminifera. This assemblage seems to form a transitional fauna as bottom conditions become inhospitable throughout Westgate deposition.

Geochemistry. TOC and HI values are quite variable within the lagoonal-estuarine facies association. A significant peak in both TOC and HI values was recorded in a sample from mudstone laminae of Facies 3 (4.15 wt% and 69 mgHC/gTOC respectively) and probably represent a fault in measurements.

In the offshore facies association TOC and HI values slightly decrease upwards in Facies 6 (from 2.21 wt% to 1.49 wt% and 135 mgHC/gTOC to 85 mgHC/gTOC respectively) and are very constant within Facies 7 (1.3 wt% and 86 mgHC/gTOC – 112 mgHC/gTOC).

11-28-9-21W4

A total of nine facies were described within the core 11-28-9-21W4 and grouped into the shoreface facies association and the tidal channel facies association of the Upper Bow Island and the offshore facies association of the Westgate and the Fish Scale formations (fig. 18).

The shoreface facies association is represented by facies 1 to 5. Low angle, wavy cross-lamination within the sharp-based sandstone beds of Facies 1 is interpreted as hummocky cross-stratification (HCS). Fining upward succession that was observed within few beds indicates an energy reduction at the end of an individual storm. Preservation of HCS usually is typical for the environments with a weak tidal activity below fair weather wave base (Walker and Plint, 1992). Absence of bioturbation within as hummocky cross-stratified sandstone beds was caused by high sedimentation rate during storm episodes. Dominance of *Skolithos* borrows and presence of *Ophiomorpha* and *Cylindrichmus* (escape structures) within moderately bioturbated interlaminating mudstone and siltstone intervals characterize an environment with overall high energy regime, although presence of deposit feeding

Agglutinated
Bathysiphon spp.
Hippocrepina spp.
Reophax spp.
Amnobaeculites spp.
Amnobaeculites fragmentatus
Amnobaeculites tyrrelli •
Amnobaeculoides whitneyi
Bathysiphon brosgel
Gaudryina spp.
Gaudryina canadensis
Gaudryina nanushukensis
Miliammina spp.

Figure 18. Core 11-28-9-21W4.

	Bathysiphon brosgel	.		
	Gaudryina spp.	.		
	Gaudryina canadensis	.		
	Gaudryina nanushukensis	.		
	Miliammina spp.	.		
	Miliammina awunensis	.		
	Miliammina ischnia	.		
	Miliammina manitobensis	.		
	Reophax (Scherchorella) minuta	.		
	Saccammima lathrami	.		
	Textularia topogorukensis	.		
	Textularia sp. A	.		
	Thuramininoides septagonalis	.		
	Verneuilinoides spp.	.		
	Verneuilinoides cf. fischeri	.		
	Miliammina cf. sproulei	.		
	Saccammima alexanderi	.		
	Ammomarginulina cragini	.		
	Gravellina chamneyi	.		
	Miliammina inflata	.		
	Pseudobolivina varians	.		
	Reophax sp. A	.		
	Textulariopsis minuta	.		
	Trochammima spp.	.		
	Trochammima rainwateri	.		
	Verneuilinoides borealis	.		
	Verneuilinoides perplexus	.		
	Haplophragminoides postis goodrichi	.		
	Total amount of foraminifera	.		
	Radiolaria	.		
	petrified plant material	.		
	shell fragment	.		
	fish remains	.		

<i>Millammina cf. sproulei</i>	
<i>Saccammina alexanderi</i>	
<i>Ammonomarginulina cragini</i>	
<i>Gravellina chameleyi</i>	
<i>Millammina inflata</i>	
<i>Pseudobolivina variana</i>	
<i>Reophax</i> sp. A	
<i>Textulariopsis minuta</i>	
<i>Trochammina</i> spp.	
<i>Trochammina rainwateri</i>	
<i>Verneuilinoides borealis</i>	
<i>Verneuilinoides perplexus</i>	
<i>Haplophragmoides postis goodrichi</i>	
Total amount of foraminifera	
Radularia	
petrified plant material	
shell fragment	
fish remains	
algal cysts	

- present (for species)
- single
- few (2-5)
- some (6-10)
- common (11-20)
- abundant (21-50)
- rich (>50)

structures such as *Thalassinoides* and *Asterosoma* (?) indicates reduced energy levels. Slight to moderate bioturbation in mudstone laminae is represented mainly by deposit feeders such as *Planolites* and *Chondrites* indicating periods of sedimentation between storm events. The abundant and diverse foraminiferal assemblage indicates a fully marine environment. Facies 1 is interpreted as a storm-dominated lower to middle shoreface setting.

The thin conglomerate of Facies 2 represents a transgressive lag deposit. Coarse material was deposited during a drop in sea level, and later reworked by a transgressive sea. Intense and diverse bioturbation and a diverse foraminiferal assemblage within the interbedded mudstone, siltstone and very fine-grained sandstone of Facies 4 lead to an assumption of a fully marine origin of the sediments. Sharp-based wavy to sub-parallel laminated thin sandstone and siltstone beds with occasional presence of normal gradation record preserved storm beds below fairweather wave base and above storm-weather wave base. An upward increasing sand component together with introduction of *Skolithos* escape borrows reflect an energy increase. Deposition of Facies 4 took place within the prograding upper offshore to lower shoreface.

The fine-grained character of the sediments with presence of floating pebbles in facies 3 and 5 indicates presence of both high and low energy regimes. Also the dominance of *Skolithos* and *Arenicolites* in Facies 5 represent an escape of buried or sediment-entrained organisms during periods of high sedimentation rate or high energy regime. The nature of floating pebbles within mudstones can be interpreted in many different ways. For example, it was described as deposition during high-energy events such as storms or high fluvial discharge into an estuarine embayment (Cox, 1993), as the evidence of subaqueous debris flows (Leckie, 1986) or as deposits of sediment-gravity flows that later have been reworked by organisms and homogenized with surrounding mud (Hein et al., 1986). Based on a trace-fossil assemblage MacEachern et al. (1998, 1999) determined that deposition of similar sediments took place within the upper offshore setting. Absence of micropaleontological data within facies 3 and 5, as well as lack of preserved sedimentary structures

due to the intensive bioturbation make a conclusion about the depositional environment difficult. It is believed that pebbles were derived to the shoreface from rivers that cut through the infilled estuary during the lowering of the relative sea-level. Later they were transported by tidal or storm currents into more distal (offshore?) settings dominated by the mudstones. Intense bioturbation homogenized pebbles and mudstones.

Facies 6 and 7 represent an overall fining upwards succession of the tidal channel facies association. Domination of trough cross-bedding within the medium-grained sandstones of Facies 6 indicates an overall high-energy environment with periods of relatively quiet conditions (deposition of interlaminated muddy siltstone and sandstone). Absence of foraminifera and bioturbation indicates stressed benthic conditions probably caused by high energy, high sedimentation rate and/or salinity reduction. Variations in grain size within Facies 7 from mudstone to medium-grained sandstone and occasional pebbles is characteristic of an environment with variable energy conditions. Double mud drapes and flaser bedding present in Facies 7 indicate tidal deposition (Bjørlykke, 1989). Facies 7 can represent a tidally influenced environment with a very variable energy regime. Presence of scarce foraminiferal specimens only in the uppermost sample indicates inhospitable conditions. Trace-fossils are abundant, but low in diversity and mainly occur within sediments deposited during the quiet periods.

Presence of small pebble and granular stringers on the foresets in the lower part of Facies 6 and erosional nature of the lower boundary of this unit can be characteristic of channel incision. Gradual transition from Facies 6 to Facies 7 shows an overall decrease in energy regime with short episodes of high energy. Facies 6 and 7 are interpreted as tidal channel deposits within either lagoonal-estuarine or the marine setting.

The offshore facies association is represented by the sediments of the Westgate and Fish Scales formations. Facies 8 represents the typical sediments of the Westgate Formation (see cores 6-32-13-27W4, 11-33-11-26W4, 11 17-10-21W4, and 10-25-07-20W4) that consists of laminated mudstone and sharp-

based siltstone/very fine-grained sandstone. Deposition took place within a low energy offshore environment with presence of current action (asymmetrical ripple cross-stratification) and distal or low-intensity storm events (parallel and graded lamination). Absence of foraminifera as well as any bioclastic material together with the presence of slight bioturbation only at the lower part of the unit indicates stressed marine conditions. These could have been caused by fresh water discharge from the nearby estuary that led to salinity reduction creating water column stratification and subsequent depletion in bottom water oxygenation.

Black mudstones with siltstone and very fine-grained thin sandstone laminae of Facies 9 represent deposits of the Fish Scales Formation. Sediments are slightly sandier than the Westgate Formation and indicate shallowing. Appearance of foraminifera suggests slight improvement of benthic conditions, although absence of bioturbation still indicates oxygen deficiency within the benthic habitat. Facies 9 represents upper offshore to lower shoreface deposits.

Geochemistry. Within the shoreface facies association TOC and HI values are higher within the mudstone laminae of Facies 1 than within the bioturbated sandy mudstone of Facies 4.

Facies 6 and 7 from the tidal channel facies association show low TOC and HI values that slightly increase upwards with increasing mud content from 0.44 wt% and 51 mgHC/gTOC to 1.63 wt% and 92 mgHC/gTOC.

Within the offshore facies association (facies 8 and 9) TOC values vary insignificantly (1.55 wt%- 1.26 wt%), while HI data from Facies 9 show higher values of 151 mgHC/gTOC in comparison with Facies 8 (103 mgHC/gTOC - 76 mgHC/gTOC).

10-25-7-20W4

A total of six facies were described in the core 10-25-7-20W4 and were grouped into the shoreface facies association and the channel facies association of the Upper Bow Island and the offshore facies association of the Westgate

Well	10-25-07-20W4
Logged	June 22, 1997
Core intervals	785-802 m
Samples	20
# of cores	1
Core name	Husky et. al. Coaldale

[illegible]

Figure 19. Core 10-25-7-20W4.

<i>Uvigerinammina alhabascensis</i>	<i>Uvigerinammina mantobensis</i>	<i>Verneulinoides cf. fischeri</i>	<i>Ammotium spp</i>	<i>Reophax cf. daskeri</i>	<i>Psammimopelta subcircularis</i>	<i>Textularia topagorukensis</i>	<i>Ammobaculites phaulus</i>	<i>Ammodiscus kowensis</i>	<i>Glomospira glomerosa (?)</i>	<i>Gaudryina faileuri</i>	<i>Gravellina chamneyi</i>	Total amount of foraminifera	fish remains	<i>Inoceramus</i> prisms	pyrite concretions	algal cysts	diatoms	petrified plant material
												10	•					○
	•										•	103	•		•			
												18						
	•								•	•		57	○	○				
	•											21	○					
	■			•	○		○	•				11	○	○				○
												247	○					
												34						
												39				•	•	
			•		○	•						89	○		○	○	○	•
												61	○		○			
			•									33			•			
○	○																	
	•											171	○	•				
	•											269						
	•											306						
												315	○					
	■											101						
												60						

- present (for species)
- single
- few (2-5)
- some (6-10)
- common (11-20)
- abundant (21-50)
- rich (>50)

Formation (fig. 19).

The shoreface facies association is represented by facies 1, 2 and 3. According to the gamma-ray log the lowermost appearance of Facies 1 represents the top sediments of the coarsening upward cycle. Deposition of Facies 1 took place within an environment of variable energy regime, where low energy periods (mudstone deposition) were alternating with high energy periods (sandstone deposition). Low angle, wavy cross-lamination within the sand beds can be interpreted as hummocky cross-stratification (HCS). The heavy to moderate bioturbation in mudstones is generated mainly by deposit feeders and grazers and indicates a quiet hospitable environment with slow rates of deposition. Bioturbation sometimes penetrates into sandstone beds and disturbs them especially if the beds are thin. Primary sedimentary structures are preserved in thicker sand beds, especially when storm events are frequent without time for organisms to colonize interstorm beds. No to very few trace fossils were observed within the storm beds, due to fast sediment deposition and high energy, supporting opportunistic colonization.

The sharp contact between sandy Facies 1 and the muddy base of Facies 2 represents a flooding surface between two coarsening upward cycles. Sedimentary structures and lithological characteristics of Facies 2 result from a lower energy environment than in Facies 1. The coarsening upward succession of Facies 2 is gradually passing into - Facies 1, again demonstrating an upward increase in energy. The sharp based thin sandstone beds represent the distal storm deposits with occasional presence of current flow (ripple cross-lamination). The highly diverse trace-fossil assemblage together with diverse and abundant foraminifera are characteristic of a fully marine environment. Foraminiferal and trace-fossil assemblages reduce upward with increase of the sand component.

Hummocky cross-stratified sandstone of Facies 3 with rare mudstone laminae shows continued increase in energy. These sediments tops the coarsening upward cycle composed of facies 2-1-3. In this storm-dominated environment foraminiferal and trace-fossil assemblages drop in abundance and

diversity. Deposition likely took place within the middle shoreface environment.

At the top of the shoreface facies association the last appearance of Facies 1 probably represents the base of the third coarsening upward cycle, that mainly has been eroded by incision of the channel facies association. Coarsening upward cycles represent a progradation from the lower shoreface (Facies 2) to lower middle shoreface (Facies 1) and to upper middle shoreface (Facies 3).

The tidal-channel facies association is represented by Facies 4. Presence of the mudstone laminae within the high angle cross-bedded medium-grained sandstone indicates large energy fluctuations within the depositional environment with current-generated sediment transportation and deposition. Fining of the sediments in the upper portion of Facies 4 together with increase of the mudstone laminae frequency and disappearance of the high-angle cross-bedding show a decrease in energy level. The erosional nature of the lower boundary of this unit could indicate the event of the channel incision into the underlying shoreface deposits. Double mud drapes within the rare mudstone laminae are diagnostic of tidal influence (Leckie, 1986; Reinson et al., 1988; Dalrymple, 1992). Mud rip-up clasts at the lower part of the facies suggest short distance of current transportation of the intraformational mud from the low energy environment such as tidal flats or bank settings into the channel. General low level of bioturbation and absence of foraminifera suggests a stressed benthic environment caused by salinity fluctuations, or more likely by a high-energy regime with high sedimentation rate. Similar sediments were recognized from the Viking Formation in Central Alberta and were interpreted as tidal-channel deposits within estuaries (Reinson et al., 1988), or tidal sand ridges on tidally-influenced shelf environments (Leckie, 1986). Preservation of the mudstone laminae would not be likely within the high-angle cross-bedded sandstones of the upper shoreface environment. Therefore it is believed that Facies 4 represents the tidal channel fill deposition possibly within the estuarine

environment. Lowering of the relative sea-level caused the incision of the channel into the older strata.

The offshore facies association is represented by Facies 5 and Facies 6 of the Westgate Formation. Intensively bioturbated sandy siltstone of Facies 5 characterizes a relatively quiet marine environment with hospitable conditions for benthic organisms. Facies 6 represents an upward coarsening succession, that consists of interlaminated mudstone, siltstone and very fine-grained sandstone. The deposition of these sediments took place within the low energy offshore environment with evidence of current action and distal or low-intensity storm events (see cores 6-32-13-27W4, 11-33-11-26W4, 11 17-10-21W4, and 11-28-9-21W4). Foraminifera from the Westgate Formation shows reduced diversity and abundance in comparison with the Bow Island shoreface assemblages, however in comparison with the Westgate assemblages in other cores this one is particularly rich. It is believed that in this portion of the study area the influence of the fresh water input seems to be significantly reduced (see chapter *Paleoecology of the agglutinated foraminifera* for further discussion). The poorly developed trace-fossil assemblage mainly consists of *Planolites* deposit feeding structures.

Geochemistry. Within the shoreface facies association Facies 2 shows variations of TOC values from 2.15 wt% and 1.56 wt% in the shaly samples 1 and 6, to 0.95 wt% in more sandy sample 5, with general tendency of upward decrease. HI values vary between 110 mgHC/gTOC (sample 6) and 65 mgHC/gTOC (samples 4 and 5). In Facies 3 both TOC and HI values are relatively low (0.8 wt% and 62 mgHC/gTOC), possibly due to the high sedimentation rate and therefore low concentration of the organic matter.

In Facies 4 (the tidal-channel facies association) TOC and HI values are low due to the high sand content within the sediments.

In Facies 6, which represents the offshore facies association TOC and HI values generally slightly increase upwards, showing the higher amount of organic matter within the mudstone laminae of sandy intervals.

7-2-8-21W4

A total of six facies of the Upper Bow Island were described in the core 7-2-8-21W4. Facies 1, 3, 4, 5 and 6 represent the offshore - shoreface facies association, whereas the channel facies association is composed of Facies 2 (fig. 20).

Sharp-based Facies 2 of the channel facies association is erosionally overlying the shoreface facies association. It is characterized by trough- and planar-tabular cross-bedded fine- to medium-grained sandstone that reflects high flow velocities with short-term changes in the flow conditions (presence of the reactivation surfaces). Presence of the intraformational mud clasts suggests the short distance in current transportation of sediment from the closely located low-energy environments with mudstone deposition and indicate an erosion of a muddy substrate. Absence of bioturbation and foraminifera can be a result of a strong energy regime and rapid sediment deposition that made the environment inhospitable for benthic organisms. Presence of thin mud stringers that were deposited out of suspension at times of slack water, can indicate a presence of tidal activity within the depositional environment. Facies 2 more likely represents tidally influenced channel fill deposits either within the high energy marine or estuarine settings. Presence of mud clasts would not be likely within a marine setting. Incision of the channel was probably deep enough to remove all previously deposited estuarine sediments, therefore the channel facies association directly overlies the shoreface facies association.

The offshore - shoreface facies association consists of three major coarsening cycles (fig. 20). Five facies make up a complete coarsening upward cycle. A thin transgressive lag at the base (Facies 6) is overlain by black mudstone (Facies 3) that grades upward into interlaminated mudstone, siltstone and very fine-grained sandstone (Facies 1) through interlaminated very fine- to fine-grained sandstone and muddy siltstone (Facies 4), and into hummocky cross-stratified fine-grained sandstone (Facies 5).

Agglutinated
Anniobaculites spp.
Anniobaculites fragmentarius
Anniobaculites petilus
Anniobaculites tyrelli
Anniolithum spp.
Gaudryina spp.
Gaudryina canadensis
Gaudryina irenensis
Milliammina spp.
Milliammina awunensis
Milliammina ischnia
Milliammina maritobensis
Decebar spp.

Figure 20. Core 7-2-8-21W4

[illegible]

TOC
(mgHC/gTOC)

0 0.5 1 1.5 2 2.5

Facies 6 consists of a thin matrix-supported granule to pebble lag that marks the discontinuity between first and second and second and third coarsening cycles. Facies 6 represents the transgressive lag deposits formed by the reworking of the coarse lowstand sediments during the transgression.

Facies 3 were described from the basal parts of the first and second coarsening cycles. Black shale with rare thin parallel-laminated siltstone and very fine-grained sandstone beds and laminae in its upper part indicate a low energy regime within the depositional environments with occasional presence of infrequent distal storm beds accumulated below fairweather wave base. Foraminiferal assemblages from Facies 3 are the most abundant and diverse within the core showing fully marine conditions. Slight to moderate degree of the bioturbation confirms benthic activity, although the degree of bioturbation can be underestimated due to the lack of the color contrast within the sediment. It is believed that facies 3 was deposited within the upper offshore environment. With upward increasing sand and silt component Facies 3 is gradually passing into Facies 1.

Interlaminated mudstones, siltstones and fine-grained sandstones of Facies 1 reflect a higher energy regime in comparison with Facies 3. The lower contact of these sediments is gradational with Facies 3, and sharp with Facies 4. A variety of sedimentary structures occur within sandstone and siltstone beds such as parallel lamination, current ripple, combined flow ripple and oscillation ripple lamination indicating presence of both current and wave action, that was possibly generated by storms. Appearance of mudstone as thin wavy or flaser beds with occasional presence of double mud drapes characterizes tidal influence within the depositional setting. Sediments appear to be intensively bioturbated and occasionally nonbioturbated to slightly bioturbated (interval 870.00 m - 869.75 m) with presence of high numbers of deposit feeding structures of the *Cruziana* ichnofacies. High diversity and abundance of trace-fossils and their generally uniform distribution within the sediments characterize the slow continuous deposition under marine conditions. Foraminiferal assemblages from Facies 1 in general show low to moderate

abundance and diversity and have a better representation within the muddier sediments (sample 18). Absence of foraminifera in sample 7 from the first coarsening cycle was unexpected. Deposition of Facies 1 took place within the lower shoreface environment with evidences of storm and tidal activity.

Sandy sediments of Facies 4 with a gradational lower contact with Facies 1 reflect the continuation of the increase in energy within the depositional environment. Similarities of the sedimentary structures within facies 1 and 4 and their close relationship within the core lead to an assumption that Facies 4 can represent the more sandy variation of Facies 1 related to a progressive shallowing of the depositional setting. Sharp-based sandstones are thicker and more frequent than in Facies 1 and show characteristics of storm beds, such as occasional hummocky cross-stratification. With increase of storm influence within the depositional environment, sedimentary structures such as wavy, flaser and lenticular bedding still show the presence of tidal activity. Bioturbation shows moderate to high intensity with a significant number of borrows within the sandier appearances of Facies 4 in the upper part of the core. Trace-fossil assemblages show the presence of the fairweather association within the mudstone beds with dominance of *Planolites*, *Chondrites*, *Teichichnus* and *Thalassinoides*, while the sandstones show an increased number of the escape borrows (fugichnia) reflecting increase in sedimentation rate and energy regime associated with storm sedimentation. Foraminiferal assemblages from muddy intervals of Facies 4 show high diversity and abundance (samples 13 and 14). With an increase of the sand component the foraminiferal assemblage significantly decreases in numbers of specimens and is represented only by the most environmentally tolerant forms. Facies 4 is interpreted to represent a proximal lower shoreface deposits.

Sandstones of Facies 5 are very similar to those observed in core 11-17-10-21W4 (Facies 5) and 11-28-9-21W4 (Facies 1). Hummocky cross-stratification (HCS) indicates a storm origin of the sediments. Grading from HCS into the oscillation ripple cross-stratification within few upward fining beds demonstrate an energy reduction at the end of an individual storm event. A

poorly developed trace-fossil assemblage within the storm beds indicates stressful bottom conditions caused by high sedimentation rate during storm episodes and is indicated by opportunistic colonization of mainly *Skolithos* escape borrows. Moderately to intensely bioturbated interlaminated mudstone and siltstone intervals show the higher diversity of ichnogenera with high number of deposit feeding structures. Such distribution of the trace-fossil assemblages characterizes the storm dominated environment with fairweather conditions during the interstorm periods. Foraminiferal assemblages with high abundance but relatively low diversity also reflects stress within the marine environment. Deposition of Facies 5 probably took place within the middle shoreface setting.

Three coarsening upward cycles represent prograding parasequences and show a progressive shallowing within the depositional environment from upper offshore to middle shoreface settings (the first coarsening cycle) or upper offshore to proximal lower shoreface settings (the second coarsening cycle).

Geochemistry. The channel facies association represented by Facies 2 shows extremely low TOC values (0.05 wt% - 0.15 wt%) due to the very high sand content. HI values are relatively high in the lower part of the unit (100 mgHC/gTOC) and decrease upwards (46 mgHC/gTOC).

Within the offshore - shoreface facies association Facies 3 shows very slight variations of TOC values between 1.12 wt% and 1.31 wt%. HI values of Facies 3 within the first coarsening upward cycle are lower than within the second coarsening cycle (52 mgHC/gTOC - 43 mgHC/gTOC and 99 mgHC/gTOC - 87 mgHC/gTOC respectively). Difference in HI values with relatively stable TOC values can indicate difference in types of organic matter. TOC values from Facies 1 show variations from 0.56 wt% to 1.06 wt%. HI values are higher within the samples with higher TOC values. The combination of very high TOC and low HI values in Facies 1 at the base of the core (samples 1 and 2) can indicate the high amount of the type III organic matter within the sediments. Facies 4 in the lower part of the core shows lower TOC values, than in the upper part (0.62 wt% and 1.14 wt%). HI values of Facies 4

are also higher within the first coarsening cycle. High availability of the organic matter is shown by high TOC and HI values within the muddy intervals of Facies 5 (1.38 wt% - 2.30wt% and 110 mgHC/gTOC - 120 mgHC/gTOC respectively).

Foraminiferal Zones in the Upper Bow Island and Westgate Formations

The entirely agglutinated benthic foraminiferal assemblages from the Upper Bow Island and the Westgate formations carry faunal elements of the *Haplophragmoides gigas* and *Miliammina manitobensis* zones, established by Caldwell et al. (1978) for Western Canada. Both zones have been widely recognized within the Western Interior of Canada (see chapter *Age and Foraminiferal Biostratigraphy*) and contain numerous foraminiferal taxa with long stratigraphic ranges. Also the stratigraphic range of some of the zonal diagnostic species of Caldwell et al. (1978) has been extended by subsequent authors. For example subzonal index-species of the *Miliammina manitobensis* Zone such as *Verneuilina canadensis* and *Haplophragmoides postis goodrichi* were described from the *Haplophragmoides gigas* Zone (Koke and Stelck, 1985; Stritch and Schröder-Adams, 1999). Due to the taxonomical similarities of the foraminiferal assemblages the discrimination between two zones is based not only on appearance or disappearance of certain species but also on proportionate representation of taxa.

Foraminiferal assemblages recovered from the Upper Bow Island and Westgate formations have a similar composition and are represented predominantly by tolerant species. Both faunae show a higher affinity with the *Miliammina manitobensis* Zone than with the *Haplophragmoides gigas* Zone, and in most cases represent the *Verneuilina canadensis* Subzone.

Upper Bow Island foraminiferal assemblages assigned to the *Verneuilina canadensis* Subzone of the *Miliammina manitobensis* Zone were recovered from the following facies associations: the offshore-shoreface facies association of core 7-2-8-21W4, the shoreface facies associations of cores 11-28-9-21W4, 11-33-11-26W4 and 10-25-7-20W4, the estuarine facies association of core 6-16-6-22W4 and estuarine deposits of Facies 4 of the lagoonal-estuarine facies association in core 11-17-10-21W4. The lagoonal-estuarine facies associations in cores 6-15-9-24W4 and 6-32-13-27W4 contain low abundant and low diverse foraminiferal assemblages, composed mainly of tolerant species with

long stratigraphic ranges. In core 6-15-9-21W4 a foraminiferal zone is difficult to determine due to the poor representation of fauna. The Bow Island foraminiferal assemblage in core 6-32-13-27W4 is more typical for the *Verneuilina canadensis* Subzone of the *Miliammina manitobensis* Zone, even though many of the diagnostic zonal species listed by Caldwell et al. (1978) are missing.

Westgate foraminiferal assemblages recovered from the offshore-lower shoreface facies associations in cores 6-32-13-27W4, 11-33-11-26W4 and 6-16-6-22W4 were assigned to the *Miliammina manitobensis* Zone. Rich faunae of the offshore facies associations in cores 11-17-10-21W4 and 10-25-9-20W4 are typical for the *Verneuilina canadensis* Subzone of the *Miliammina manitobensis* Zone.

In more distal settings within the basin the Fish Scales Formation is barren of foraminifera (Schroder-Adams et al., 1996). In southwestern Alberta the Fish Scales Formation contains a few long ranging species making a zonal placement difficult. Presence of the subzonal marker *Haplophragmoides postis goodrichi* in core 11-28-9-21W4 may indicate that the upper subzone of the *Miliammina manitobensis* Zone is extended at least into the lower part of the Fish Scales Formation, although the biostratigraphic value of this subspecies sensitive to the variations of the paleoenvironmental conditions is questionable (Stritch and Schröder-Adams, 1999).

Changes in foraminiferal composition are believed to be controlled by local environmental factors, therefore no more detail foraminiferal subdivisions are proposed for the study interval.

Biostratigraphic comparisons. As it was shown above, foraminiferal assemblages recovered from the sediments of the Upper Bow Island and the Westgate formations were assigned to the *Miliammina manitobensis* Zone, and in most cases to the *Verneuilina canadensis* Subzone.

The Upper Bow Island - Westgate assemblage of this study closely correlates with the *Miliammina manitobensis* fauna from the upper portion of Viking and the Westgate formations of central Alberta (Stritch and Schröder-

Adams, 1999). *Gravellina chamneyi* and *Textularia minuta* described as characteristic species of the Viking Formation in central Alberta (Stritch and Schröder-Adams, 1999, fig. 11, p. 1639) were found in insignificant numbers only within the deeper more distal environments of the Upper Bow Island (cores 11-28-9-21W4 and 7-2-8-21W4). Their study shows that the faunal contrast between the Viking and the Westgate formations in central Alberta declines towards the south due to numerous long-ranging species.

Foraminiferal assemblages from the shales above the Viking Formation in the Suffield area, southeastern Alberta, recovered by Tizzard and Lebrekmo (1975) and assigned to the *Miliammina manitobensis* Zone, and the Bow Island - Westgate assemblage of this study also show similarities, having sixteen foraminiferal taxa in common. Presence of *Miliammina manitobensis*, *Tritaxia (Uvigerinammina) manitobensis* and *Gravellina chamneyi* was explained by the shallow waters of the Mowry Sea at the beginning of the transgression. Within this study *Gravellina chamneyi* is rare within the Upper Bow Island and Westgate formations and *Uvigerinammina manitobensis* and *Miliammina manitobensis* are the most abundant within the deeper environments. Sparse microfaunal assemblages recovered from the shale breaks in the upper Viking sand of the Suffield area by Tizzard and Lebrekmo (1975) make biostratigraphic comparison difficult.

Eicher (1960) described the *Miliammina manitobensis* fauna from the Lower Cretaceous Shell Creek Shale in the Big Horn Basin of Wyoming and recorded twelve species with nine of them also occurring in the Upper-Bow Island - Westgate assemblage. Only fourteen species of the twenty five species reported from the *Haplophragmoides gigas* Zone of the underlying upper Thermopolis shale (Eicher, 1960) were recovered within the assemblage of this study.

The foraminiferal assemblage from the basal part of the Sunkay Member (the equivalent of the Westgate Formation) of the Blackstone Formation in the Rocky Mountain foothills of central Alberta described by Wall (1967) includes **Miliammina manitobensis*, **Ammobaculites fragmentarius*, **Verneuilina*

canadensis, **Uvigerinammina* sp. cf. *U. manitobensis*, *Gaudryina spiritensis*, *Ammodiscus* sp. 1, *Haplophragmoides* sp. 1 with four of them, marked with an asterisk, being present within the Bow Island and the Westgate formations.

In northwestern Alberta the foraminiferal assemblage described by Stelck and Leckie (1990a) from the upper part of the Paddy Member and the lower part of the Shaftesbury Formation is assigned to the *Verneuulina canadensis* Subzone of the *Miliammina manitobensis* Zone. This assemblage carries twenty two taxa in common with the Upper-Bow Island - Westgate assemblage. Many of the agglutinated foraminifera from their assemblage are known from the *Reophax troyeri* Subzone of the *Haplophragmoides gigas* Zone of the Hasler Formation, northeastern British Columbia (Stelck and Koke, 1987). The *Reophax tundraensis* Subzone of the *Haplophragmoides gigas* Zone described by Stelck and Koke (1987) from the lower mid-portion of the Hasler Formation, northeastern British Columbia, contains the "Viking" marker bed correlative with the lower part of the Bow Island Sand in southern Alberta. None of the seven subzones of the *Haplophragmoides gigas* Zone described by Stelck and Koke (1987) and Stelck (1991) were recognized within this study, although many of the faunal elements are present.

The Upper Bow Island - Westgate fauna is very similar to those described from the upper Buckinghorse Shale and Sikanni Sandstones in the Sikanni Chief River area, northeastern British Columbia assigned to the *Miliammina manitobensis* Zone by Stelck (1975). However, *Haplophragmium swareni* abundant in the Sikanni Chief River Area was rarely found within Bow Island - Westgate assemblages.

The *Miliammina manitobensis* fauna of the studied interval shows close relationships with the Arctic fauna. As it was shown by Stelck (1975) the *Miliammina manitobensis* Zone of Alberta and British Columbia can be correlated to the upper part of the *Verneuulinoides borealis* Zone of Alaska described by Tappan (1957, 1962) and Berquist (1966) from the Torok, Tuktu, Grandstand and Topagoruk formations. The *Psamminopelta subcircularis* - *Verneuulinoides borealis* Assemblage Zone described from the upper silty

member of the Arctic Red River Formation in northern Yukon Territory by Mountjoy and Chamney (1969) and later renamed into the *Psamminopelta subcircularis* - *Verneuilinoides tailleuri* Assemblage Zone by Chamney (1978) contains **Psamminopelta subcircularis*, **Verneuilinoides borealis*, **Hippocrepina* cf. *H. barksdalei*, **Reophax minuta*, **Reophax troyeri*, **Reophax vasiformis*, **Trochammina* cf. *T. rainwateri*, **Gaudryina* cf. *G. nanushukensis*, **Verneuilinoides* (*Gaudryina*) *tailleuri*, *Ammodiscus rotalarius*, *Haplophragmoides* cf. *H. neocomianus*, *Haplophragmoides* cf. *H. topagorukensis*, *Haplophragmoides multiplum* (associated with **Miliammina* spp. in equivalent stratigraphic horizons) with more than half of the species (marked with asterisk) being present within the Upper Bow Island - Westgate interval. In this study *Psamminopelta subcircularis* was recovered only within the sediments of the Westgate Formation. Based on the lack of the *Miliammina manitobensis*, “*Tritaxia*” (*Uvigerinammina*), and *Ammobaculites* spp. Stelck (1975) suggested that the Yukon assemblage is somewhat older than the assemblage from the Sikanni Chief River area. However, it is possible that absence of these species can be facies related. Some species such as *Bathysiphon brosgiei*, *Gaudryina* cf. *G. canadensis*, *Saccammina* sp., *Ammobaculites fragmentarius*, *Textularia topagorukensis*, *Tritaxia solea*, *Psamminopelta bowsheri* from the underlying *Ammobaculites fragmentarius* Assemblage Zone, which they correlated with the Joli Fou fauna was also recovered within the Upper Bow Island - Westgate assemblage. It becomes clear that most of these species are long ranging which makes them not reliable biostratigraphic marker species. Chamney (1978) stated that the major faunal change, characterizing the upper boundary of the *Ammobaculites fragmentarius* Assemblage Zone, might be correlative to the faunal changes at the boundary between the Joli Fou and Viking formations. *Tritaxia solea*, newly described by Chamney (1978) in association with *Haplophragmoides* aff. *H. gigas* from the *Ammobaculites fragmentarius* Assemblage Zone, was recovered only within the core 7-2-9-19W4 from the Upper Bow Island sediments. It seems that the *Miliammina manitobensis* Zone in the Canadian Western Interior Plains is

younger than the described assemblage zones of the Yukon, confirming the findings of Stelck (1975).

Biostratigraphy vs. Paleoecology. Presence of faunal elements, representing both the *Miliammina manitobensis* and *Haplophragmoides gigas* zones, within Upper Bow Island and Westgate assemblages brings forward the discussion about possible environmental influence on biostratigraphy. The *Miliammina manitobensis* fauna has a definite boreal nature, while the fauna of the *Haplophragmoides gigas* Zone carries boreal and Gulfian elements, determining the connection between Boreal and Tethyan seas (Stelck, 1975; Williams and Stelck, 1975; Caldwell et al., 1978; Stelck and Koke, 1987; Stritch and Schröder-Adams, 1999). During the early late Albian time the Joli Fou Seaway provided a narrow migration path for the Boreal and Gulfian faunae. The *Haplophragmoides gigas* foraminiferal assemblage, established within the Joli Fou shales and its equivalents has been later replaced by the *Miliammina manitobensis* fauna, when the southern connection of the seaway closed or became severely restricted, resulting into the Mowry Sea. The phase of closing is documented in the Bow Island/Viking strata. Foraminiferal assemblages from the Bow Island Formation (this study) and its equivalent the Viking Formation in central Alberta show presence of both *Haplophragmoides gigas* and *Miliammina manitobensis* elements (Stritch and Schröder-Adams, 1999). Bullock (1950) reported no significant faunal change between Joli Fou and Lloydminster Shale (Westgate equivalent) through the Viking Sandstone. Based on Bullock's observations Stelck (1975) concluded that the *Miliammina manitobensis* fauna is not much younger than the fauna from the Joli Fou Shale. McNeil and Caldwell (1981) show that in the Manitoba Escarpment environmental conditions of the *Haplophragmoides gigas* and *Miliammina manitobensis* faunae were quite similar. Many researchers believe in the influence of the environmental factors on the range of foraminiferal taxa (e.g. Newell, 1956; Sylvester Bradley, 1956; Tappan, 1962). Due to the ability of faunae to migrate towards the hospitable habitats it is often impossible to determine whether the faunal changes are geographically or stratigraphically

controlled (Tappan, 1962). Only within the deeper environments with more stable ecological conditions faunal zones can represent a true time zonation. Caldwell et al. (1978) pointed out that within near-shore environments with more restricted conditions abundance and composition of zonal assemblages as well as ranges of some taxa may differ. Foraminiferal assemblages from the Upper Bow Island and Westgate formations in southwestern Alberta are of agglutinated nature indicating marginal marine to shallow marine waters. Therefore it is possible that numerous faunal elements from the *Haplophragmoides gigas* and *Miliammina manitobensis* zones are facies controlled and can alternate or be found within the same assemblage depending on environmental conditions. The occasional presence of faunal elements characteristic of the *Haplophragmoides gigas* Zone within the sediments of the Upper Bow Island and Westgate formations possibly represent species survived within areas of favorable conditions allowing for reappearance within the environments inhabited by the *Miliammina manitobensis* fauna.

Paleoecology of the agglutinated foraminifera. The Bow Island and Westgate formations show the variety of different environments from non-marine coastal plain facies of the Middle Bow Island to marine facies within the Upper Bow Island and Westgate formations (see chapter *Interpretation of the Facies Associations*). Sediments of the Upper Bow Island within the study area have been deposited within a marginal-marine setting that is characterized by changeable environmental factors such as salinity and energy regime. Fluctuations in foraminiferal abundance, diversity and composition remarkably reflect the paleoenvironmental changes within the Bow Island Formation (fig. 21 and fig. 22). Numerous controversies about the ecology of fossil foraminifera exist within the literature, indicating large environmental tolerance of some taxa. Genera described as an indicator of deeper marine environments by some authors are listed among brackish water inhabitants by others. For example, *Ammobaculites* has been mentioned as a genus of low saline water by Gulioy (1967), Sutherland and Stelck (1972) and Stelck (1975), and has been

FORMATION	BOW ISLAND					WESTGATE	
	PALEOENVIRONMENTS PALEOECOLOGICAL PARAMETERS	coastal plain	lagoonal - estuarine	estuarine	offshore - shoreface	offshore	
					proximal	distal	
CORE		6-32-13-27W4 6-15-9-21W4	6-32-13-27W4 6-15-9-21W4 11-17-10-21W4	11-17-10-21W4 6-16-6-22W4	11-28-9-21W4 11-33-11-26W4 10-25-7-20W4 7-2-8-21W4	6-32-13-27W4 11-33-11-26W4 6-16-6-22W4	11-17-10-21W4 10-25-9-21W4
ENERGY REGIME		—	variable	variable	low (offshore) to high (upper shoreface)	low	low
FORAMINIFERAL ABUNDANCE		barren	barren to low	low to moderate	moderate to high	low	moderate
FORAMINIFERAL DIVERSITY		barren	low (tolerant forms)	low to moderate	moderate to high	low	moderate

Figure 21. Characteristics of the foraminiferal assemblages within different marginal-marine environments of the Upper Bow Island and Westgate formations.

assigned to the marine salinity waters by Koke and Stelck (1984) and Stelck (1991).

Guliov (1967) and Koke and Stelck (1984) believed that abundant *Miliammina* were assigned to areas with deeper and more normal marine conditions, while within the modern environments it is a characteristic taxon of low saline shallow waters (Murray, 1973). No modern analogues of intracratonic basins are available which makes paleoecological interpretations of Cretaceous foraminiferal assemblages difficult. Combination of micropaleontological, sedimentological and geochemical data has to be the base for evaluation of foraminiferal paleoecology.

The Bow Island Formation. Low abundant and low diverse foraminiferal assemblages from the lagoonal-estuarine facies associations (cores 6-32-13-27W4 and 6-15-9-21W4) are composed mainly of paleoecologically tolerant species with long stratigraphic ranges demonstrating stressed benthic environments. Core 6-32-13-27W4 has the largest assemblage composed by *Gaudryina*, *Miliammina*, *Trochammina* and *Verneuilioides* species. *Gaudryina canadensis*, *Miliammina manitobensis* and *Trochammina rutherfordi* recovered from this core were also found within the low diverse assemblages from the brackish water sediments of the Grandstand and Ninuluk formations in Alaska (Tappan, 1962). In core 11-17-10-21W4 the lagoonal facies 1-3 of the lagoonal-estuarine facies association are barren of foraminifera except a single sample from the very base of the core that contains 3 poorly preserved foraminiferal specimens.

In contrast the estuarine deposits of Facies 4 of the lagoonal-estuarine facies association in core 11-17-10-21W4 (sample 6') and the estuarine facies association in core 6-16-6-22W4 demonstrate increased marine influence within the depositional setting reflected in relatively diverse and abundant foraminiferal assemblages. High numbers of species with simple chamber arrangements (e.g. *Ammobaculites*, *Hippocrepina*, *Hyperammina*) within the assemblage in core 6-16-6-22W4 can be characteristic of a brackish water environment (Bandy, 1960; Brasier, 1980). As diversity and abundance increase

in core 11-17-10-21W4, dominance of *Ammotium* and *Gaudryina* species is observed. Stelck and Leckie (1990a) stated that an *Ammotium*-bearing fauna is highly facies controlled and can be an indicator of a low salinity environment. However few *Ammotium* specimens were also recovered within the offshore shale of the Westgate formation. Therefore this species is not considered to be facies restricted, unless their appearance within the Westgate strata is a result of reworking.

Foraminiferal assemblages from the shoreface facies associations in cores 11-28-9-21W4, 11-33-11-26W4 and 10-25-7-20W4 and the offshore-lower shoreface facies association in core 7-2-8-21W4 are abundant and diverse demonstrating the open marine conditions. Two distinctive foraminiferal assemblages can be determined in core 11-28-9-21W4. The lower foraminiferal assemblage from the upper to middle shoreface sediments of Facies 1 is dominated by *Ammobaculites* and *Miliammina* with noticeable numbers of *Ammobaculites fragmentarius* and *Miliammina manitobensis*. The second assemblage from Facies 4 (upper offshore to lower shoreface sediments) is characterized by the appearance of several new foraminiferal genera and species and shows the high abundance of *Gaudryina canadensis* that was also abundant within the lagoonal-estuarine (core 6-32-13-27W4) and estuarine (core 11-17-10-21W4) facies associations. It is believed that *Gaudryina canadensis* is a tolerant genera and can be found in high numbers within different environments.

The composition of the foraminiferal assemblage in core 11-33-11-26W4 varies from sample to sample reflecting fluctuations of the environmental conditions within the shoreface environment. The assemblage from the shoreface facies association in core 10-25-7-20W4 shows a high abundance of *Gaudryina canadensis*, *Gaudryina irenensis* and *Miliammina ischnia* and the robust large specimens of *Ammobaculites fragmentarius*, *Miliammina manitobensis*, *Reophax vasiformis*, *Reophax sikanniensis* and *Uvigerinammina manitobensis*. The dominance of the robust large species of *Miliammina*, *Uvigerinammina*, *Ammobaculites* and *Haplophragmoides* were

also recorded within at least partially turbidity-controlled shelf sediments of the Topagoruk and Grandstand formations in Alaska (Tappan, 1962). Constant presence of *Bathysiphon* through the shoreface facies association in core 10-25-7-20W4 indicates the normal marine salinity within the depositional environment (Stelck, 1991). Abundant *Miliammina* together with presence of *Bathysiphon*, *Psamminopelta* and *Uvigerinammina* can be found within close to normal marine environments (Guliov, 1967). Increased numbers of the *Miliammina* and *Uvigerinammina* were observed in the deeper water assemblages by Koke and Stelck (1984). Also occasional presence of *Haplophragmium* can be a sign of deeper water environment (Stelck, 1975; Stelck and Hedinger, 1983; Koke and Stelck, 1984). Diverse and abundant species of *Reophax* in assemblages with abundant *Ammobaculites*, *Gaudryina*, *Miliammina* and *Uvigerinammina* seems to indicate a more normal salinity.

In core 7-2-8-21W4 foraminifera from the three major coarsening upward sequences comprising the offshore-shoreface facies association (see chapter *Interpretation of the Facies Associations*) demonstrate foraminiferal response to the facies changes from the upper offshore to the middle shoreface environment. Flooding events are characterized by the offshore deposits of Facies 3 (samples 5, 6, 11 and 12), which contain abundant and diverse foraminiferal assemblages with high numbers of *Miliammina manitobensis*, *Miliammina ischnia*, *Miliammina inflata*, *Gaudryina canadensis*, and *Verneuilinoides borealis*. Even though the lithological and sedimentological characteristics of Facies 3 in the first and second coarsening sequences are the same, the foraminiferal assemblages show significant differences. The second sequence is marked by first appearance datums of foraminiferal taxa with additionally abundant species such as *Uvigerinammina manitobensis*, *Trochammina rutherfordi* and *Bathysiphon brosgiei*. This indicates changing, more favorable paleoecological conditions, not identified in lithology. The foraminiferal assemblage has similarities with the one recovered from the shoreface facies association in core 10-25-7-20W4. Lack of abundance and diversity of *Reophax* is more likely to be explained by a deeper environment.

With shallowing of the depositional environment and increase of the sand component foraminiferal abundance and diversity decline significantly leaving only the tolerant forms within the assemblage. Only within the muddy intervals foraminifera persist to be relative abundant and diverse.

Marginal-marine environments are known possessing unstable physical factors such as salinity, temperature, turbidity, sedimentation rate etc. It is difficult to determine what environmental factor is the most influential on foraminiferal distribution, abundance and diversity. Being sensitive to environmental changes, benthic foraminiferal assemblages of the Bow Island Formation are extremely variable in abundance and diversity even within similar environments and generally reflect local paleoenvironmental changes. This makes biostratigraphic correlations difficult even within the study area. More work is needed to understand the geographical and paleoecological distribution of certain species to evaluate their biostratigraphic significance.

The Westgate Formation. The abundance and composition of the foraminiferal assemblages of the Westgate Formation are variable at different localities within the study area.

Absence of foraminifera in the offshore facies association of the Westgate Formation in core 11-28-9-21W4 indicates extremely stressful conditions for these benthic organisms. The offshore-lower shoreface facies associations of the Westgate Formation in the eastern cores 6-32-13-27W4 and 11-33-11-26W4 and southern core 6-16-6-22W4 contain poorly developed foraminiferal assemblages indicating also environmental stress (fig. 22). Insignificant faunal change between the Bow Island and Westgate formations is marked by few newly appearing species. Presence of *Haplophragmium* spp. and *Bathysiphon brosgel* in core 6-32-13-27W4 indicates a deeper, although stressful marine environment. Sedimentological characteristics of the Westgate Formation in core 11-33-11-26W4 together with high abundance of the marine biotic remains suggest marine conditions. However there is a noticeable reduction in foraminiferal abundance and diversity in comparison with the Bow Island assemblages from the shoreface environments.

Figure 22. Principal diagram of the proximal and distal paleoenvironments of the Upper Bow Island and Westgate formations. For symbols see fig. 13.

More hospitable environmental conditions are observed within the offshore facies association of the Westgate Formation in the more eastern cores 11-17-10-21W4 and 10-25-9-20W4 that contain diverse and relatively abundant foraminiferal assemblages. In core 11-17-10-21W4 appearances of the new foraminiferal taxa were recorded almost in every sample determining improving environmental conditions. A significant faunal change is recorded in sample 14, where the abundant but low diverse foraminiferal assemblage dominated by *Psammimopelta bowsheri*, *Miliammina manitobensis*, *Miliammina ischnia* and *Pseudobolivina variana* consists of small fine-grained foraminiferal tests. Such assemblage of stunted foraminiferal specimens indicates stressed environments, where few adoptable taxa become numerous due to decreased competition, but respond for stress with stunted growth (Tappan, 1962).

Numerous foraminiferal taxa from the Westgate Formation in core 10-25-7-20W4 range down to the Bow Island Formation with only few first appearances within the Westgate shales. In comparison with the Bow Island assemblage foraminiferal abundance and diversity decreases. Genera such as *Uvigerinammina* and *Reophax* recovered in high numbers within the Bow Island assemblage (see above) appear only sporadically within the Westgate. *Miliammina* and *Gaudryina* seem to be adaptive to broad environmental conditions and remain abundantly throughout the Westgate and Bow Island formations. Foraminiferal composition of the Westgate Formation and the shoreface deposits of the Bow Island Formation suggests similar environments, only interrupted by the tidal channel of Facies 4.

Such significant variations of the foraminiferal assemblages within almost identical lithologically and sedimentologically sediments of the Westgate Formation within the study area is the result of fluctuating paleoecological conditions within the basin during Westgate time. It is likely that fresh water discharge from rivers reduced the salinity of surface waters and possibly created freshwater lid and density stratification in the water column that lead to oxygen deficiency of bottom waters. Western cores located closer to

the paleoshoreline at Westgate time (cores 6-32-13-27W4, 11-33-11-26W4 and 6-16-6-22W4) have been more affected by the fresh water lid than those in more distal parts of the basin (cores 11-17-10-21W4 and 10-25-9-20W4). Schröder-Adams et al. (1996) suggests that limited foraminiferal populations within the Westgate Formation can be caused by brackish water conditions in an enclosed Mowry Sea. Stelck (1975) suggested that if a southern connection of the seaway remained during Westgate time, flooding of the Mowry Sea during the *Miliammina manitobensis* time may have brought about mixing of boreal and gulfian faunae. Stelck and Leckie (1990a) came to the same conclusion, based on foraminiferal data from the upper part of the Paddy Member of the Peace River Formation and the superjacent lower Shaftesbury Formation in the Goodfare area of northwestern Alberta. If this supposition is correct, the incomplete mixture of the Tethyan and Boreal waters can also bring a water column stratification. It is also possible that the sediments of the Westgate Formation to the east and to the north were deposited at the earlier stage of the Mowry sea transgression and therefore foraminiferal assemblages had a longer time to be established.

The Fish Scales Formation. In comparison with distal parts of the basin where the Fish Scales Formation is completely barren of foraminifera (Schröder-Adams et al., 1996), the offshore-lower shoreface facies associations of the Fish Scales Formation in cores 11-33-11-26W4, 11-28-9-21W4 and 6-16-6-22W4 contain poor foraminiferal assemblages. Only in core 6-32-13-27W4 no foraminifera have been recovered from the Fish Scales Formation. Such a poor faunal representation can reflect bottom-water dysoxia, confirming the findings of Leckie et al. (1992) and Schröder-Adams et al. (1996). It is likely that within the study area, that represent a shallow part of the basin, energy was strong enough to provide some oxygen to the bottom waters, allowing for a minor assemblage.

Depositional History of the Bow Island and Westgate Formations

Sediments of the Bow Island and Westgate formations reflect fluctuations of relative sea level during late Albian time (fig. 23). In southwestern Alberta the Bow Island Formation lays disconformably on non-marine sediments of the Upper Mannville Group that represent a thick clastic wedge of coastal plain deposits, prograding northward (Leckie and Smith, 1992). The boundary between the Bow Island Formation and the Upper Mannville Group (see figs. 6, 7, 8) is marked by a transgressive erosional surface that formed during the widespread transgression of the Joli Fou Sea in early late Albian time (Stritch and Schröder-Adams, 1999) and can be traced over the extended areas of the Western Interior basin. Sea-level rise is expressed in deposition of the marine shales of the Joli Fou Formation in central Alberta and its equivalents throughout the southern plains of Canada and the northern plains of the United States (Caldwell, 1984). This transgression represents a transgressive phase of the late Albian Kiowa-Skull Creek marine cycle (Caldwell, 1984) that is believed to be eustatically controlled (Kauffmann, 1977). The Bow Island - Upper Mannville boundary represents a sequence boundary that coincides with the sequence boundary between the Mannville and the Joli Fou formations in central Alberta (Reinson et al., 1994). Shales of the Joli Fou Formation represent the transgressive systems tract (TST) (Reinson et al., 1994). Within the study area the Joli Fou Formation is absent, therefore the lowermost shoreface sediments of the Lower Bow Island, overlying the Upper Mannville Group, can represent TST deposits (Cox, 1993).

The Lower Bow Island is comprised of numerous coarsening upward sequences separated by minor flooding surfaces (figs. 6, 7, 8). These shelf-shoreface parasequences prograded basinward (northward and eastward) in response to the increase of clastic material coming from the uplifting Cordillera to the west (Cox, 1993). Sediments of the Lower Bow Island represent deposits of the highstand systems tract (HST). The regional Viking shelf-to-shoreface

06-14-08-21W4

Figure 23. Depositional history of the Bow Island and Westgate formations. GR - gamma-ray well-log, RES - resistivity well-log, SB - sequence boundary, RS - reactivation surface.

sequence of central Alberta termed by Reinson et al. (1988) is constituted by a set of prograding parasequences of the HST (MacEachern et al., 1992, 1998, 1999a, 1999b; Zaitlin et al., 1995). It is quite possible that the shelf-shoreface parasequences of the Lower Bow Island can be correlated with the regional parasequences of the Viking Formation. The HST is characterized by the slowing of the relative sea-level rise, which reflects on the slowing of the landwards movement of the shoreline, and, eventually, after passing the stillstand point, relative sea-level begins to fall giving way to regression (Posamentier and Vail, 1988).

Retreat of the sea was associated with a progradation of the coastal-plain deposits of the Middle Bow Island into the basin. Long subaerial exposure related to the sea-level fall is expressed in well developed paleosols of the Middle Bow Island (cores 6-32-13-27W4 and 6-15-9-24W4). Northeastward sediments of the coastal-plain become thinner and eventually dying out in the deeper parts of the basin. Bradshaw (2000) proposed a major sequence boundary (SB) between the Lower and the Middle Bow Island. In this situation the sediments of the Middle Bow Island and the Upper Bow Island might represent the lowstand systems tract (LST) and the transgressive systems tract (TST) respectively, separated one from another by the first major flooding surface. The well-log analysis of this study as well as the core and well-log data collected by Cox (1993) show no indication of the major sea-level fall, which would be expressed in the development of an incised valley system, characteristic of the type 1 unconformity at the upper boundary of the HST (Posamentier and Vail, 1988; Posamentier et al, 1988). However, if the subaerial exposure of the shelf was limited due to the absence of the knickpoint (term defined in Bates and Jackson, 1980, p. 341), a slow widespread erosion of the landscape will take place without the valley incision, which will characterize the type 2 unconformity (Posamentier and Vail, 1988). It is more likely that the boundary between the Lower and the Middle Bow Island represents a facies transition from the shelf-shoreface deposits into non-marine coastal-plain deposits (see chapter *Stratigraphic Cross-sections* and fig. 7).

therefore the sediments of the Middle Bow Island possibly represent the final stage of the HST confirming the findings of Cox (1993) and Reinson et al. (1994). If this model is correct, the unconformity on top of the Middle Bow Island represents a combined sequence boundary/transgressive reworking surface with the sediments of the LST being deposited further out in the basin. This sequence boundary between the Middle and the Upper Bow Island surface represent the type 2 unconformity and can be correlated with the sequence boundary in the middle of the Viking Formation separating the HST deposits from the TST deposits (Reinson et al., 1994).

The Upper Bow Island is characterized by several changes in relative sea-level during an overall transgression. The early stage of the transgression is indicated by deposition of the shoreface and the offshore-shoreface facies associations in the distal part of the study area, typified by very abundant and diverse foraminiferal assemblages (cores 7-2-8-21W4, 10-25-7-20W4 and 11-28-9-21W4). With the continuation of the transgression the shoreface sediments were overlapping further landwards on top of the Middle Bow Island HST deposits. Possibly the shoreface sediments of the Upper Bow Island in the west are somewhat younger than the Upper Bow Island sediments in the east. To the east several coarsening upward successions, separated from each other by flooding surfaces (as seen in core 7-2-8-21W4), indicate a change in sediment flux or, more likely, a multiple rise in relative sea level. These parasequences represent the fourth-order cycles of Haq et al. (1988) during an overall transgression. Thin transgressive lag deposits that mark the discontinuity between the coarsening successions can be an indication of several sea-level drops caused the deposition of coarser material in a distal (eastern) parts of the study area which has been later reworked during the following transgressions. Drops of the relative sea-level coincided with the fluvial erosion, which created the basal sequence boundary of the incised valleys, cut into the shoreface deposits of the Upper Bow Island (cores 6-32-13-27W4, 6-15-9-24W4, 11-17-10-21W4 and 11-28-7-20W4) (fig. 22). During the following rise of the sea-level those valleys were filled with the estuarine and lagoonal-estuarine

Figure 24. Schematic diagram illustrating (A) simple and (B) compound incised-valley systems. Numbers 1-3 refer to the successive episodes of erosion and deposition within the incised valley. FS - flooding surface (modified from Zaitlin et. al., 1994). For symbols see fig. 13.

deposits (fig. 24) (Pedersn, *pers. com.*), characterized by foraminiferal assemblages with reduced abundance and diversity, reflecting environments with extremely variable physical factors such as salinity, temperature, turbidity, sedimentation rate etc. Due to the fluctuations of the relative sea-level within the Upper Bow Island, the incised valleys possibly contain a compound fill, characterized by several cycles of the incision and deposition as discussed by Zaitlin et al. (1995) for the Viking Formation. Only core 11-28-7-20W4 contains the record of the deposition of both shoreface deposits and the estuarine deposits, infilling the incised valley. In most of the cores valley incision eroded sediments of the shoreface deposits cutting into the coastal-plain deposits of the Middle Bow Island (e.g. cores 6-32-13-27W4, 6-15-9-24W4, 6-16-6-22W4). However, some areas did not experienced valley incision, and therefore the shoreface deposits remain preserved (core 11-33-1126W4). Within the study area the incised valleys represent relatively small channel cuts, in comparison with the incised valleys of the Viking Formation, therefore the mapping of the valleys and relationship interpretations is very difficult. Possibly not all of the estuarine and lagoonal-estuarine deposits represent fill of the valley, incised during the drop of the sea-level within the Upper Bow Island, but were deposited during the transgression, infilling the relief left on top of the Middle Bow Island and therefore represent piedmont estuaries (Zaitlin et al., 1995). Sea-level changes happened within relatively short periods of time, and therefore are outside the foraminiferal biostratigraphic resolution. More detailed correlations are needed to solve this problem. Sedimentological and micropaleontological evidences indicate that even the deeper, more distal environments of the Upper Bow Island experienced fluctuations in paleoecological conditions, characteristic of the shallow restricted basin.

The transgressive lag deposits at the base of the Westgate Formation that can be traced over extended areas of Alberta, mark a transgression phase of the Greenhorn marine cycle (Caldwell et al., 1993, Stritch and Schröder-Adams, 1999). Significant variations in foraminiferal assemblages of the offshore to

lower shoreface Westgate deposits, caused by the fluctuations of paleoecological conditions within the basin during the Westgate time, have been discussed in chapter *Foraminiferal Assemblages and Paleoecology*. Increase of fresh water discharge is believed to be responsible for the dramatic reduction of foraminiferal populations in the western and southern parts of the study area (cores 6-32-13-27W4, 11-33-11-26W4 and 6-16-6-22W4). However Westgate foraminiferal assemblages recovered from the distal part of the study area (core 10-25-7-20W4) do not indicate a significant change in foraminiferal composition, which would be expected at the beginning of a new global cycle. Therefore, within the study area, it is questionable whether the Westgate flooding represents the beginning of the Greenhorn transgression, or just represents the new, although a significant stage of the transgressive event, that started at the base of the Upper Bow Island. The mudstones of the Westgate Formation thin toward the southwest (fig. 11), which is believed to be perpendicular to the direction of the paleoshoreline of the Westgate time until it pinches out in the southwestern corner of the study area. It is difficult to determine, whether the topographic surface of the Bow Island Formation, nature of the Westgate transgression or the lowstand event at the Fish Scales time or a combination of these factors have been responsible for the geometry of the Westgate Formation.

Correlations with the Viking Formation

The relationship between the Viking and the Bow Island formations is not clearly understood. Cox (1993) and Reinson et al. (1994) made an attempt to correlate these two very complex formations, using the well-log correlations together with the core analysis (Reinson et al., p. 359, fig. 21.8). Both the Lower Bow Island and Viking formations are characterized by TST deposits As it was discussed above the shelf-shoreface parasequences of the Lower Bow Island can be correlative with the parasequences of the regional Viking Formation. If this assumption is correct than the basinward prograding

parasequences of the Lower Bow Island should be older than the parasequences of the regional Viking. It can explain why the coastal-plain sediments of the Middle Bow Island, prograded basinward from the west during the final stage of the HST, are not present in the more distal “Viking” areas. Cox (1993) also proposed that the Viking-Joli Fou interval represents a more distal equivalent to the Lower Bow Island. However more detailed studies of the geometry of the Lower Bow Island parasequences incorporated with the paleontological data is needed to confirm this hypothesis.

Reinson et al. (1994) believed that the sequence boundary between the Middle (HST) and the Upper Bow Island (TST) can be correlated with the sequence boundary in the middle of the Viking Formation, separating the HST deposits from the TST deposits. Both the sediments of the Upper Bow Island and the Viking Formation, overlying the sequence boundary, represent the deposits of TST. It is possible that the incised valleys within the Upper Bow Island and the Viking Formation are time equivalent. However the incised valleys within the Bow Island are not as developed as those of the Viking Formation, possibly due to the lack of the topographic knickpoint.

Foraminiferal assemblages show that the sediments of the Upper Bow Island can be correlated with at least the upper part of the Viking Formation that carries faunal elements of the *Miliammina manitobensis* Zone (Stritch and Schröder-Adams, 1999). For a better understanding of the relationship between the Bow Island and the Viking formations, micropaleontological analysis of the Lower Bow Island is needed as well as the relationship between the foraminiferal zonations and sequence stratigraphic framework of the Viking Formation. However biostratigraphy can be used for the correlation purposes only if the biostratigraphic zones are not facies controlled, but represent true time zones as discussed in chapter *Foraminiferal Zones in the Upper Bow Island and the Westgate Formation*. This seems to have limitations in shallow marine settings.

Conclusions

A multidisciplinary study of the Bow Island and Westgate formations in southwestern Alberta (6-18W4 to 14-28W4) (fig. 2), including sedimentological, micropaleontological, petrophysical and geochemical analyses, has led to several conclusions:

1. Following Cox (1993) the Bow Island Formation is subdivided into three distinct informal lithostratigraphic units in the study area of southwestern Alberta: the Lower Bow Island, the Middle Bow Island, and the Upper Bow Island that can be clearly distinguished on the well-logs.

The Lower Bow Island represents deposits of the highstand systems tract (HST). Based on wire line log signatures this unit is composed of several shelf-shoreface parasequences prograding basinward (Cox, 1993) in response to the sediment input, coming from the uplifting Cordillera to the west.

The Middle Bow Island is composed predominantly of the paleosols of coastal-plain associations, prograding into the basin and disappearing to the northeast of the study area. The boundary between the Lower and the Middle Bow Island represents a facies transition from the shelf-shoreface deposits into non-marine coastal-plain deposits. The Middle Bow Island represents possibly the final stage of the HST started in the Lower Bow Island. This confirms the findings of Cox (1993) and Reinson et al. (1994). The Middle Bow Island-Upper Bow Island boundary represents a combined sequence boundary / transgressive reworking surface and, as no major incision has occurred, it is characterized as a type 2 sequence boundary (Posamentier et al., 1988).

Sediments of the Upper Bow Island Formation represent the transgressive systems tract (TST). The initial stage of the transgression is marked by widespread deposition of the shoreface and offshore-shoreface facies association. Several relative sea-level drops during an overall transgression were recorded as the transgressive lag deposits within the shoreface and offshore-shoreface facies association on the east and as valley incisions on the west (fig. 22). Deposits of the estuarine and lagoonal-estuarine

facies associations filled valleys during the subsequent sea-level rise. Possibly multiple incision and deposition created compound fill of the incised valleys. Some estuarine and lagoonal-estuarine deposits might represent an infill of the relief left on top of the Middle Bow Island.

Transgressive lag deposits at the base of the Westgate Formation mark a major flooding event. Due to the absence of a biostratigraphic boundary between the Bow Island and the Westgate formations, it is more likely that the Westgate flooding represents a new, although significant stage of the transgressive event, started at the base of the Upper Bow Island, and does not necessarily correspond with the beginning of the global Greenhorn transgression. In western and southern parts of the study area foraminiferal assemblages recorded fluctuations of the paleoecological conditions and possibly presence of the oxygen deficiency within the bottom waters. Poorly represented foraminiferal assemblages of the Fish Scales Formation confirm bottom-water anoxia by Leckie et al. (1992) and Schröder-Adams et al. (1996).

2. The Lower Bow Island and the Middle Bow Island can be correlative to the parasequences of the regional Viking Formation east of the study area. The sequence boundary between the Middle and the Upper Bow Island is possibly time equivalent to the sequence boundary in the middle of the Viking Formation. Incised valleys of the Upper Bow Island and the Viking Formation can therefore be considered as the result of the same higher ordered sea-level drops. Biostratigraphically the Upper Bow Island is correlated with the upper part of the Viking Formation.

3. Foraminiferal assemblages from the Upper Bow Island and the Westgate Formation have very similar composition, and are both assigned to the *Miliammina manitobensis* Zone, in most cases to its *Verneuilina canadensis* Subzone. However, some elements of the *Haplophragmoides gigas* fauna are also present. The studied microfossil assemblages demonstrate that foraminiferal zonations established for the late Albian interval do not stay uniform in composition over regional areas but show some variations. It is obvious that many faunal elements of the *Miliammina manitobensis* and the

Haplophragmoides gigas zones are facies controlled can alternate or be found within the same assemblage depending on environmental conditions.

4. The Upper Bow Island - Westgate assemblages of this study are similar to the *Miliammina manitobensis* fauna previously reported from the upper portion of the Viking and the Westgate formations of central Alberta (Stritch and Schröder-Adams, 1999), from the shales above the Viking Formation in the Suffield area, southeastern Alberta (Tizzard and Lebrekmo, 1975), from the Shell Creek Shale in the Big Horn Basin of Wyoming (Eicher, 1960), from the basal part of the Sunkay Member of the Blackstone Formation in the Rocky Mountain foothills of central Alberta (Wall, 1967), from the upper part of the Paddy Member and the lower part of the Shaftesbury Formation, Goodfare area of northwestern Alberta (Stelck and Leckie, 1990a), from the upper Buckinghamshire Shale and Sikanni Sandstones in the Sikanni Chief River area, northeastern British Columbia (Stelck, 1975), showing the wide extent of the Mowry Sea. Also the Upper Bow Island - Westgate assemblages show a close relationship with the fauna of Alaska (Tappan, 1957, 1962; Berquist, 1966) and northern Yukon (Mountjoy and Chamney, 1969; Chamney, 1978).

5. The Upper Bow Island - Westgate benthic foraminiferal assemblages show extreme variations in abundance, diversity and composition, responding to the fluctuations of paleoecological conditions within the shallow sea. During Westgate time fresh water discharge from the land caused salinity reduction and possibly created density stratification of the water column, leading to the oxygen deficiency of bottom waters in the western part of the study area.

6. In general sediments of both the Bow Island and Westgate formations show low TOC and HI values and are not likely to be a source of a hydrocarbon generation.

Plate 1

- 1, 2** *Bathysiphon brosegi* Tappan. **(1)** The Westgate Formation, 11-17-10-21W4, sample 14 (3081.5 ft). **(2)** The Westgate Formation, 10-25-7-20W4, sample 14' (785.02 m).
- 3** *Hyperammina* spp. The Westgate Formation, 10-25-7-20W4, sample 11 (789.4 m).
- 4, 5** *Hyperammina emancerata* (Chamney) **(4)** The Westgate Formation, 10-25-7-20W4, sample 11 (789.4 m). **(5)** The Westgate Formation, 6-16-6-22W4, sample 16 (985.5 m).
- 6** *Psammosphaera* sp. The Westgate Formation, 11-17-10-21W4, sample 8 (3095.0 ft)
- 7** *Ammodiscus kiowensis* Loeblich and Tappan. The Westgate Formation, 10-25-7-20W4, sample 11 (789.4 m).
- 8** *Saccammina alexanderi* (Loeblich and Tappan). The Bow Island Formation, 10-25-7-20W4, sample 5 (798.55 m).
- 9** *Saccammina lathrami* Tappan. The Bow Island Formation, 10-25-7-20W4, sample 6 (797.85 m).
- 10, 11** *Saccammina globosa* Crespin **(10)** The Bow Island Formation, 10-25-7-20W4, sample 4 (799.2 m). **(11)** The Westgate Formation, 11-17-10-21W4, sample 10 (3092 ft).
- 12, 13** *Ammotium* spp. **(12)** The Westgate Formation, 11-17-10-21W4, sample 6' (3103 ft). **(13)** The Westgate Formation, 11-17-10-21W4, sample 6' (3103 ft).
- 14** *Ammomarginulina* spp. The Bow Island Formation, 7-2-8-21W4, sample 13 (859.03 m).
- 15 a, b** *Ammomarginulina cragini* Loeblich and Tappan. The Bow Island Formation, 11-28-9-21W4, sample 4 (3050 ft).
- 16, 17** *Reophax vasiformis* Chamney. **(16)** The Bow Island Formation, 10-25-7-20W4, sample 4 (799.2 m). **(17)** The Westgate Formation, 10-25-7-20W4, sample 11 (789.4 m).
- 18** *Reophax* cf. *pepperensis* Loeblich. The Bow Island Formation, 10-25-7-20W4, sample 3 (800.6 m).
- 19 a, b** *Reophax (Scherochorella) minuta* Tappan. The Westgate Formation, 10-25-7-20W4, sample 11 (789.4 m).
- 20** *Reophax tundraensis* Chamney. The Bow Island Formation, 10-25-7-20W4, sample 6 (797.85 m).
- 21** *Reophax troyeri* Tappan. The Bow Island Formation, 10-25-7-20W4, sample 4 (799.2 m).
- 22 a, b** *Reophax sikanniensis* Stelck. The Bow Island Formation, 10-25-7-20W4, sample 4 (799.2 m).

Plate 2

- 1 *Ammobaculites fragmentarius* Cushman. The Westgate Formation, 11-17-10-21W4, sample 13 (3089 ft).
- 2 *Ammobaculites tyrrelli* Nauss. The Westgate Formation, 11-17-10-21W4, sample 9 (3092.5 ft).
- 3 *Ammobaculites pacalis* Stelck and Wall. The Bow Island Formation, 7-2-8-21W4, sample 18 (854.21 m).
- 4 a, b *Ammobaculites petilus* Eicher. The Bow Island Formation, 10-25-7-20W4, sample 4 (799.2 m).
- 5, 6 *Haplophragmium* cf. *engleri* Stelck and Hedinger. (5) The Bow Island Formation, 10-25-7-20W4, sample 4 (799.2 m). (6) The Westgate Formation, 11-17-10-21W4, sample 9 (3092.5 ft).
- 7 *Ammobaculites* cf. *plummerae* Loeblich. The Bow Island Formation, 7-2-8-21W4, sample 6 (866.85 m).
- 8 *Ammobaculoides whitneyi* (Cushman and Alexander). The Bow Island Formation, 10-25-7-20W4, sample 2 (801.15 m).
- 9 a, b *Ammobaculoides* cf. *phaulus* Loeblich and Tappan. The Westgate Formation, 10-25-7-20W4, sample 11 (789.4 m).
- 10, 11 *Gaudryina canadensis* Cushman. (10) The Bow Island Formation, 10-25-7-20W4, sample 4 (799.2 m). (11) The Westgate Formation, 11-17-10-21W4, sample 12 (3090 ft).
- 12 *Gaudryina irenensis* Stelck and Wall. The Bow Island Formation, 10-25-7-20W4, sample 5 (798.55 m).
- 13 *Gaudryina* cf. *nanushukensis* Tappan. The Bow Island Formation, 10-25-7-20W4, sample 5 (798.55 m).
- 14 *Gaudryina tailleuri* (Tappan). The Bow Island Formation, 7-2-8-21W4, sample 6 (866.85 m).
- 15, 16 *Verneuilinoides perplexus* (Loeblich). (15) The Bow Island Formation, 10-25-7-20W4, sample 2 (801.15 m). (16) The Westgate Formation, 10-25-7-20W4, sample 11 (789.4 m).
- 17 *Verneuilinoides borealis* Tappan. The Bow Island Formation, 10-25-7-20W4, sample 2 (801.15 m).
- 18 a, b *Verneuilina canadensis* Cushman. The Bow Island Formation, 7-2-8-21W4, sample 6 (866.85 m).
- 19, 20 *Verneuilinoides* cf. *fischeri* Tappan. (19) The Bow Island Formation, 7-2-8-21W4, sample 11 (861.4 m). (20) The Bow Island Formation, 7-2-8-21W4, sample 5 (867.3 m).
- 21 *Tritaxia solea* Chamney. The Bow Island Formation, 7-2-8-21W4, sample 6 (866.85 m).

Plate 3

- 1 a, b** *Uvigerinammina athabascensis* (Mellon and Wall). The Bow Island Formation, 10-25-7-20W4, sample 3 (800.6 m).
- 2 a, b** *Uvigerinammina manitobensis* (Wickenden). The Bow Island Formation, 10-25-7-20W4, sample 6 (797.85 m).
- 3, 4** *Miliammina manitobensis* Wickenden. **(3)** The Bow Island Formation, 10-25-7-20W4, sample 5 (798.55 m). **(4)** The Bow Island Formation, 7-2-8-21W4, sample 11 (861.4 m).
- 5** *Miliammina ischnia* Tappan. The Bow Island Formation, 7-2-8-21W4, sample 11 (861.4 m).
- 6** *Miliammina inflata* Eicher. The Westgate Formation, 10-25-7-20W4, sample 11 (789.4 m).
- 7** *Miliammina* cf. *sproulei* (Nauss). The Westgate Formation, 10-25-7-20W4, sample 9 (792.3 m).
- 8, 9** *Miliammina awunensis* Tappan. **(8)** The Westgate Formation, 11-28-9-21W4, sample 11 (2980 ft). **(9)** The Bow Island Formation, 7-2-8-21W4, sample 11 (861.4 m).
- 10** *Psammimopelta bowsheri* Tappan. The Westgate Formation, 10-25-7-20W4, sample 11 (789.4 m).
- 11, 12** *Psammimopelta subcircularis* Tappan. **(11)** The Westgate Formation, 10-25-7-20W4, sample 11 (789.4 m). **(12)** The Westgate Formation, sample 14 (3081.5 ft).
- 13** *Spiroplectaminina* cf. *ammovitrea* Tappan. The Bow Island Formation, 7-2-8-21W4, sample 11 (861.4 m).
- 14** *Textularia* sp. A. The Westgate Formation, 10-25-7-20W4, sample 11 (789.4 m).
- 15, 16** *Textularia topagorukensis* Tappan. **(15)** The Westgate Formation, 10-25-7-20W4, sample 8 (792.6 m). **(16)** The Westgate Formation, 11-17-10-21W4, sample 9 (3092.6 ft).
- 17** *Textulariopsis minuta* Berthelin. The Bow Island Formation, 10-25-7-20W4, sample 5 (798.55 m).
- 18 a, b, 19, 20** *Pseudobolivina variana* Eicher. **(18 a, b)** The Bow Island Formation, 10-25-7-20W4, sample 5 (798.55 m). **(19)** The Westgate Formation, 11-17-10-21W4, sample 11 (3091 ft). **(20)** The Bow Island Formation, 7-2-8-21W4, sample 18 (854.21 m).

Plate 4

- 1 a, b, c** *Trochammina alcanensis* Stelck. (**1 a**) Spiral view. (**2 b, c**) Umbilical view. The Bow Island Formation, sample 4 (799.2 m)
- 2 a, b, c** *Trochammina depressa* Lozo. (**2 a, c**) Spiral view. (**2 b**) Umbilical view. The Westgate Formation. 10-25-7-20W4, sample 11 (789.4 m).
- 3, 4** *Trochammina rutherfordi* Stelck and Wall. (**3**) The Bow Island Formation. 7-2-8-21W4, sample 12 (860.73 m). (**4**) The Westgate Formation, 10-25-7-20W4, sample 11 (789.4 m).
- 5 a, b** *Trochammina umiatensis* Tappan. (**5 a**) Spiral view. (**5 b**) Umbilical view. The Westgate Formation. 11-17-10-21W4, sample 12 (3090 ft).
- 6 a, b** *Trochammina rainwateri* Cushman and Applin. (**6 a**) Spiral view. (**6 b**) Umbilical view. The Westgate Formation. 11-17-10-21W4, sample 15 (3072 ft).
- 7 a, b** *Haplophragmoides* cf. *bonanzaense* Stelck and Wall. (**7 a**) Side view. (**7 b**) Apertural view. The Bow Island Formation. 10-25-7-20W4, sample 2 (801.15 m).
- 8** *Haplophragmoides* cf. *gilberti* Eicher. The Westgate Formation. 10-25-7-20W4, sample 14 (785.6 m).
- 9** *Haplophragmoides* spp. The Bow Island Formation. 7-2-8-21W4, sample 10 (862.12 m).
- 10 a, b, c** *Haplophragmoides postis goodrichi* Sutherland and Stelck. (**10 a, c**) Side view. (**10 b**) Aperturacal view. The Westgate Formation. 10-25-7-20W4, sample 11 (789.4 m).
- 11 a, b** *Haplophragmoides linki* Nauss. (**11 a**) Side view. (**11 b**) Apertural view. The Westgate Formation. 10-25-7-20W4, sample 11' (789.1 m).

Foraminiferal Reference List

Family **ASTRORHIZIDAE** Brady, 1881

Genus ***Bathysiphon*** Sars, 1872

Bathysiphon brosgiei Tappan, 1957

- 1957 *Bathysiphon brosgiei* Tappan: p. 202, pl. 65, figs. 1-5
 1962 *Bathysiphon brosgiei* Tappan: Tappan, p. 128, pl. 29, figs. 1-5
 1972 *Bathysiphon brosgiei* Tappan: Sutherland and Stelck, p. 558, pl. 1, figs. 1, 2
 1975 *Bathysiphon brosgiei* Tappan: Stelck, pl. 1, figs. 1-3
 1975b *Bathysiphon brosgiei* Tappan: North and Caldwell, pl. 6, fig. 2
 1981 *Bathysiphon brosgiei* Tappan: McNeil and Caldwell, p. 129, pl. 9, fig. 1
 1981 *Bathysiphon brosgiei* Tappan: Sliter, p. 52, pl. 9, figs. 1, 2
 1987 *Bathysiphon brosgiei* Tappan: Stelck and Koke, pl. 1, figs. 1-3
 1988 *Bathysiphon brosgiei* Tappan: Harrison, p. 21-23, pl. 1, fig. 1
 1999 *Bathysiphon brosgiei* Tappan: Stritch and Schröder-Adams, pl. 1, figs. 1, 2

Family **SACCAMMINIDAE** Brady, 1884

Genus ***Psammosphaera*** Schulze, 1875

***Psammosphaera* sp.**

- 1958 *Saccammina* sp. Stelck, Wall, and Wetter, p. 31, pl. 4, fig. 11
 1972 *Saccammina* sp. C Sutherland and Stelck, p. 560-562, pl. 1, fig. 9
 1984 *Psammosphaera* spp. Koke and Stelck, pl. 1, figs. 6-11
 1985 *Psammosphaera* sp. A Koke and Stelck, pl. 1, figs. 11, 12
 1987 *Psammosphaera* sp. C Stelck and Koke, pl. 1, figs. 18
 1987 *Psammosphaera* sp. A Stelck and Koke, pl. 1, figs. 19-22
 1988 *Psammosphaera* sp. Harrison, p. 25-26, pl. 1, figs. 12-14
 1999 *Psammosphaera* sp. A Stritch and Schröder-Adams, pl. 1, fig. 4

Genus ***Saccammina*** Sars, 1869

Saccammina alexanderi (Loeblich and Tappan), 1950

- 1950 *Priteonina alexanderi* Loeblich and Tappan, p. 5, pl. 1, figs. 1, 2

- 1955 *Priteonina alexanderi* Loeblich and Tappan; Stelck and Wall, p. 52-53.
pl. 1, fïgs. 5, 6
- 1960 *Saccammina alexanderi* (Loeblich and Tappan); Eicher, p. 55. pl. 1, fïgs.
10-12
- 1963 *Saccammina alexanderi* (Loeblich and Tappan); Crespin, p. 20-21. pl. 1.
fïgs. 10-12
- 1965 *Saccammina alexanderi* (Loeblich and Tappan); Eicher, p. 891-892, pl.
103, fig. 1
- 1967 *Saccammina alexanderi* (Loeblich and Tappan):: Eicher, p. 180. pl. 17.
fig. 1
- 1967 *Saccammina alexanderi* (Loeblich and Tappan); Wall, p. 40-41. pl. 8.
fïgs. 16, 17, pl. 14, fïgs. 17, 18
- 1967 *Saccammina alexanderi* (Loeblich and Tappan); Guliov, p. 1617. pl. 1.
fïgs. 3a, b
- 1970 *Saccammina alexanderi* (Loeblich and Tappan); North and Caldwell, p.
14-15, pl. 1, fig. 6
- 1972 *Saccammina alexanderi* (Loeblich and Tappan); Sutherland and Stelck.
p. 558-559. pl. 1, fïgs. 3, 4
- 1975b *Saccammina alexanderi* (Loeblich and Tappan); North and Caldwell, pl.
1, fig. 4, pl. 6, fig. 6
- 1983 *Saccammina alexanderi* (Loeblich and Tappan); Stelck and Hedinger, pl.
1, fig. 6
- 1984 *Saccammina alexanderi* (Loeblich and Tappan); Koke and Stelck, pl. 1.
fig. 9
- 1985 *Saccammina alexanderi* (Loeblich and Tappan); Koke and Stelck, pl. 1.
fïgs. 14, 15
- 1987 *Saccammina alexanderi* (Loeblich and Tappan) ssp. C Stelck and Koke.
pl. 1, fïgs. 14, 15
- 1987 *Saccammina alexanderi alexanderi* (Loeblich and Tappan); Stelck and
Koke, pl. 1, fïgs. 34, 35

1988 *Saccammina alexanderi* (Loeblich and Tappan); Harrison, p. 26-28, pl. 1.
figs. 17, 18, 24, 25, 26

1999 *Saccammina alexanderi* (Loeblich and Tappan); Stritch and Schröder-
Adams, pl. 1, fig. 4

***Saccammina globosa* Crespin, 1963**

1963 *Saccammina globosa* Crespin, p. 21, pl. 1, figs. 13-17

1999 *Saccammina globosa* Crespin; Stritch and Schröder-Adams, pl. 1, fig. 6.
7

***Saccammina lathrami* Tappan, 1960**

1960 *Saccammina lathrami* Tappan: p. 289, pl. 1, figs. 1, 2

1962 *Saccammina lathrami* Tappan: Tappan, p. 129, pl. 29, figs. 9-12

1964 *Saccammina* cf. *lathrami* Tappan: North and Caldwell, p. 15, pl. 1, fig. 3

1970 *Saccammina lathrami* Tappan: North and Caldwell, p. 15, p. 1, fig. 4

1975b *Saccammina lathrami* Tappan: North and Caldwell, pl. 1, fig. 5, pl. 6.
fig. 5

1985 *Saccammina lathrami* Tappan: Koke and Stelck, pl. 1, figs. 13, 16

1987 *Saccammina lathrami* Tappan: Stelck and Koke, pl. 1, figs. 13, 16

1988 *Saccammina lathrami* Tappan: Harrison, p. 28-30, pl. 1, figs. 19-21

1999 *Saccammina lathrami* Tappan: Stritch and Schröder-Adams, pl. 1, figs. 5,
10, 11

Genus ***Thuramminoides* Plummer, 1945**

***Thuramminoides septagonalis* Chamney, 1969**

1969 *Thuramminoides septagonalis* Chamney, p. 14, pl. 1, figs. 8-11

1975b *Thuramminoides septagonalis* Chamney: Stelck, pl. 1, figs. 11-13

1984 *Thuramminoides* sp. cf. *T. septagonalis* Chamney: Koke and Stelck, pl. 1,
figs. 12, 13

1987 *Thuramminoides septagonalis* Chamney: Stelck and Koke, pl. 1, figs. 15,
16

1988 *Thuramminoides septagonalis* Chamney: Harrison, p. 30-31, pl. 1, figs.
29, 30, 34, 35

Family **HIPPOCREPINIDAE** Rhumbler, 1895Genus *Hippocrepina* Parker, 1870*Hippocrepina barksdalei* (Tappan), 19571957 *Hyperamminoides barksdalei* Tappan, p. 202, pl. 65, figs. 6-121962 *Hyperamminoides barksdalei* Tappan; Tappan, 1962, p. 129, pl. 29, figs.
21-271964 *Hippocrepina barksdalei* (Tappan); Loeblich and Tappan, p. C-1881981 *Hippocrepina barksdalei* (Tappan); Sliter, p. 52, pl. 9, figs. 8, 9, 131984 *Hippocrepina barksdalei* (Tappan); Koke and Stelck, pl. 1, fig. 1, 21985 *Hippocrepina barksdalei* (Tappan); Stelck and Koke, pl. 1, fig. 6, 71987 *Hippocrepina barksdalei* (Tappan); Stelck and Koke, pl. 2, fig. 81988 *Hippocrepina barksdalei* (Tappan); Harrison, p. 32-33, pl. 1, figs. 4-7.
15, 161999 *Hippocrepina barksdalei* (Tappan); Stritch and Schröder-Adams, pl. 1,
figs. 2, 15Genus *Hyperammina* Brady, 1978*Hyperammina emancerata* (Chamney), 19781978 *Bathysiphon emancerata* Chamney, p. 9, figs. 4, 51985 *Hyperammina emancerata* (Chamney); Koke and Stelck, pl. 1, figs. 5, 81987 *Hyperammina emancerata* (Chamney), Stelck and Koke, pl. 1, figs. 6-9,
12-131999 *Hyperammina emancerata* (Chamney); Stritch and Schröder-Adams, pl.
1, fig. 3Family **AMMODISCIDAE** Reuss, 1862Genus *Ammodiscus* Reuss, 1862*Ammodiscus kiowensis* Loeblich and Tappan, 19501950 *Ammodiscus kiowensis* Loeblich and Tappan, p. 5-6, pl. 1, figs. 3a, b1960 *Involutina kiowensis* (Loeblich and Tappan), Eicher, p. 55-56, pl. 3, fig. 31967 *Ammodiscus kiowensis* Loeblich and Tappan; Guliov, p. 18, pl. 1, figs.
7a, b

1975b *Ammodiscus kiowensis* Loeblich and Tappan; North and Caldwell, pl. 1, figs. 7a, b

1981 *Ammodiscus kiowensis* Loeblich and Tappan; McNeil and Caldwell, p. 136, pl. 9, fig. 14

1984 *Ammodiscus kiowensis* Loeblich and Tappan; Stelck and Koke, pl. 1, fig. 1, 15

1987 *Ammodiscus kiowensis* Loeblich and Tappan; Stelck and Koke, pl. 2, fig. 18

Genus ***Glomospira*** Rzehak. 1885

Glomospira glomerosa Eicher. 1960

1960 *Glomospira glomerosa* Eicher, p. 56, pl. 3, fig. 6

1972 *Glomospira glomerosa* Eicher; Suherland and Stelck, p. 563, pl. 1, figs. 14, 15

1975b *Glomospira glomerosa* Eicher; North and Caldwell, pl. 1, figs. 8a, b

1981 *Glomospira glomerosa* Eicher; p. 138, pl. 9, figs. 18a, b

Family **HORMOSINIDAE** Haeckel. 1894

Genus ***Reophax*** de Montfort. 1808

***Reophax* sp. A**

Reophax* cf. *R. deskeri Tappan. 1940

1940 *Reophax deskeri* Tappan, p. 94, pl. 1, figs. 3a, b

1943 *Reophax deskeri* Tappan; Tappan, p. 479, pl. 77, fig. 3

1963 *Reophax deskeri* Tappan; Crespin, p. 23, pl. 3, figs. 1-10

1981 *Reophax deskeri* Tappan; Sliter, p. 53, pl. 9, figs. 5, 6

1988 *Reophax deskeri* Tappan; Harrison, p. 48-49, pl. 2, figs. 5-7

1991 *Reophax deskeri* Tappan; Stelck, pl. 4, figs. 2, 4, 5

1999 *Reophax deskeri* Tappan; Stritch and Schröder-Adams, pl. 1, figs. 16, 17

Reophax* cf. *R. recta (Beissel) Eicher. 1967

1967 *Reophax recta* (Beissel) Eicher, p. 180, pl. 17, figs. 3, 4

1972 *Reophax recta* (Beissel) Eicher; Sutherland and Stelck, p. 563, pl. 1, figs. 16, 17

***Reophax sikanniensis* Stelck, 1975**

1975 *Reophax sikanniensis* Stelck: p. 266, pl. 1, figs. 16-18

1999 *Reophax sikanniensis* Stelck: Stritch and Schröder-Adams, pl. 1, fig. 18

***Reophax troyeri* Tappan, 1960**

1960 *Reophax troyeri* Tappan, p. 291, pl. 1, figs. 10-12

1962 *Reophax troyeri* Tappan: Tappan, p. 133, pl. 30, figs. 11-13

1967 *Reophax* sp. Guliov, p. 19-20, pl. 2, fig. 4

1981 *Reophax troyeri* Tappan: McNeil and Caldwell, p. 139-140, pl. 10, figs.

1, 2a, b

1981 *Reophax troyeri* Tappan: Sliter, p. 53, pl. 9, figs. 17, 18

1985 *Reophax troyeri* Tappan: Koke and Stelck, pl. 1, figs. 20-24

1987 *Reophax troyeri* Tappan: Stelck and Koke, pl. 2, figs. 2, 6, 7

1988 *Reophax troyeri* Tappan: Harrison, p. 5051, pl. 2, figs. 9, 10

1991 *Reophax troyeri* Tappan: Stelck, pl. 1, fig. 12

1999 *Reophax troyeri* Tappan: Stritch and Schröder-Adams, pl. 1, fig. 19, pl. 2,

fig. 1

***Reophax tundraensis* Chamney, 1969**

1969 *Reophax tundraensis* Chamney, p. 22-23, pl. 4, figs. 2-4

1975 *Reophax tundraensis* Chamney: Stelck, pl. 1, fig. 19

1987 *Reophax tundraensis* Chamney: Stelck and Koke, pl. 2, fig. 1

1999 *Reophax tundraensis* Chamney: Stritch and Schröder-Adams, pl. 2, fig. 2

***Reophax vasiformis* Chamney, 1978**

1978 *Reophax vasiformis* Chamney, p. 10, pl. 1, figs. 12-14

1985 *Reophax vasiformis* Chamney: Koke and Stelck, pl. 1, figs. 17, 18, 19

1987 *Reophax vasiformis vasiformis* Chamney: Stelck and Koke, pl. 1, figs. 36,

37

***Reophax (Scherochorella) minuta* Tappan, 1940**

1940 *Reophax minuta* Tappan, p. 94, pl. 14, figs. 4a-b

1962 *Reophax minuta* Tappan: Tappan, p. 132, pl. 30, fig. 10

1965 *Reophax minuta* Tappan: Eicher, p. 892, pl. 105, fig. 1

1975 *Reophax minuta* Tappan: Stelck, pl. 1, fig. 24

- 1983 *Reophax minuta* Tappan: Stelck and Hedinger, pl. 1, figs. 17, 18
 1984 *Scherochorella minuta* (Tappan); Loeblich and Tappan, p. 1160
 1985 *Reophax minuta* Tappan: Koke and Stelck, pl. 1, figs. 25, 26
 1988 *Scherochorella minuta* (Tappan); Harrison, p. 56-57, pl. 2, fig. 22
 1990a *Scherochorella minuta* (Tappan): Stelck and Leckie, pl. 1, fig. 14
 1991 *Scherochorella minuta* (Tappan): Stelck, pl. 4, fig. 14
***Reophax (Scherochorella) pepperensis* Loeblich, 1946**
 1946 *Reophax pepperensis* Loeblich, p. 133, pl. 22, figs. 1a, b
 1962 *Reophax pepperensis* Loeblich: Tappan, p. 133, pl. 30, fig. 14
 1987 *Reophax (Scherochorella) pepperensis* Loeblich: Stelck and Koke, pl. 2, figs. 4, 5

Family **RZEHAKINIDAE** Cushman, 1933

Genus ***Miliammina*** Heron-Allen and Earland, 1930

***Miliammina awunensis* Tappan, 1957**

- 1957 *Miliammina awunensis* Tappan, p. 210, pl. 67, figs. 19-21
 1962 *Miliammina awunensis* Tappan: Tappan, p. 159-160, pl. 36, figs. 20-24
 1975 *Miliammina awunensis* Tappan: Stelck, pl. 1, fig. 33-35
 1987 *Miliammina awunensis* Tappan: Stelck and Koke, pl. 2, figs. 23, 24
 1988 *Miliammina awunensis* Tappan: Harrison, p. 39-40, pl. 2, fig. 19-21
 1999 *Miliammina awunensis* Tappan: Stritch and Schröder-Adams, pl. 2, fig. 3

***Miliammina inflata* Eicher, 1960**

- 1960 *Miliammina inflata* Eicher, p. 70-71, pl. 5, figs. 13, 14
 1967 *Miliammina inflata* Eicher: Gulio, p. 21, pl. 3, figs. 2a-c
 1972 *Miliammina inflata* Eicher: Sutherland and Stelck, p. 564, pl. 2, figs. 1, 2
 1985 *Miliammina inflata* Eicher: Koke and Stelck, pl. 2, figs. 4, 5
 1987 *Miliammina inflata* Eicher: Stelck and Koke, pl. 2, figs. 21, 22
 1988 *Miliammina inflata* Eicher: Harrison, p. 40-42, pl. 2, figs. 28-30

***Miliammina ischnia* Tappan, 1957**

- 1957 *Miliammina ischnia* Tappan, p. 211, pl. 67, figs. 25, 26
 1960 *Miliammina ischnia* Tappan: Eicher, p. 71, pl. 5, figs. 11, 12

- 1962 *Miliammina ischnia* Tappan: Tappan, p. 160-161, pl. 37, figs. 1-5
- 1972 *Miliammina ischnia* Tappan: Sutherland and Stelck, p. 564, pl. 2, figs. 3-5
- 1985 *Miliammina sproulei* Nauss: Koke and Stelck, pl. 2, figs. 2, 3, 7, 8
- 1987 *Miliammina sproulei* Nauss: Stelck and Koke, pl. 2, figs. 19, 20
- 1988 *Miliammina ischnia* Tappan: p. 42-43, pl. 2, fig. 31
- 1999 *Miliammina ischnia* Tappan: Stritch and Schröder-Adams, pl. 2, fig. 5
- Miliammina manitobensis* Wickenden, 1932**
- 1932 *Miliammina manitobensis* Wickenden, p. 90, pl. 1, figs. 11a-c
- 1960 *Miliammina manitobensis* Wickenden: Eicher, p. 71, pl. 5, figs. 15, 16
- 1962 *Miliammina manitobensis* Wickenden: Tappan, p. 160, pl. 36, figs. 12-18
- 1967 *Miliammina manitobensis* Wickenden: Guliov, p. 22, pl. 3, figs. 3a, b
- 1972 *Miliammina manitobensis* Wickenden: Sutherland and Stelck, p. 566, pl. 2, figs. 6-9
- 1975 *Miliammina manitobensis* Wickenden: Stelck, pl. 1, figs. 31, 32
- 1975b *Miliammina manitobensis* Wickenden: North and Caldwell, pl. 1, figs. 12a, b, 14a, b
- 1981 *Miliammina manitobensis* Wickenden: McNeil and Caldwell, p. 143-144, pl. 10, figs. 9-14
- 1981 *Miliammina manitobensis* Wickenden: Sliter, p. 53, pl. 12, figs. 8, 12, 16
- 1983 *Miliammina manitobensis* Wickenden: Stelck and Hedinger, pl. 1, fig. 15
- 1985 *Miliammina manitobensis* Wickenden: Koke and Stelck, pl. 1, figs. 30, 31
- 1988 *Miliammina manitobensis* Wickenden: Harrison, p. 43-45, pl. 2, figs. 35-38
- 1999 *Miliammina manitobensis* Wickenden: Stritch and Schröder-Adams, pl. 2, figs. 4, 6
- Miliammina* cf. *M. sproulei* Nauss, 1947**
- 1947 *Miliammina sproulei* Nauss, p. 339, pl. 48, figs. 13a-c
- 1956 *Miliammina sproulei* Nauss: Stelck et al., p. 45, pl. 5, figs. 7-12

1960 *Miliammina* sp. cf. *M. sproulei* Nauss; Eicher, 1960, p. 72, pl. 5, figs. 17, 18

1967 *Miliammina sproulei* Nauss; Guliov, p. 22, pl. 3, figs. 6a-c

Genus ***Psamminopelta*** Tappan, 1957

Psamminopelta bowsheri Tappan, 1957

1957 *Psamminopelta bowsheri* Tappan, p. 11, pl. 67, figs. 11-18, 22-24

1962 *Psamminopelta bowsheri* Tappan; Tappan, p. 157, pl. 37, figs. 11-22

1965 *Spirolocammina bowsheri* (Tappan); Eicher, p. 893, pl. 103, figs. 6, 10

1967 *Psamminopelta* sp. Tappan; Guliov, p. 23, pl. 3, figs. 4, 5

1972 *Psamminopelta bowsheri* Tappan; Sutherland and Stelck, p. 566-567, pl. 2, figs. 14-17, pl. 3, figs. 1-4

1975b *Psamminopelta bowsheri* Tappan; North and Caldwell, p. 144-145, pl. 1, figs. 10a, b, 11

1981 *Psamminopelta bowsheri* Tappan; McNeil and Caldwell, p. 144-145, pl. 10, fig. 17

1981 *Psamminopelta bowsheri* Tappan; Sliter, p. 53, pl. 12, figs. 13, 14

1983 *Psamminopelta bowsheri* Tappan; Stelck and Hedinger, pl. 1, fig. 16

1984 *Psamminopelta bowsheri* Tappan; Koke and Stelck, pl. 1, figs. 22, 23

1985 *Psamminopelta bowsheri* Tappan; Koke and Stelck, pl. 2, fig. 6

1987 *Psamminopelta bowsheri* Tappan; Stelck and Koke; pl. 2, figs. 27, 28

1988 *Psamminopelta bowsheri* Tappan; Harrison, p. 46-48, pl. 3, figs. 1-4

1999 *Psamminopelta bowsheri* Tappan; Stritch and Schröder-Adams, pl. 2, figs. 7, 8

Psamminopelta subcircularis Tappan, 1957

1957 *Psamminopelta subcircularis* Tappan, p. 213, pl. 67, figs. 8-10

1960 *Spirolocammina subcircularis* (Tappan); Eicher, p. 73-74, pl. 5, figs. 19, 20

1962 *Psamminopelta subcircularis* Tappan; Tappan, p. 158-159, pl. 37, figs. 7-10

Family **LITUOLIDAE** de Blainville, 1825

Genus *Ammobaculites* Cushman, 1910

Ammobaculites fragmentarius Cushman, 1927

- 1927a *Ammobaculites fragmentaria* Cushman, p. 130, pl. 1, fig. 8
- 1956 *Ammobaculites fragmentarius* Cushman: Stelck et al., p. 21-22, pl. 5, figs. 18, 19
- 1960 *Ammobaculites fragmentarius* Cushman: Eicher, p. 61-62, pl. 4, fig. 11
- 1967 *Ammobaculites fragmentarius* Cushman variety: Guliov, p. 27-28, pl. 5, figs. 1a, b
- 1967 *Ammobaculites fragmentarius* Cushman: Wall, p. 55, pl. 4, figs. 7-9
- 1975 *Ammobaculites fragmentarius* Cushman: Stelck, pl. 2, figs. 21-23, 25-27; pl. 3, figs. 1, 2, 15
- 1975b *Ammobaculites fragmentarius* Cushman: North and Caldwell, pl. 2, figs. 2-5
- 1978 *Ammobaculites fragmentarius* Cushman: Chamney, p. 14, pl. 3, figs. 9a, b, 10
- 1981 *Ammobaculites fragmentarius* Cushman: McNeil and Caldwell, p. 158-159, pl. 12, figs. 6, 7
- 1981 *Ammobaculites fragmentarius* Cushman: Sliter, p. 54, pl. 22, figs. 1-5
- 1984 *Ammobaculites fragmentarius* Cushman: Koke and Stelck, pl. 1, fig. 42
- 1985 *Ammobaculites fragmentarius* Cushman: Koke and Stelck, pl. 3, figs. 3, 6, 12
- 1985 *Ammobaculites tyrrelli tyrrelli* Nauss: Koke and Stelck, pl. 3, figs. 13
- 1987 *Ammobaculites fragmentarius* Cushman: Stelck and Koke, pl. 3, figs. 31, 32
- 1988 *Ammobaculites fragmentarius* Cushman: Harrison, p. 73-76, pl. 5, figs. 4-7, 15
- 1999 *Ammobaculites fragmentarius* Cushman: Stritch and Schröder-Adams, pl. 3, figs. 5-8

Ammobaculites cf. *A. humei* Nauss, 1947

- 1947 *Ammobaculites humei* Nauss, p. 333, pl. 48, fig. 1

1984 *Ammobaculites humei* Nauss; Koke and Stelck, pl. 1, figs. 36, 37, 40, 41, 43, 44

***Ammobaculites pacalis* Stelck and Wall, 1954**

1954 *Ammobaculites pacalis* Stelck and Wall, pl. 1, fig. 19

***Ammibaculites petilus* Eicher, 1960**

1960 *Ammibaculites petilus* Eicher, p. 62-63, pl. 4, figs. 2, 4

1967 *Ammibaculites petilus* Eicher; Guliov, p. 28, pl. 5, fig. 2

1975b *Ammibaculites petilus* Eicher; North and Caldwell, pl. 2, figs. 6, 7

1981 *Ammibaculites petilus* Eicher; McNeil and Caldwell, p. 159, pl. 12, fig. 8

1999 *Ammibaculites petilus* Eicher; Stritch and Schröder-Adams, pl. 3, fig. 9

***Ammobaculites tyrrelli* Nauss, 1947**

1947 *Ammobaculites tyrrelli* Nauss, p. 333, pl. 48, fig. 2

1960 *Ammobaculites tyrrelli* Nauss; Eicher, p. 64, pl. 4, fig. 1

1967 *Ammobaculites tyrrelli* Nauss; Guliov, p. 28-29, pl. 5, figs. 3a, b

1975b *Ammobaculites tyrrelli* Nauss; North and Caldwell, pl. 2, figs. 8, 9

1981 *Ammobaculites tyrrelli* Nauss; McNeil and Caldwell, p. 159-160, pl. 12, figs. 9, 10

1984 *Ammobaculites tyrrelli* Nauss; Koke and Stelck, pl. 1, figs. 38, 39, 45, 46

1985 *Ammobaculites tyrrelli tyrrelli* Nauss; Koke and Stelck; pl. 3, figs. 1, 2, 4, 5

1985 *Ammobaculites tyrrelli* Nauss var. *jolifoungnsis* Stelck and Wall; Koke and Stelck, pl. 3, fig. 7

1987 *Ammobaculites tyrrelli tyrrelli* Nauss; Stelck and Koke; pl. 3, figs. 16, 17

1987 *Ammobaculites tyrrelli* Nauss var. *jolifoungnsis* Stelck and Wall; Stelck and Koke, pl. 3, fig. 35, 36

1999 *Ammobaculites tyrrelli* Nauss; Stritch and Schröder-Adams, pl. 3, fig. 13-15, pl. 4, fig. 1

***Ammobaculites* cf. *A. wallaensis* Crespin, 1963**

1963 *Ammobaculites wallaensis* Crespin, p. 45, pl. 11, figs. 1-5

1987 *Ammobaculites wallaensis* Crespin; Stelck and Koke, pl. 3, figs. 2, 25

1988 *Ammobaculites wallaensis* Crespin; Harrison, p. 80-81, pl. 5, figs. 22, 23

Ammobaculites cf. *A. wenonahae* Tappan, 1960

- 1960 *Ammobaculites wenonahae* Tappan, p. 291, pl. 1, figs. 3-6
 1962 *Ammobaculites wenonahae* Tappan; Tappan, p. 138-139, pl. 32, figs. 1-7
 1984 *Ammobaculites wenonahae* Tappan; Koke and Stelck, pl. 1, figs. 34, 35
 1999 *Ammobaculites wenonahae* Tappan; Stritch and Schröder-Adams, pl. 4,
 figs. 2, 3, 7

Genus *Ammobaculoides* Plummer, 1932

Ammobaculoides cf. *A. phaulus* Loeblich and Tappan, 1950

- 1950 *Ammobaculoides phaulus* Loeblich and Tappan, p. 8, pl. 1, figs. 18-20
 1960 *Ammobaculoides* cf. *phaulus* Loeblich and Tappan; Eicher, p. 64, pl. 4,
 figs. 7-10
 1967 *Ammobaculoides phaulus* Loeblich and Tappan; Guliov, p. 29, pl. 5, fig.
 5

Ammobaculoides cf. *A. plummerae* Loeblich, 1950

- 1950 *Ammobaculoides* cf. *A. plummerae* Loeblich, pl. 1, figs. 24-27

Ammobaculoides whitneyi (Cushman and Alexander), 1930

- 1930 *Spiroplectammina whitneyi* Cushman and Alexander, p. 8, pl. 2, fig. 12
 1949 *Ammobaculoides whitneyi* (Cushman and Alexander); Loeblich and
 Tappan, p. 252, pl. 47, figs. 2-4
 1960 *Ammobaculoides whitneyi* (Cushman and Alexander); Eicher, p. 65, pl. 4,
 figs. 12-14
 1967 *Ammobaculoides whitneyi* (Cushman and Alexander); Guliov, p. 30-31,
 pl. 5, figs. 6-8
 1975b *Ammobaculoides whitneyi* (Cushman and Alexander); North and
 Caldwell, pl. 2, fig. 12
 1981 *Ammobaculoides whitneyi* (Cushman and Alexander); McNeil and
 Caldwell, p. 160-161, pl. 12, figs. 11, 12

Genus *Ammomarginulina* Wiesner, 1931

Ammomarginulina cragini Loeblich and Tappan, 1950

- 1950 *Ammomarginulina cragini* Loeblich and Tappan, p. 6, pl. 1, figs. 4-6

1960 *Ammomarginulina cragini* Loeblich and Tappan; Eicher, p. 60, pl. 3, fig. 20

1985 *Ammomarginulina cragini* Loeblich and Tappan; Koke and Stelck, pl. 3, 18-22

1987 *Ammomarginulina cragini* Loeblich and Tappan; Stelck and Koke, pl. 3, fig. 15

1988 *Ammomarginulina cragini* Loeblich and Tappan; Harrison, p. 85-86, pl. 5, figs. 30-35

1999 *Ammomarginulina cragini* Loeblich and Tappan; Stritch and Schröder-Adams, pl. 4, fig. 4

Genus *Ammotium* Loeblich and Tappan, 1953

Ammotium spp.

1955 *Ammomarginulina lorangerae* Stelck and Wall, 1955, pl. 1, figs. 13, 27

1983 *Ammotium* sp. Stelck and Hedinger, p. 1257, pl. 2, fig. 32

1988 *Ammotium* sp. Harrison, p. 87, pl. 6, fig. 1

1990 *Ammotium lorangerae* (Stelck and Wall); Stelck and Leckie, pl. 1, figs. 22, 23

Genus *Haplophragmoides* Cushman, 1910

Haplophragmoides bonanzaense Stelck and Wall, 1954

1954 *Haplophragmoides bonanzaense* Stelck and Wall, p. 24, pl. 2, fig. 10

1962 *Haplophragmoides bonanzaensis* Stelck and Wall; Tappan, p. 133, pl. 30, figs. 10

Haplophragmoides gilberti Eicher, 1965

1965 *Haplophragmoides gilberti* Eicher, p. 894-895, pl. 103, fig. 11, 13, 14

1984 *Haplophragmoides* sp. cf. *H. gilberti* Eicher, Koke and Stelck, pl. 1, figs. 24-32

1987 *Haplophragmoides gilberti* Eicher; Stelck and Koke, pl. 2, fig. 35-39

Haplophragmoides linki Nauss, 1947

1947 *Haplophragmoides linki* Nauss, p. 339, pl. 49, figs. 7a, b

1956 *Haplophragmoides linki* Nauss; Stelck et al., p. 36-37, pl. 4, figs. 17, 18, pl. 5, figs. 5, 6

- 1960 *Alveophragmium linki* (Nauss); Eicher, p. 59-60, pl. 3, figs. 9-11
 1967 *Haplophragmoides linki* Nauss; Guliov, p. 25, pl. 4, figs. 3a, b
 1975b *Haplophragmoides linki* Nauss; North and Caldwell, pl. 1, figs. 17a, b
 1978 *Haplophragmoides linki* Nauss; Chamney, p. 13-14, pl. 3, figs. 6a, b, 7
 1981 *Haplophragmoides linki* Nauss; McNeil and Caldwell, p. 153, pl. 11, figs. 11a, b

***Haplophragmoides postis goodrichi* Sutherland and Stelck, 1972**

- 1972 *Haplophragmoides postis goodrichi* Sutherland and Stelck; p. 570, pl. 3, figs. 13-15
 1999 *Haplophragmoides postis goodrichi* Sutherland and Stelck; Stritch and Schröder-Adams, pl. 3, fig. 2

Family **EGGERELLIDAE** Cushman, 1925

Genus ***Egerella*** Cushman, 1933

***Egerella* spp.**

- 1956 *Egerella* sp. A Stelck and Wall; Stelck *et al.*, p. 3, pl. 2, figs. 17-20
 1985 Koke and Stelck, pl. 4, figs. 24-26
 1999 *Egerella* sp. A Stritch and Schröder-Adams, pl. 4, fig. 15

Family **TEXTULARIIDAE** Ehrenberg, 1838

Genus ***Textularia*** DeFrance, 1984

***Textularia* sp. A**

***Textularia topagorukensis* Tappan, 1957**

- 1957 *Textularia topagorukensis* Tappan, p. 205, pl. 66, figs. 8-9
 1962 *Textularia topagorukensis* Tappan; Tappan p. 141, pl. 33, figs. 7-11
 1975 *Textularia topagorukensis* Tappan; Stelck, pl. 3, figs. 22, 23
 1981 *Textularia topagorukensis* Tappan; Sliter, p. 54, pl. 11, figs. 6, 7, 8
 1999 *Textularia topagorukensis* Tappan; Stritch and Schröder-Adams, pl. 4, figs. 5, 6

Genus ***Pseudobolivina*** Wiesner, 1931

***Pseudobolivina variana* (Eicher), 1960**

- 1960 *Bimonolina variana* Eicher. p. 67, pl. 4, figs. 15-19
- 1963 *Bimonolina variana* Eicher. Crespín, p. 55-56, pl. 14, figs. 15-19
- 1965 *Pseudobolivina variana* (Eicher); Eicher, p. 897-898, pl. 104, figs. 8
- 1967 *Pseudobolivina variana* (Eicher); Eicher, p. 183, pl. 18, fig. 1
- 1967 *Pseudobolivina* sp. A (Eicher); Wall, p. 66-67, pl. 4, fig. 24; pl. 11, figs. 17-24
- 1975b *Pseudobolivina variana* (Eicher); North and Caldwell, pl. 2, figs. 19a, b, 20
- 1981 *Pseudobolivina variana* (Eicher); McNeil and Caldwell, p. 166, pl. 13, fig. 3
- 1985 *Pseudobolivina variana* (Eicher); Koke and Stelck, pl. 4, fig. 10
- 1987 *Pseudobolivina variana* (Eicher) var. A. Stelck and Koke, pl. 4, figs. 20, 21
- 1988 *Pseudobolivina variana* (Eicher); Harrison, p. 116-118, pl. 6, figs. 14-17
- Genus *Spiroplectammina* Cushman. 1927
- Spiroplectammina* cf. *S. ammovitrea* Tappan. 1940
- 1940 *Spiroplectammina. ammovitrea* Tappan: p. 97, pl. 14, figs. 13a-b
- 1962 *Spiroplectammina. ammovitrea* Tappan: Tappan, p. 139, pl. 33, fig. 4

Family **TEXTULARIOPSIDAE** Loeblich and Tappan. 1982

Genus *Textulariopsis* Banner and Perra. 1981

Textulariopsis minuta (Berthelin). 1880

- 1985 *Textulariopsis minuta* (Berthelin); Koke and Stelck, pl. 4, figs. 27, 28
- 1987 *Textulariopsis minuta* (Berthelin); Stelck and Koke, pl. 4, figs. 26, 27
- 1991 *Textulariopsis minuta* (Berthelin); Stelck, pl. 3, figs. 30-32
- 1999 *Textulariopsis minuta* (Berthelin); Stritch and Schröder-Adams, pl. 4, figs. 8, 10, 11

Family **TROCHAMMINIDAE** Schwager. 1877

Genus *Trochammina* Parker and Jones. 1859

Trochammina alcanensis Stelck. 1975

- 1975b *Trochammina alcanensis* Stelck, p. 266-267, pl. 3, figs. 16, 17, 20, 21
 1987 *Trochammina alcanensis* Stelck: Stelck and Koke, pl. 4, figs. 14-16
 1988 *Trochammina alcanensis* Stelck: Harrison, p. 92, pl. 6, figs. 18-20
 1999 *Trochammina alcanensis* Stelck: Stritch and Schröder-Adams, pl. 4, fig.

9

***Trochammina depressa* Lozo, 1944**

- 1944 *Trochammina depressa* Lozo: p. 552, pl. 2, figs. 4, 5
 1949 *Trochammina depressa* Lozo: Loeblich and Tappan, p. 256, pl. 149, figs.
 1, 2
 1960 *Trochammina depressa* Lozo: Eicher, p. 74, pl. 6, figs. 3, 4
 1967 *Trochammina depressa* Lozo: Guliov, p. 33-3, pl. 7, figs. 1a-c
 1981 *Trochammina depressa* Lozo: McNeil and Caldwell, p. 168, pl. 13, figs.
 81-c

- 1985 *Trochammina depressa* Lozo: Koke and Stelck, pl. , figs. 68, 16
 1987 *Trochammina depressa* Lozo: Stelck and Koke, pl. 4, figs. 12, 13

***Trochammina cf. T. gatesensis* Stelck and Wall, 1956**

- 1956 *Trochammina gatesensis* Stelck and Wall, p. 53, pl. 4, figs. 9-11
 1960 *Trochammina gatesensis* Stelck and Wall: Eicher, p. 74-75, pl. 6, figs. 6,
 7
 1984 *Trochammina gatesensis* Stelck and Wall, Koke and Stelck, pl. 1, figs.
 52-53.
 1991 *Trochammina gatesensis* Stelck and Wall: Stelck, pl. 3, figs. 13, 14.
 1999 *Trochammina gatesensis* Stelck and Wall: Stritch and Schröder-Adams,
 pl. 4, fig. 12

***Trochammina rainwateri* Cushman and Applin, 1946**

- 1946 *Trochammina rainwateri* Cushman and Applin: p. 75, pl. 13, fig. 9
 1962 *Trochammina rainwateri* Cushman and Applin: Tappan p. 153, pl. 39,
 figs. 7-12
 1965 *Trochammina rainwateri* Cushman and Applin: Eicher, . p. 898-899, pl.
 105, figs. 16a-c

- 1967 *Trochammina rainwateri* Cushman and Applin; Eicher, p. 183-184,
pl.18, figs. 10a-c, 13a-c
- 1970 *Trochammina rainwateri* Cushman and Applin; Eicher and Worstell, p.
282, pl. . figs. 15a, b
- 1975b *Trochammina rainwateri* Cushman and Applin; North and Caldwell, pl.
2, figs. 21a, b, 22, 23a, b
- 1978 *Trochammina rainwateri* Cushman and Applin; Chamney, p. 22, pl. 4,
figs. 18, 19
- 1981 *Trochammina rainwateri* Cushman and Applin; McNeil and Caldwell, p.
169-170, pl. 13, figs. 11a-c, 12a-c
- 1984 *Trochammina* sp. cf. *T. rainwateri* Cushman and Applin; pl. 1, figs. 49-
51
- Trochammina rutherfordi* Stelck and Wall. 1955**
- 1955 *Trochammina rutherfordi* Stelck and Wall, p. 56-57, pl. 1, figs. 11, 12
- 1955 *Trochammina rutherfordi* var. 1 Stelck and Wall, p. 57-58, pl. 1, figs.
14a-c, pl. 3, figs. 20, 21
- 1955 *Trochammina rutherfordi* var. 2 Stelck and Wall, p. 58-59, pl. 1, figs. 15,
16, pl. 3, figs. 36, 37
- 1958 *Trochammina rutherfordi* var. 2 Stelck and Wall; Stelck, Wall and
Wetter, p. 33-34, pl. 4, figs. 6-10
- 1962 *Trochammina ribstonensis* Wickenden subspecies *rutherfordi* Stelck and
Wall; Tappan, p. 155-156, pl. 39, figs. 18-20
- 1965 *Trochammina rutherfordi* Stelck and Wall; Eicher, p. 899-900, pl. 105,
figs. 1a-c
- 1967 *Trochammina rutherfordi* Stelck and Wall; Wall, p. 70-71, pl. 2, figs. 8-
31, pl. 4, figs. 813
- 1975b *Trochammina rutherfordi* Stelck and Wall; North and Caldwell, pl. 3,
figs. 1a-b
- 1981 *Trochammina rutherfordi* Stelck and Wall; McNeil and Caldwell, p. 171-
172, pl. 14, figs. 2a-c

- 1985 *Trochammina rutherfordi rutherfordi* Stelck and Wall; Koke and Stelck, pl. 4, figs. 13-15
- 1988 *Trochammina rutherfordi rutherfordi* Stelck and Wall; Harrison, p. 93-95, pl. 6, figs. 23-25, 28-32
- 1999 *Trochammina rutherfordi* Stelck and Wall; Stritch and Schröder-Adams, pl. 4, fig. 13

***Trochammina umiatensis* Tappan, 1957**

- 1957 *Trochammina umiatensis* Tappan, p. 214, pl. 67, figs. 27-29
- 1962 *Trochammina umiatensis* Tappan; Tappan, p. 156, pl. 38, figs. 5-8
- 1972 *Trochammina umiatensis* Tappan.; Sutherland and Stelck, p. 575, pl. 5, figs. 1-4
- 1975 *Trochammina umiatensis* Tappan; Stelck, pl. 3, figs. 9, 10, 18, 19
- 1981 *Trochammina umiatensis* Tappan; Sliter, p. 57, pl. 12, figs. 9-11
- 1987 *Trochammina umiatensis* Tappan; Stelck and Koke, pl. 4, figs. 5-11, 17, 18
- 1988 *Trochammina umiatensis* Tappan; Harrison, p. 95-97, pl. 6, figs. 33-40, pl. 7, figs. 1, 2, 7, 8
- 1999 *Trochammina umiatensis* Tappan; Stritch and Schröder-Adams, pl. 4, fig. 14

Family **VERNEUILIINIDAE** Cushman, 1911

Genus ***Gaudryina*** d'Orbigny, 1839

Gaudryina canadensis Cushman, 1943

- 1943 *Gaudryina canadensis* Cushman, p. 28, pl. 6, figs. 7, 8
- 1962 *Gaudryina canadensis* Cushman; Tappan, p. 146, pl. 35, figs. 1-7
- 1975b *Gaudryina canadensis* Cushman; North and Caldwell, pl. 3, figs. 9a, b, 10a, b, 11a, b
- 1978 *Gaudryina canadensis* Cushman; Chamney, p. 20, pl. ., figs. 9-11
- 1981 *Gaudryina canadensis* Cushman; McNeil and Caldwell, p. 176, pl. 14, figs. 10, 11
- 1985 *Gaudryina canadensis* Cushman; Koke and Stelck, pl. 3, figs. 23, 24

- 1987 *Gaudryina canadensis* Cushman; Stelck and Koke, pl. 4, fig. 28
 1999 *Gaudryina canadensis* Cushman; Stritch and Schröder-Adams, pl. 5, figs.
 1, 2

***Gaudryina irenensis* Stelck and Wall, 1955**

- 1955 *Gaudryina irenensis* Stelck and Wall, p. 42-43, pl. 2, figs. 4, 5
 1962 *Gaudryina irenensis* Stelck and Wall; Tappan, p. 147, pl. 35, figs. 17-21
 1975b *Gaudryina irenensis* Stelck and Wall; North and Caldwell, pl. 3, figs.
 12-15
 1981 *Gaudryina irenensis* Stelck and Wall; McNeil and Caldwell, p. 177, pl. 1,
 figs. 8, 9

***Gaudryina* cf. *G. nanushukensis* Tappan, 1951**

- 1951 *Gaudryina nanushukensis* Tappan, p. 2, pl. 1, figs. 8a-11
 1962 *Gaudryina nanushukensis* Tappan; Tappan, p. 148, pl. 34, figs. 11-15
 1978 *Gaudryina nanushukensis* Tappan; Chamney, p. 18, pl. 4, figs. 3a-5
 1999 *Gaudryina nanushukensis* Tappan; Stritch and Schröder-Adams, pl. 5,
 fig. 4

***Gaudryina tailleuri* (Tappan), 1957**

- 1957 *Verneuiliinoides tailleuri* Tappan, p. 208, pl. 66, figs. 19-22
 1962 *Gaudryina tailleuri* (Tappan); Tappan, p. 149, pl. 35, figs. 29-30
 1975 *Verneuiliinoides tailleuri* Tappan; Stelck, pl. 3, figs. 29-31
 1978 *Verneuiliinoides tailleuri* Tappan; Chamney, p. 15, pl. 3, figs. 17, 18
 1999 *Gaudryina tailleuri* (Tappan); Stritch and Schröder-Adams, pl. 5, fig. 6

Genus *Tritaxia* Reuss, 1860

***Tritaxia solea* Chamney, 1978**

- 1978 *Tritaxia solea* Chamney, p. 15-16, pl. 3, figs. 19-21

Genus *Uvigerinammmina* Majzon, 1943

***Uvigerinammmina athabascensis* (Mellon and Wall) 1956**

- 1956 *Tritaxia athabascensis* Mellon and Wall, 1956, p. 27, pl. 1, figs. 16, 17
 1962 *Uvigerinammmina athabascensis* (Mellon and Wall); p. 144, pl. 33, fig. 12
 1967 *Uvigerinammmina* sp. cf. *U. athabascensis* (Mellon and Wall); Wall, pl. 1,
 figs. 10-13

1999 *Uvigerinammina athabascensis* (Mellon and Wall): Stritch and Schröder-Adams, pl. 5, fig. 9

***Uvigerinammina manitobensis* (Wickenden). 1932**

1932 *Tritaxia manitobensis* Wickenden, p. 87-88, pl. 1, fig. 10

1937 *Tritaxia manitobensis* Wickenden: Cushman, p. 27, pl. , fig. 7

1946 *Tritaxia manitobensis* Wickenden: Cushman, p. 31, pl. 7, fig. 8

1962 *Uvigerinammina manitobensis* (Wickenden): Tappan, p. 145, pl. 33, figs. 18-23

1964 *Uvigerinammina manitobensis* (Wickenden): Loeblich and Tappan, p. C272

1967 *Uvigerinammina cf. manitobensis* (Wickenden): Gulio, p. 35-36, pl. 7, fig. 3

1975 "*Tritaxia*" *manitobensis* Wickenden: Stelck, pl. 3, fig. 24

1975b *Uvigerinammina manitobensis* (Wickenden): North and Caldwell, pl. 3, figs. 18a, b

1981 *Uvigerinammina manitobensis* (Wickenden): McNeil and Caldwell, p. 179, pl. 14, figs. 15-18

1981 *Uvigerinammina manitobensis* (Wickenden): Sliter, p. 57, pl. 11, fig. 12

1985 *Uvigerinammina manitobensis* (Wickenden): Koke and Stelck, pl. 4, figs. 2-5

1987 *Uvigerinammina manitobensis* (Wickenden): Stelck and Koke, pl. 4, figs. 22, 23, 38-41

1988 *Uvigerinammina manitobensis* (Wickenden): Harrison, p. 111-113, pl. 8, figs. 11-14

Genus ***Verneuilina*** d'Orbigny, 1839

Verneuilina canadensis Cushman, 1927

1927 *Verneuilina canadensis* Cushman, p. 131, pl. 1, fig. 11

1937 *Verneuilina canadensis* Cushman: Cushman, p. 13, pl. 1, figs. 16, 17

1946 *Verneuilina canadensis* Cushman: Cushman, p. 12, pl. 7, figs. 2, 3

1960 *Verneuilina canadensis* Cushman: Eicher, p. 67-68, pl. 5, figs. 1, 2

1965 *Verneuilina canadensis* Cushman: Eicher, p. 901, pl. 105, fig. 5

- 1967 *Verneuilina canadensis* Cushman; Wall, p. 74-75, pl. 1, figs. 14, 15
- 1975b *Verneuilina canadensis* Cushman; North and Caldwell, pl. 3, figs. 9-11
- 1981 *Verneuilina canadensis* Cushman; McNeil and Caldwell, p. 175, pl. 14, fig. 3
- 1985 *Verneuilina canadensis* Cushman; Koke and Stelck, pl. 4, fig. 1
- 1987 *Verneuilina canadensis* Cushman; Stelck and Koke, pl. 4, figs. 36, 37
- 1988 *Verneuilina* cf. *V. canadensis* Cushman; Harrison, p. 108, pl. 8, figs. 1-4
- 1999 *Verneuilina canadensis* Cushman; Stritch and Schröder-Adams, pl. 4, fig. 16

Genus *Verneulinoides* Loeblich and Tappan, 1949

Verneulinoides borealis Tappan, 1957

- 1957 *Verneulinoides borealis* Tappan, p. 206, pl. 66, figs. 10-18
- 1962 *Verneulinoides borealis* Tappan; p. 142-143, pl. 34, figs. 1-9
- 1987 *Verneulinoides borealis* Tappan; Stelck and Koke, pl. 4, fig. 42
- 1990 *Verneulinoides borealis* Tappan; Stelck and Leckie, pl. 1, figs. 35-37
- 1999 *Verneulinoides borealis* Tappan; Stritch and Schröder-Adams, pl. 5, figs. 7, 8, 10

Verneulinoides cf. *V. fischeri* Tappan, 1957

- 1957 *Verneulinoides fischeri* Tappan, p. 207-208, pl. 66, figs. 23-28
- 1962 *Verneulinoides fischeri* Tappan; Tappan, p. 143-144, pl. 32, figs. 12-17
- 1975 *Verneulinoides* sp. cf. *V. fischeri* Tappan; Stelck, pl. 3, figs. 25, 26
- 1988 *Verneulinoides fischeri* Tappan; Harrison, p. 113-114, pl. 8, figs. 16-18

Verneulinoides perplexus (Loeblich) 1946

- 1946 *Verneuilina perplexa* Loeblich, p. 138, pl. 22, figs. 14-16
- 1950 *Verneulinoides kansasensis* Loeblich and Tappan, p. 10, pl. 2, figs. 1, 2
- 1960 *Verneulinoides kansasensis* Loeblich and Tappan; Eicher, p. 69, pl. 5, figs. 6-10
- 1963 *Verneulinoides kansasensis* Loeblich and Tappan; Crespin, p. 57, pl. 15, figs. 4-7
- 1965 *Verneulinoides perplexus* (Loeblich); Eicher, p. 901-902, pl. 5, figs. 10, 11, 14, 15

- 1967 *Verneuulinoides kansasensis* Loeblich and Tappan; Wall, p. 76-77, pl. 2, figs. 1-7
- 1972 *Verneuulinoides perplexus* (Loeblich); Sutherland and Stelck, p. 578, pl. 5, fig. 18
- 1975b *Verneuulinoides perplexus* (Loeblich); North and Caldwell, pl. 3, figs. 7, 8
- 1981 *Verneuulinoides perplexus* (Loeblich); McNeil and Caldwell, p. 180, 182, pl. 14, figs. 19-21
- 1988 *Verneuulinoides perplexus* (Loeblich); Harrison, p. 114-115, pl. 8, fig. 19-21

Family **ATAXOPHRAGMIIDAE** Schwager, 1877

Genus *Arenobulimina* Cushman, 1927

Arenobulimina paynei Tappan

- 1957 *Arenobulimina* (?) *paynei* Tappan, p. 208, pl. 67, figs. 1-4
- 1962 *Arenobulimina prayei* Tappan; Tappan, p. 151-152, pl. 36, figs. 1-4
- 1975b *Arenobulimina prayei* Tappan; North and Caldwell, pl. 3, figs. 16a, b, 17a, b
- 1984 *Arenobulimina paynei* Tappan; Koke and Stelck, pl. 1, figs. 63-66
- 1988 *Arenobulimina paynei* Tappan; Harrison, p. 118-119, pl. 8, figs. 15, 22

Family **GLOBOTEXTULARIIDAE** Cushman, 1927

Genus *Gravellina* Bronnimann, 1933

Gravellina chamneyi Stelck, 1975

- 1975 *Gravellina chamneyi* Stelck, p. 267-268, pl. 3, figs. 27, 28, 37-44
- 1975b *Gravellina chamneyi* Stelck; North and Caldwell, pl. 3, figs. 16, 17
- 1981 *Gravellina chamneyi* Stelck; McNeil and Caldwell, p. 186, pl. 14, figs. 22a, b
- 1983 *Gravellina chamneyi* Stelck; Stelck and Hedinger, pl. 2, figs. 34, 38, 39, 35, 36
- 1985 *Gravellina chamneyi* Stelck var. A; Koke and Stelck, pl. 4, figs. 30, 31

- 1987 *Gravellina chamneyi* Stelck; Stelck and Koke, pl. 4, figs. 33, 34
 1988 *Gravellina chamneyi* Stelck; Harrison, p. 120-121, pl. 8, figs. 25-33
 1999 *Gravellina chamneyi* Stelck; Stritch and Schröder-Adams, pl. 5, figs. 11-13

Family **HAPLOPHRAGMIIDAE** Eimer and Fickert, 1899

Genus *Haplophragmium* Reuss, 1860

Haplophragmium cf. *H. engleri* Stelck and Hedinger, 1976

- 1976 *Haplophragmium engleri* Stelck and Hedinger, p. 140, pl. 1, figs. 1-5
 1983 *Haplophragmium engleri* Stelck and Hedinger; Stelck and Hedinger, pl. 2, figs. 3, 4, 6, 14, 15
 1987 *Haplophragmium engleri* Stelck and Hedinger var. *A* Stelck and Koke, pl. 3, figs. 33, 34, 37, pl. 4, fig. 1

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Appendix 1

Facies Description

6-32-13-27W4

Facies 1: Gray-green massive pedified muddy siltstone (2096.95 m - 2093.29 m)

Description: Facies 1 consists of massive gray pedified muddy siltstone that becomes greenish gray to green upwards with increasing mud component. Occasionally mottling can be seen. Siltstone is very compacted and is breaking mainly in rubbly blocks. Numerous primary sedimentary structures were deformed during the soil forming processes, although parallel lamination and ripple cross-lamination can be observed within the unaltered material. Pyrite nodules that replaced organic material, siderite nodules and vertical root-traces, usually infilled with black mudstone, are common within this facies. Carbonate material occasionally appears within sediments in the lower part of the unit. A greenish- gray medium sandstone bed, 63 cm thick, with sharp contacts and low angle parallel cross-bedding, occurs at 2095.15 m. At the top of Facies 1 few black mud clasts and less compacted beds with slickenslide surfaces can be observed.

Geochemistry: Samples 1, 2, 3 and 4

Foraminifera: No foraminifera have been recovered within this facies.

Facies 2 Brownish-gray pedified silty mudstone (2093.29 m - 2087.85 m)

Description: Facies 2 shows similarities to Facies 1, but differs mainly in coloration, degree of consolidation, percentage of mud component, presence of pyrite nodules and abundance of slickenslide surfaces. They consist of silty mudstones, brownish-gray to gray with a gradational basal contact. These more muddy and less consolidated sediments of Facies 2 are broken into subrounded tabular blocks rather than rubbly ones with some granular-nodular structure. Some primary structures such as parallel lamination and ripple cross-lamination are occasionally preserved within the sediments. Larger blocks may contain

vertical root-traces and clasts of yellow-green and black mudstone. Abundant slickenslide surfaces are polished with waxy texture and are randomly oriented. No pyrite nodules have been recorded within Facies 2. Two very fine sandstone beds are around 10 cm in thickness, massive, with no visible structures, and few mudstone inclusions occur at depth 2089.75 m and 2089 m. Few petrified wood and plant material was observed at the top of the unit.

Geochemistry: Samples 5, 6, 7, 8, 9, and 10

Foraminifera: No foraminifera have been recovered within this facies.

Facies 3: Interbedded dark gray silty mudstone and coal (2087.85 m - 2087.50 m)

Description: Facies 3 is sharp-based and consists of interbedded silty mudstone, dark gray, parallel thinly laminated, 2 - 3 cm thick, coal beds and laminae 0.3 - 1 cm thick. Frequency of individual coal fragments and laminae is increasing upwards. Coal carries wood and leave prints and amber fragments. The shale is consolidated and breakage of the unit occurs only along the coal laminae.

Geochemistry: Sample 11

Foraminifera: No foraminifera have been recovered within these facies.

Facies 4: Massive clean fine sandstone (2087.50 m - 2087.08 m)

Description: Clean fine sandstone, compacted, light gray, overly the mudstone of Facies 3 with a sharp lower contact. Sandstone is slightly coarsening upwards. Due to the lack of mudstone, sedimentary structures are poorly defined within this unit and are shown only as an occasional parallel interlamination and high angle cross-lamination of lighter gray and darker gray colored laminae. No trace fossils have been observed.

Geochemistry: Sample 12

Foraminifera: No foraminifera have been recovered within this facies, but one radiolarian test was found.

Facies 5: Fine-grained sandstone with silty mudstone laminae (2087.08 m - 2086.78 m)

Description: The unit is composed of light gray fine-grained sandstone beds with dark gray silty mudstone laminae. The basal contact was not observed due

to poor preservation of the lower part of the unit. Thickness of sandstone beds vary from 0.3 cm to 3 cm, thickness of thin mudstone laminae is around 0.2 - 0.5 cm. Mudstones have sharp contacts with sandstones and occur mainly as wave laminae and occasionally as flaser bedding. Primary sedimentary structures within the sandstone have been partly destroyed by postdepositional soft sediment deformation and bioturbation. Syneresis cracks, especially clear in dark gray mudstone laminae, occur within this unit and are characterized by curvy tubes infilled with coarser and lighter material (siltstone or sandstone). Bioturbation is slight to moderate within the sandstone, and moderate to intense within the mudstones. Typical trace-fossils are *Planolites* and *Teichichnus*.

Geochemistry: Sample 13

Foraminifera: No foraminifera have been recovered within this facies.

Facies 6: Intensively bioturbated mudstone and sandstone (2086.78 m - 2085.90 m)

Description: This Facies is composed of interbedded fine-grained sandstone, siltstone and mudstone beds and laminae. Intensive bioturbation gives a “chunky” appearance in the lower part of the unit. Facies 6 has a sharp-based erosional contact with Facies 5 with few distinctive vertical borrows. Sparsely preserved sandstone beds are 1-3 cm thick and decrease in thickness upwards; mudstone laminae range from 0.2 cm to 2 cm in thickness increasing upwards. A 10-cm thick bed of medium-grained sandstone appears at 2086.48 m. It has sharp (erosional) base and top contacts. No mudstone laminae, sedimentary structures or bioturbation were observed within this bed. Bases and tops of sandstone and mudstone beds and laminae are bioturbated by *Planolites*, *Teichichnus* and *Skolithos*. Degree of bioturbation increases upwards together with increasing mud content. Few coal fragments were recovered at the top, and few pyrite nodules appear within this interval.

Geochemistry: Samples 14 and 15

Foraminifera: No foraminifera have been recovered within sample 14. Sample 15 has three specimens of *Gaudryina canadensis*.

Facies 7: Medium-grained sandstone (2085.90 m - 2085.33 m)

Description: Facies 7 has some similarities with Facies 4 and 5, but differs in grain-size and internal sedimentary structures of the sandstone and the amount of mudstone laminae. Sandstone beds are predominantly medium-grained, occasionally fine-grained with a sharp basal contact. Internal sedimentary structures, indistinct at the basal part, probably due to bioturbation and/ or lack of grain and color differentiation, become more recognizable upwards. They are low-angle cross-bedding, small-scale wavy cross-bedding and high-angle cross-bedding of lighter and darker gray beds. Darkening of laminae is related to the addition of a silt component. Thin, 1 cm thick cross-beds are stacked with evidence of bipolar orientation of foresets within the sandstone sets. Inflated rip-up mud clasts with wavy appearance slightly to moderately bioturbated and one round chert pebble 1 cm in diameter were observed within the unit. At the top of facies 7 there is a high-angle cross-bedded sharp-based sandstone. Sets and individual beds are approximately 6 cm and 1-2 cm respectively. Vertical burrows dominate within this sandy facies. In most cases burrows are infilled with the same sand as hosting sand making trace-fossils indistinct. Although *Skolithos*, *Thalassinoides* (?), *Teichichnus* (?), and *Arenicolites* have been recognized among borrows.

Geochemistry: Sample 16 (taken from the shell-rich interval).

Foraminifera: No foraminifera have been recovered within this facies.

Facies 6: Intensively bioturbated mudstone and sandstone (2085.33 m – 2085. 23 m)

Description: Facies 6 has a sharp slightly bioturbated basal contact with facies 7 and is similar to those described above (see description of facies 6 from 2086.78 m - 2085.90 m interval).

No samples have been taken for geochemical and micropaleontological analysis.

Facies 8: Horizontally laminated mudstone, siltstone and fine-grained sandstone (2085.23 m - 2085.13 m)

Description: Facies 8 is characterized by slightly bioturbated laminations of mudstone, siltstone and sandstone. The relative absence of bioturbation contrasts this facies from Facies 6. A sharp basal contact was placed at the base of first relatively clean and very slightly bioturbated mudstone laminae. Thickness of laminae varies from few millimeters to about 1 centimeter. Amount of sandstone thickness and siltstone laminae and degree of bioturbation decrease upwards. Sandstone and siltstone beds are sharp-based and well sorted with appearance of faint color gradation, indicating the fining upward. The trace-fossil assemblage in Facies 8 is dominated by *Planolites* (commonly sand filled oval borrows in mud matrix). Few *Skolithos* borrows penetrate shaly sediments of Facies 8 from the top and are infilled with the overlying sandstone.

Geochemistry: Sample 17

Foraminifera: Single appearances of *Gaudryina canadensis*, *Miliammina manitobensis* and *Verneuilinoides* sp. were recorded in sample 17. Biogenic material is represented by petrified plant debris, fish remains, pyritized diatoms and pyrite concretions.

Facies 6: Intensively bioturbated mudstone and sandstone (2085.13 m - 2084.48 m)

Description: This facies has the same lithological characteristics as described above (see description of Facies 6). A medium-grained, very slightly bioturbated, 6 cm thick sandstone bed occurs at 2084.38 m. Mud rip-up clasts are observed above its sharp-based contact. Its upper contact with bioturbated sandstones and mudstones is either gradational or became invisible through intensive bioturbation.

Geochemistry: Sample 18

Foraminifera: The foraminiferal assemblage consists of *Gaudryina canadensis*, *Trochammina rutherfordi* and a single specimen of *Miliammina inflata*.

Petrified plant material, fish remains and pyrite concretions are found within the sample.

Facies 8: Horizontally laminated mudstone, siltstone and fine-grained sandstone (2084.48 m – 2083.95 m)

Description: In comparison with the first appearance of Facies 8 sedimentary structures are much better developed and preserved and are characterized by parallel and wavy bedding and parallel and rare ripple cross-lamination. Parallel lamination is dominated within usually sharp-based sandstone laminae. A sharp lower boundary separates heavily bioturbated Facies 6 and fissile shale at the base of Facies 8. Facies are slightly bioturbated dominated by *Planolites* and *Teichichnus*. Above sample 19 (2085.85 m) a 5 cm thick bed of medium sandstone, poorly sorted with few mudstone and fine-grained sandstone laminae, with sharp contacts occurs. *Skolithos* borrows were recognized within this bed. At 2084.10 m a bentonite is present within a very fine nonbioturbated, laminated, fissile mudstone and fine- to very fine-grained sandstone and can be observed for about 6 cm. Towards the top amount and thickness of sandstone laminae decrease.

Geochemistry: Sample 19

Foraminifera: The foraminiferal assemblage is poor and is presented by few specimens of *Gaudryina canadensis* and *Miliammina inflata*.

Facies 9: Moderately bioturbated silty mudstone and sandstone (2083.95 m – 2083.77 m)

Description: Facies 9 consists of thinly interbedded silty mudstone and fine sandstone. The basal contact is gradational and is characterized by an increase in sand component. Thickness of sandstone laminae vary from few millimeters to about 1 cm and generally increases upwards. While thin sandstone laminae of the lower part are almost structureless due to bioturbation, thicker laminae at the top contain parallel to lenticular bedding, parallel and rare ripple cross-lamination, soft sediment deformation (load structures). Double mud drapes and syneresis cracks were also observed. Usually sandstone laminae have sharp

lower contacts. Trace fossils are represented by *Skolithos*, *Planolites*, *Teichichnus* and *Chondrites* (?).

Geochemistry: Sample 20.

Foraminifera: *Gaudryina canadensis*, *Miliammina* spp., *Miliammina inflata*, and *Trochammina alcanensis* were found in Facies 9. Also two *Inoceramus* prisms were recorded.

**Facies 10: Cross-bedded medium- to coarse-grained sandstone
(2083.77 m – 2082. 00 m)**

Description: The unit consists of medium- to coarse-grained, poorly sorted sandstone with an upward coarsening trend. The lower contact represents the boundary between beds with thin fine-grained sandstone/mudstone interlamination and medium-grained sandstone/mudstone interbedding. Sedimentary structures represent a combination of those described within Facies 5 and Facies 7. The lower part of Facies 10 shows 1cm thick, moderately bioturbated sandstone beds with irregular wavy mudstone laminae around 0.2 cm thick. Soft sediment deformation is expressed as loaded lower contacts of sandstone beds with ball, pillow or flame structures, therefore internal sedimentary structures became invisible. Bioturbation is poorly preserved at the lower part of the unit and is not observed within the rest of the unit. Individual sandstone beds increase in thickness upwards from few centimeters up to 30 cm and are separated by black, 0.1 cm – 1 cm thick mudstone layers. Basal contacts of individual sandstone beds are sharp and occasionally loaded into underlying mudstone laminae. Trough cross-bedding, subangular and subrounded mud rip-up clasts, and double mud drapes are common.

Geochemistry: Samples 21, 22, and 23

Foraminifera: No foraminifera have been recovered within these facies. Few small pyrite concretions were found in the fine residue.

**Facies 11: Medium- to coarse-grained sandstone with pebbles
(2082.15 m – 2082. 00 m)**

Description: The unit consists of poorly sorted medium- to coarse-grained cross-bedded sandstone with rounded to subangular pebbles. No bioturbation has been observed within the sediments.

No samples have been taken for geochemical and micropaleontological analyses.

Facies 12: Interlaminated mudstone and siltstone to very fine-grained sandstone (2082m – 2078.20 m)

Description: Facies 11 sharply overlies the pebbly sandstone of Facies 10 and consists of black to dark gray fissile mudstone finely interbedded and interlaminated with sharp-based siltstone and very fine-grained sandstone. Lenticular to parallel bedded siltstones and sandstones are 0.2 – 5 cm thick and show subtle color grading that indicates upward fining. Parallel lamination is more common than asymmetrical ripple cross-lamination. Some sandstone/siltstone beds show evidence of loading at their basal contact. Sediments are non-bioturbated to very slightly bioturbated by *Planolites* and *Terebellina* (rare).

Geochemistry: Samples 24, 25, 26, and 27

Foraminifera: Sample 24 taken from Facies 11 demonstrates the most diverse and abundant foraminiferal assemblage in comparison with those recovered from previous facies. It includes *Ammobaculites tyrrelli*, *A. petilus*, *A. fragmentarius*, *Reophax* cf. *pepperensis*, and *Gaudryina* spp. The sample is rich in fish remains and contains petrified plant material, diatoms and pyrite concretions. Within the next three samples diversity and abundance dramatically decreases and the assemblage consists only of single specimens of *Ammobaculites tyrrelli*, *Bathysiphon brosgiei* (sample 25), *Trochammina* spp. (?), *Bathysiphon* spp. (?) (sample 26), and *Miliammina manitobensis* (sample 27). Within these samples petrified plant material disappears, fish remains are reduced and algal cysts appear. Abundance of *Inoceramus* prisms increase upwards and diatoms are present.

Facies 13: Massive to finely laminated mudstone with very fine-grained sandstone and siltstone laminae and beds (2078.20m - 2075 m)

Description: Facies 12 consists of nonbioturbated massive to finely laminated mudstone with lenticular laminae of siltstone and very fine-grained sandstone. This This facies has similar sedimentological characteristics than previously described Facies 11, and can be distinguished by the abundant fish and other vertebrate remains. The lithological boundary between Facies 11 and 12 is expressed as a thin medium-grained poorly sorted sandstone bed. A relatively thick (14cm), fine-grained sandstone bed, parallel stratified to structureless occurs close to the top. A bentonite occurs at 2078 m and 2075.30m.

Geochemistry: Samples 28, 29, 30, 31, 32, and 33. This facies is characterized by a significant increase in TOC and HI values.

Foraminifera: No foraminifera have been recovered within this facies. Petrified plant material and small pyrite concretions were found in sand-size fraction (>63mm) of samples 30/31 and sample 33 respectively. Fish remains are present throughout the entire unit and are the most abundant in sample 28.

6-15-9-24W4

Facies 1: Massive pedified gray-green muddy siltstone (1467.00 m – 1465.37 m)

Description: Facies 1 consists of a massive gray, coarsening upwards pedified muddy siltstone changing upwards to green. Mottling can be observed within the sediments. Primary sedimentary structures could not be seen within the most part of the unit and probably were destroyed by soil forming processes. Occasionally parallel bedding and some fine parallel lamination were noticed especially at the very top of the unit. Vertical root-traces usually in-filled with black mudstone and pyrite nodules that replaced organic material are common within this facies.

Geochemistry: Sample 1.

Foraminifera: No foraminifera have been recovered within this Facies 1 (sample 1).

Facies 2: Massive pedified dark gray silty mudstone (1465.37 m – 1461.06 m)

Description: Facies 2 sharply overlies Facies 1 and consists of silty, dark gray mudstone with few greenish gray intervals and occasional mottling. Sediments are muddier and less consolidated than Facies 1 and are broken into small fragments. Granular-nodular structures can be seen occasionally as well as parallel lamination within silty intervals. Brecciated yellowish green mud clasts and cracks within silty mudstone are common for greenish gray. Vertical root-traces have been observed at the lower part of Facies 2.

Geochemistry: Samples 2, 3, 4, 5, 6, and 7.

Foraminifera: No foraminifera have been recovered within this facies (samples 2, 3, 4, 5, 6, and 7).

Facies 3: Interlaminated mudstone and siltstone (1461.06 m - 1459.78 m)

Description: The lower part of the Facies 3 is represented by silty massive mudstone and very fine-grained sandstone with randomly oriented coal debris. The lower contact could not be observed due to poor preservation of the core.

The lower 10 cm is a matrix-supported poorly sorted breccia with angular clasts about 1 cm within the fine-grained sandstone. Clasts decrease in size upwards to 0.2 cm and the matrix becomes finer. Pyrite concretions are common within the interval. The upper part of the facies (1460.81 m – 1459.78 m) consists of very fine parallel laminated mudstone and siltstone with occasional fine-grained sandstone beds. Siltstone laminae are fining upwards. Individual sandstone beds have scoured basal and top contacts and are 2 cm to 5 cm in thickness increasing upwards. Mud laminae often show truncation at the contact. Cracks, in-filled with overlying sand, have been observed on top of mudstone. Sandstone beds have asymmetrical ripple cross-stratification. Very thin mudstone laminae are present within sandstone beds as flaser bedding and small mud clasts are found in some sandstone beds. No bioturbation to slight bioturbation has been recorded.

Geochemistry: Samples 8, and 9.

Foraminifera: No foraminifera have been recorded within this facies. Few pyrite concretions were found in sample 8, petrified plant material and pieces of amber were recovered from sample 9.

**Facies 4: Interbedded fine-grained sandstone and mudstone
(1459.78 m – 1458.11 m)**

Description: Facies 4 consists of interbedded fine-grained sandstone and mudstone beds. Sandstone beds are very similar to those described from facies 3, although increase in thickness to 40cm interbedded with 1-5 cm mudstone beds. The boundary was placed at the base of the first thick sandstone bed. Sandstone beds are well sorted, commonly with scoured bases, and contain very thin mudstone lenses that appear as flaser bedding. Mud content within Facies 4 is increasing upwards. Sandstones show wavy to subparallel cross-bedding with occasional high-angle cross-beds. Petrified plant material, small mud clasts, double mud drapes and pyrite concretions are common within sandstone beds. Few syneresis cracks were recorded within thin mudstone laminae. Mudstone beds are predominantly massive with occasional fine parallel lamination. No trace fossils were identified.

Geochemistry: Sample 10.

Foraminifera: No foraminifera have been recorded within Facies 5. One fish tooth has been recovered within the sand-size fraction.

**Facies 5: Interbedded mudstone and fine-grained sandstone
(1458.11 m – 1456.81 m)**

Description: Facies 5 consists of interbedded dark gray mudstone and fine-grained whitish gray sandstone that sharply overlies Facies 4. The lower part of the unit (1458.11 m -1457.93 m) consists of intensively bioturbated muddy siltstone and fine-grained sandstone. No primary sedimentary structures or bed thickness can be determined within the sediments due to the high degree of bioturbation. Big pyrite concretion (2 cm) were recorded at the base of the unit. Few very coarse chert grains were recovered from the sand-sized residue. The upper part of the facies is slightly to moderately bioturbated. Fissile to massive mudstone beds vary in thickness from 2 cm to 30 cm. Sandstone beds are sharp-based or scoured-based of variable thickness from few millimeter to 7 cm. Dominant sedimentary structures of the sandstone beds are sub-parallel to slightly wavy lamination and combined-flow ripples with occasional symmetrical and asymmetrical cross-lamination. A upward change from lighter (coarser) to darker (finer) colors can be observed in laminae within sandstone beds with occasional multiple-graded bedding. Towards the top sandstone beds are rare and become thinner. A thin conglomeratic layer, underlain and overlain by shale, occurs at 1456.69 m near the top of this unit. Slight to moderate bioturbation in Facies 5 mainly occurs in mudstone laminae in-between closely situated sandstone beds and laminae and is dominated by *Planolites* (commonly sand filled oval borrows in mud matrix). Some thin sandstone laminae are intensively bioturbated while thicker beds remain undisturbed. Few pyritized trace fossils, amber pieces, and petrified plant material were observed within Facies 5.

Geochemistry: Samples 11, 12, 13, 14, 15, and 16.

Foraminifera: First appearance of foraminifera within the core was recorded in Facies 5 (Sample 11). Poorly preserved *Miliammina uvulensis* and

Verneuilinoides perplexus represent a foraminiferal assemblage of low diversity and abundance. Three specimens from sample 14 and one specimen from sample 16 were recovered and include *Miliammina awunensis*, *Miliammina manitobensis*, and *Verneuilinoides perplexus*.

Facies 6: Fine- to medium-grained sandstone with wavy mudstone laminae (1456.81 m –1449.00 m)

Description: Sharp-based Facies 6 represents an overall coarsening-upward sequence grading from whitish gray fine-grained sandstone with thinly bedded or laminated black mudstone to almost clean medium-grained sandstone. Dominant sedimentary structures are sub-parallel to wavy lamination and wavy bedding within laminated sandstone and mudstone at the base of the unit to parallel to high-angle (trough?) cross-bedded at the top of the unit. Commonly high-angle cross-bedded sandstone has sharp parallel upper and occasionally lower contacts with parallel bedded sandstone. Contacts between sandstones and mudstones are sharp, scoured, and occasionally loaded. Mud rip-up clasts, petrified plant material, and double mud drapes are observed throughout the interval. Minor to moderate bioturbation was observed with *Planolites*.

Chondrites and *Skolithos* (at the top) as the most common forms.

Geochemistry: Samples 17, 18, 19, and 20.

Foraminifera: Samples 17, 18, 19, and 20 do not contain foraminifera.

11-33-11-26W4

Facies 1a: Intensively bioturbated silty mudstone and very fine- to fine –grained sandstone (1824.00 m– 1819.90 m)

Description: Facies 1a consists of intensively bioturbated silty mudstone and very fine- to fine-grained sandstone. The lower part of this facies is sandier with an upward decrease in sand component. The overall color of the rock becomes yellowish gray due to an upward increase of a pyrite component within sediments. Primary stratification and bedding styles are typically destroyed by intense biogenic reworking. Bioturbation is more intensive within muddier intervals, while thicker beds of low angle cross-laminated sandstone (1824.00 m – 1821.6 m) remain undisturbed. These sandstone beds are sharp, scoured based, about 2 cm thick and contain low-angle, wavy cross-lamination and sub-horizontal parallel lamination with presence of reactivation surfaces. Petrified plant material and pyrite concretions are rarely observed within the sediments. Some beds demonstrate a fining upward succession. Bioturbation is represented by a very diverse uniformly distributed trace- fossil assemblage including *Planolites*, *Terebellina*, *Chondrites*, *Helminthopsis* (?), *Siphonites*, *Teichichnus*, *Thalassinoides* and rarely *Skolithos*.

Geochemistry: Samples 1, 2, 3, and 4.

Foraminifera: Foraminiferal assemblages consists of 9 genera and 10 species and include *Gaudryina*, *Ammobaculites*, *Miliammina*, that are present within the whole unit. *Reophax*, *Saccamina*, *Uvigerinammina* and *Bathysiphon* appear only in the lower part, and *Verneuilinoides* and *Trochammina* are rare. Overall abundance vary from 6 to 17 specimens.

Facies 2: Intensively bioturbated fine–grained sandstone and silty mudstone with pebble layers (1819.90 m – 1819.35 m)

Description: Facies 2 has a sharp base marked with few small pebbles and consists of intensively bioturbated interbedded sandstone and silty mudstone. Thin normal graded conglomeratic layer characterizes the top of the facies. No sedimentary structures can be identified within this unit. Few fragments of the massive sandstone beds which are preserved at the base of the facies have a

thickness of 1 cm to 5 cm. They also show thin laminae of black mudstone. *Skolithos*, *Planolites*, *Terebellina* and *Thalassinoides* were recognized among the trace fossils.

Geochemistry: Sample 5

Foraminifera: The foraminiferal assemblage from sample 5 (21 specimens) is characterized by *Gaudryina*, *Verneuilinoides* and *Verneuilina*.

Facies 1b: Intensively bioturbated muddy siltstone and very fine- to fine-grained sandstone (1819.35 m – 1817.12 m)

Description: Facies 1 has a sharp contact with Facies 2 and has similar sedimentological characteristics to Facies 1, described above from the interval 1824.00 m– 1819.90 m. Facies 1a differs from Facies 1 in being sandier and in its coarsening upward nature. Sediments are almost homogeneous in the lower muddier part where few trace fossils can be identified. Trace fossils and sedimentary structures are more distinct towards the top.

Geochemistry: Samples 6, and 7.

Foraminifera: The foraminiferal assemblage is quite similar to that from Facies 1a (1824.00 m– 1819.90 m) and consists of 7 genera and 10 species. Sample 6 is the most abundant within the core (30 specimens) and is dominated by *Gaudryina*, *Ammobaculites* and *Verneuilinoides*, *Miliammina*, *Reophax*, *Textularia*, and *Uvigerinammina*. Sample 7 is not as diverse and contains only *Gaudryina*, *Ammobaculites*, *Reophax* and *Verneuilinoides*.

Facies 3: Intensively bioturbated fine-grained sandstone with mudstone (1817.12 m – 1816.40 m)

Description: Facies 3 consists of moderately to intensively bioturbated sandstone and mudstone with sharp, scoured based, non-bioturbated, parallel laminated very fine- to fine-grained sandstone beds. Facies 3 differs from Facies 1 in bioturbation and increase of sandstone causing lightening of the bulk rock color. Diverse and abundant trace-fossil assemblages are dominated by *Terebellina* with presence of *Teichichnus*, *Planolites*, *Chondrites*, *Thalassinoides*, and *Helminthopsis* (?). Trace-fossils are relatively big in size. Few shell fragments and one diatom test were recovered from the residue.

Geochemistry: Samples 8 and 9.

Foraminifera: Both samples show a low abundant and low diverse foraminiferal assemblage dominated by *Gaudryina* (12 specimens), and single appearance of *Ammobaculites*, *Miliammina* and *Verneulinoides* in sample 8 and *Pseudobolivina* in sample 9.

Facies 4: Slightly bioturbated mudstone with silty very- fine-grained sandstone laminae (1816.40 m – 1816.10 m)

Description: Facies 4 consists of parallel laminated mudstone with siltstone and very fine-grained sandstone. Siltstone and sandstone beds are generally sharp-based with sub-parallel to wavy internal lamination. Few pyrite concretions and sandstone laminae with high pyrite concentration were observed within the unit. Bioturbation is slight to occasionally moderate with presence of *Chondrites* and rarely *Teichichnus*.

No samples have been taken for geochemical and micropaleontological analysis.

Facies 5: Moderately bioturbated silty sandstone (1816.10 m – 1815.70 m)

Description: Facies 5 represent a small coarsening upward sequence that consists of interbedded mudstone and fine-grained sandstone at the base to fine-grained sandstone and muddy siltstone towards the top. The contact with underlying Facies 4 is not preserved. Sub-parallel to wavy lamination is observed within sandstone beds. Petrified plant material was noticed within the sediment. Bioturbation is moderate to slight and concentrates in the muddier beds. *Thalassinoides* and *Planolites* are the dominant trace-fossils.

Geochemistry: Sample 10.

Foraminifera: The sample taken from the muddy interval at the base of the unit contains 16 specimens of foraminifera and *Ammobaculites*, *Gaudryina*, *Trochammina* and *Verneulinoides*.

Facies 6: Conglomerate (1815.70 m – 1815.55 m)

Description: Facies 6 is represented by a normally graded, moderately to poorly sorted, matrix-supported thin conglomeratic bed with maximum pebble size of

1 cm (base of the unit). Well rounded pebbles, mainly represented by chert, are within a medium-to coarse-grained sandstone matrix that fines upward to fine-grained sandstone. The fine-grained sandstone at the top does not contain pebbles. Few mudstone layers occasionally appear within the conglomerate, especially at the top of the facies. No sedimentary or biogenic structures are recognized within the unit.

No samples have been taken for geochemical and micropaleontological analysis.

Facies 7: Interlaminated mudstone and siltstone to very fine-grained sandstone (1815.55 m – 1810.40 m)

Description: Facies 7 sharply overlies the conglomerate of Facies 6 and consists of black to dark gray fissile mudstone finely interbedded and interlaminated with sharp-based siltstone and very fine-grained sandstone. Lenticular to parallel bedded siltstones and sandstones are 0.2 – 3 cm thick and occasionally show subtle color grading that indicates fining upward. Parallel lamination is dominated by asymmetrical ripple cross-lamination, especially within thinner beds. Frequency and thickness of siltstone and sandstone laminae are increasing upwards. Few well-rounded pebbles in mixed sandstone/mudstone matrix were observed at 1815.00 m. Also two medium-grained, 2 cm thick, massive sandstone beds were recorded. Thin lamina (0.3 cm thick), made of small *Inoceramus* debris and medium-grained sandstone, was noticed at 1811.00 m. Sediments are not bioturbated to very slightly bioturbated mainly by *Planolites*.

Geochemistry: Samples 11, 12, 13, 14, and 15.

Foraminifera: The foraminiferal assemblage shows a drop in abundance and diversity. The sample taken at the very base of the facies is the most diverse in containing *Ammobaculites* as most abundant taxon, *Miliammina*, and single occurrences of *Gaudryina*, *Bathysiphon*, and *Verneuilinoides*. Sample 12 is barren of foraminifera; sample 13 contains *Miliammina*, *Ammobaculites*, and *Trochammina*; sample 14 only *Gaudryina*, and sample 15 only *Miliammina*. Miscellaneous components consist of fish remains, diatoms, *Inoceramus* and other shell fragments, and algal cysts.

Facies 8: Massive to finely laminated mudstone with very fine-grained sandstone and siltstone (1810.40 m – 1806.00 m)

Description: Facies 8 consists of non-bioturbated massive to finely laminated mudstone with siltstone and very fine-grained sandstone laminae. The interval can be subdivided into 4 slightly coarsening upward cycles with increasing thickness and frequency of sandstone and siltstone laminae. This facies has similar sedimentological characteristics with Facies 7, and can be distinguished by its abundant fish and other vertebrate remains. The contact between the sandy top of Facies 7 and the overlying black mudstone of Facies 8 is placed at the base of a bentonite bed.

Geochemistry: Samples 16, 17, 18, 18, and 20.

Foraminifera: Very few foraminifera were recovered from Facies 8. Samples 16 and 18 are barren. Sample 15 contained *Miliammina*; Sample 19 is represented by *Gaudryina*, *Miliammina* and *Saccamina*; sample 20 contains only two specimens of *Miliammina*. The interval is rich in fish remains and contains petrified plant material.

6-16-6-22W4

Facies 1: Fine-grained sandstone with medium-grained conglomeratic sandstone beds (1005.50 ft – 1003.60 ft)

Description: Facies 1 consists of fine-grained sandstone with medium-grained conglomeratic sandstone beds mainly in the lower part of the unit. The sandstone shows an asymmetrical ripple cross-lamination with rare occurrences of rip-up mud clasts. Conglomeratic sandstone beds are well to moderately sorted, clast-supported with maximum pebble size of 1.5 cm and an average size of 0.3 cm, representing fining-upward sequences. The high-angle cross-bedding is visible within one conglomeratic bed. Occasionally mudstone laminae are present within these beds. Few trace fossils were observed at the top of the facies.

Geochemistry: Sample 1, and 2.

Foraminifera: No foraminifera, but a single specimen of *Radiolaria* have been recorded within sample 1. Sample 2 contains three poorly preserved foraminiferal specimens.

Facies 2: Wavy interbedded mudstone and sandstone (1003.60 m – 994.60 m)

Description: Facies 2 consists of fine-grained sandstone with thin beds and laminae of mudstone. Lower contacts of the sandstone beds are sharp, and usually loaded. Wavy bedding and double mud drapes are common within the unit. Few syneresis cracks were recorded within thin mudstone laminae. Slight to moderate bioturbation within the mudstone laminae is mainly represented by *Planolites*. Sandstones are commonly non-bioturbated to slightly bioturbated with the presence of *Skolithos*, *Teichichnus* and *Paleophycus*. Bioturbation improves upwards together with increase in the mud laminae.

Geochemistry: Samples 3, 4, 5, 6, 7, 8, 9, and 10.

Foraminifera: Samples 3, 4, 5, 6 and 10 contain low diverse and low abundant assemblages of poorly preserved foraminifera. Identified taxa are *Reophax* spp.(?), and *Uvigerinammina manitobensis*. Preservation and abundance

increases in samples 7, 8, and 9. *Ammobaculites* sp. and *Miliammina manitobensis* are present within all three samples.

Facies 3: Fine-grained sandstone with mudstone laminae (994.60 m – 989.20 m)

Description: Fine-grained sandstone of facies 3 contains wavy laminae of mudstone, and rare thin conglomeratic layers and individual pebbles. Petrified plant material was recorded on some bedding planes. Double mud drapes and rip-up mud clasts are also present within facies 3. The sandstones are mainly massive with presence of wave and current ripples, and subparallel bedding. The interval is slightly to moderately bioturbated with a dominance of *Skolithos* and *Ophiomorpha* within the sandstone beds and *Planolites* within mudstone laminae. Massive appearance of the sandstone beds can be caused by intense bioturbation.

Geochemistry: Samples 11, 12, 13, and 14.

Foraminifera: Only sample 11 has a single record of foraminifera. Sample 13 contains abundant *Inoceramus* prisms. Other shell fragments were recovered within the first three samples of this facies.

Facies 4: Massive conglomerate (989.20 m – 986.15 m)

Description: Facies 4 erosionally overlies Facies 3 and is represented by several poorly to moderately sorted, clast-supported conglomeratic beds. Pebbles are well-rounded to sub-rounded with maximum size of 2 cm, and are composed of chert and lithic fragments. No sedimentary structures or evidence of bioturbation were recorded within this facies.

Geochemistry: Sample 15.

Foraminifera: No foraminifera have been recorded within sample 15.

Facies 5: Thin conglomerate (986.15 m – 986.00 m)

Description: Facies 5 is represented by thin conglomeratic bed that contains relatively small amount of matrix. No sedimentary structures or evidence of bioturbation were recorded within this facies.

Facies 6: Dark gray mudstone (986.00 m – 984.00 m)

Description: Facies 6 sharply overlies Facies 5 and consists of mainly non-bioturbated fissile black mudstone with occasionally bioturbated laminae and thin beds of siltstone and very fine-grained sandstone. Rare lenticular to parallel laminated siltstone and sandstone laminae occasionally show subtle color grading that indicates fining upward. Numerous beds are sharp-based or show a scoured base surface. Parallel lamination and asymmetrical ripple cross-lamination are dominant sedimentary structures. Bivalve shell fragments and fish remains are recovered from the sediments. Bioturbation is lacking or slight with *Planolites* and *Terebellina* (rare).

Geochemistry: Samples 16, and 17.

Foraminifera: Only three, poorly preserved foraminiferal specimens were recorded within sample 16. Sample 17 contains *Bathysiphon* spp., *Reophax* spp., *Miliammina ischnia*, *Reophax* cf. *pepperensis*, *Verneulinoides* spp. and 7 unidentified specimens. First appearances of *Miliammina ischnia*, *Reophax* cf. *pepperensis* and *Verneulinoides* spp. (?) are recorded within sample 17.

Facies 7: Dark gray mudstone with abundant fish remains (984.00 m – 976.50 m)

Description: Facies 7, representing the Westgate Formation has similar lithologies and sedimentary structures than facies 6, representing the Fish Scales Formation. Both formations differ in abundance of fish remains and other bioclastic material. Placement of the boundary between both formations has to remain vague and is mainly based on the log signatures. Also geochemical data shows a significant increase of TOC and HI values in Facies 7. Sediments are non-bioturbated to very slightly bioturbated by *Planolites* and *Terebellina* (rare).

Geochemistry: Samples 18, 19, and 20.

Foraminifera: Samples 18 and 19 are barren of foraminifera. Two badly preserved specimens of agglutinated foraminifera were recovered from sample 20, also characterized by a high amount of fish remains.

Facies 8: Interlaminated mudstone and siltstone to very fine-grained sandstone (976.50 m – 970.00 m)

Description: Facies 8 consists of black to dark gray mudstone, finely interbedded and interlaminated with sharp-based siltstone and very fine-grained sandstone. Lenticular to parallel bedded siltstones and sandstones occasionally show subtle color grading, indicated fining upward. Parallel lamination is dominated by asymmetrical ripple cross-lamination, especially within thinner beds. Sediments are very slightly bioturbated mainly by *Planolites* in the lower part of the unit and become moderately bioturbated at the top of the unit

Geochemistry: Samples 21, 22, 23, 24, and 25.

Foraminifera: Samples 21, 22, and 23 contain 13 to 16 specimens, which is relatively high in comparison with other samples. Foraminifera are poorly preserved and therefore about half of the specimens remain unidentified. First appearances of *Psammosphaera* spp., *Saccamina alexanderi*, and *S. lathrami* were recorded in sample 21. *Reophax* cf. *sikannensis* appears in sample 23. Samples 24 and 25 are barren of foraminifera.

11-17-10-21W4

Facies 1: Intensively bioturbated sandy siltstone (3123.00 ft – 3120.50 ft)

Description: Facies 1 consists of intensively bioturbated, almost homogenous sandy siltstone. Thickness of the laminae and sedimentary structures could not be defined due to the high degree of bioturbation. *Planolites*, *Skolithos* (rare), *Terebellina*, and *Teichichnus* were identified among the biogenic sedimentary structures.

Geochemistry: Sample 1.

Foraminifera: Three poorly preserved specimens of foraminifera were recovered with one identified as *Verneuilioides* spp. Other biogenic material is represented by petrified plant material, fish remains and a single *Inoceramus* prism.

Facies 2: Fine-grained sandstone with mudstone laminae (3120.50 ft – 3115.50 ft)

Description: Facies 2 is a coarsening upward sequence of very fine- to fine-grained sandstone with rare thin mudstone laminae. Average thickness of sandstone beds is 15 cm. Primary sedimentary structures within the sandstone commonly have been destroyed by moderate to intense bioturbation, giving the sandstone beds a massive appearance. Few silty intervals show parallel lamination with normal graded laminae. Mudstones have sharp upper and lower contacts with sandstones and occur mainly as wavy laminae. Trace-fossil assemblages within sandstones show a dominance of vertical borrows, such as *Skolithos*, *Arenicolites*, and *Diplocraterion*. In most cases burrows are infilled with the same sand as the hosting rock making many trace-fossils indistinct. A trace-fossil assemblage within mudstone laminae is represented by *Planolites*.

Geochemistry: Sample 2.

Foraminifera: No foraminifera have been recovered within the sample. A lot of petrified plant material, and few shell fragments and algal cysts were recorded.

Facies 1: Intensively bioturbated sandy siltstone (3115.50 ft – 3113.50 ft)

Description: A sharp bioturbated contact separates Facies 1 from Facies 2 with are otherwise similar in lithology and trace-fossil assemblage (see description of the Facies 1 at the interval 3123.00 ft – 3120.50 ft).

Geochemistry: Sample 3. and 4.

Foraminifera: No foraminifera have been recovered within samples. Fish remains, petrified plant material and shell fragments were recorded in sample 4.

Facies 3: Intensively to moderately bioturbated silty sandstone (3113.50 ft - 3105.50 ft)

Description: Facies 3 is represented by a coarsening upward sequence and consists of intensively bioturbated very fine- grained silty sandstone to moderately bioturbated fine-grained sandstone with thin beds and laminae of mudstone. At the lower part of the unit (3113.50 ft - 3110.00 ft) thickness and sedimentary structures of the beds could not be defined due to the high degree of bioturbation. Upwards, mudstone laminae become distinct, increasing in thickness to a few millimeters, occasionally non-bioturbated or slightly bioturbated, with a wavy appearance. Few massive mudstone beds are up to 4 cm thick, tabular bedded, and have sharp contacts with the bounding sandstone. Double mud drapes are occasionally present. Sandstone beds become cleaner upwards with variable thickness of 1 to 7 cm and are structureless. Contacts between sandstones and mudstones are usually sharp, scoured, and occasionally loaded. Parallel lamination can be observed within few non-bioturbated siltstone beds. *Diplocraterion* and *Skolithos* are common trace fossils within the silty sandstone with occasional appearances of *Thalassinoides*, *Siphonichnus* and *Ophiomorpha* (?). *Planolites* and *Teichichnus* can be observed within the shale laminae.

Geochemistry: Samples 5. and 6.

Foraminifera: No foraminifera has been recovered within the samples.

Facies 4: Interbedded mudstone and sandstone (3105.50 ft – 3097.00

ft)

Description: Facies 4 is represented by an upward coarsening succession of interbedded mudstone and very fine- to fine-grained sandstone. The lower boundary with Facies 3 is sharp. Sandstones are light gray, wavy to tabular bedded and moderately to intensively bioturbated. Sandstone beds show presence of combined flow ripples. Within the sandstone the trace-fossil assemblage is dominated by *Skolithos* whereas *Planolites* and *Teichichnus* (rare) dominate within the mudstone beds.

Geochemistry: 6 and 7.

Foraminifera: Sample 6 is the lowest sample with diverse and relatively abundant foraminifera (48 specimens). The assemblage is represented by 10 genera and 11 species with a dominance of *Gaudryina*, *Ammotium* and *Miliammina*. Only one specimen of *Ammobaculites tyrrelli* was recovered within sample 7. Accompanied biogenic material is represented by petrified plant material, fish remains, shell fragments and algal cysts.

Facies 5: Hummocky cross-stratified, fine-grained sandstone (3097.00 ft – 3095.00 ft)

Description: Facies 5 has a gradational contact with Facies 4 and consists of sharp-based very fine- to fine-grained whitish to gray sandstone with rare thin dark gray, wavy mudstone laminae. Several double mud drapes were observed within the unit. Sandstone beds are 1 to 20 cm thick with internal stratification consisting of subhorizontal parallel lamination with low angle, inclined, intersecting surfaces (hummocky cross-stratification). No bioturbation to slight bioturbation was observed within sandstone beds. Slight to moderate bioturbation of the mudstone laminae is represented by *Planolites* and *Chondrites*.

Facies 6: Mudstone with conglomerate beds (3095.00 ft - 3090.00 ft)

Description: Facies 6 is represented by coarsening upward units that consists of black fine parallel laminated mudstone with few widely spaced conglomerate horizons. Mudstone contains rare mm-scale laminae of siltstone and very thin

fine-grained sandstone. Only two relatively thick (15 cm and 5 cm) hummocky cross-stratified and wavy cross-bedded sandstone beds were observed within the unit. Conglomerate beds are poorly sorted, 1 to 5 cm thick, matrix-supported with various colored well rounded lithic pebbles of about 1.5 cm in maximum diameter. The matrix consists of fine-grained sandstone or siltstone. No structures were observed within the conglomeratic beds. Mudstones are non-bioturbated to slightly bioturbated. Intervals with thicker and denser sandstone laminae are moderately bioturbated.

Geochemistry: Samples 9, 10, and 11

Foraminifera: Foraminifera were recovered from all samples in Facies 6. New species appear at various levels. Sample 8 is characterized by a diverse assemblage (8 genera) and the appearance and dominance of *Miliammina manitobensis*. Sample 9 contains the most abundant one within Facies 6 (55 specimens) and includes large foraminiferal specimens of *Uvigerinammina manitobensis* and *U. athabaskensis* with *Ammobaculites fragmentarius*, *A. tyrelli* and *Trochammina rutherfordi* being the most common forms. Sample 11 contains only eight poorly preserved specimens of foraminifera with 3 of them recognized as *Miliammina awunensis* and *M. ischnia*. Algal cysts, shell fragments, fish remains, and a single occurrence of petrified plant material and *Inoceramus* prism form miscellaneous biogenic material.

Facies 7: Mudstone with rare siltstone to very fine-grained sandstone laminae (3090.00 ft – 3052.00 ft)

Description: Facies 7 consists of black to dark gray fissile mudstone, finely interbedded with rare, thin, sharp-based siltstone and very fine-grained sandstone laminae. Lenticular to parallel bedded siltstones occasionally show subtle color grading that indicates fining upward. Within sandstone and siltstone laminae parallel lamination is dominated by asymmetrical ripple cross-lamination. Sediments are very slightly bioturbated mainly by *Planolites*.

Geochemistry: Samples 12, 13, 14, 15, and 16.

Foraminifera: *Gaudryina* sp. dominates the foraminiferal assemblage of sample 12. Sample 13 contains foraminifera from 15 genera including *Ammobaculites*.

Gaudryina, *Miliammina*, and *Trochammina*. Foraminifera in sample 14 are most abundant and are characterized by very small, fine-grained specimens from 10 genera dominated by *Pseudobolivina variana*, various species of *Miliammina* and *Psamminopelta*. Only nine foraminiferal specimens were recovered within sample 15 and are represented by single appearances of *Ammobaculites fragmentarius*, *Trochammina* cf. *alcanensis*, *T. rainwateri*, *Saccammina lathrami* and *Uvigerinammina manitobensis*. Sample 16 is barren of foraminifera. *Inoceramus* prisms and algal cysts are present.

11-28-9-21W4

Facies 1: Hummocky cross-stratified fine-grained sandstone

(3062.00 ft – 3053.00 ft)

Description: This facies predominantly consists of sharp-based very fine- to fine-grained whitish/gray sandstone with rare thin dark gray, wavy mudstone laminae (0.5 – 2 cm thick) and interbedded mudstone/siltstone intervals. Sandstone beds are 10 to 45 cm thick and are slightly decreasing upwards while thickness and amount of muddy intervals are increasing. The internal stratification of sandstone consists of subhorizontal parallel lamination with low angle, inclined, intersecting surfaces. Few beds demonstrate fining upward successions with wavy cross-lamination within siltier sediments at the top. No bioturbation was observed within the sandstone beds. Interlaminating mudstone and siltstone intervals are moderately bioturbated predominantly by *Skolithos*, with presence of *Ophiomorpha*, *Asterosoma* (?), *Cylindrichnus* and *Thalassinoides*. Slight to moderate bioturbation in mudstone laminae is represented mainly by *Planolites* and *Chondrites*.

Geochemistry: Samples 1, 2, and 3.

Foraminifera: Samples were taken from muddy (samples 1 and 2) and silty (sample 3) intervals. A total of 11 genera and 16 species were identified within Facies 1. The most diverse assemblage including *Ammobaculites*, *Ammobaculoides*, *Bathysiphon*, *Gaudryina*, *Miliammina*, *Reophax*, *Saccammina*, *Textularia*, *Thuraminoides* and *Verneuilinoides* were recovered from sample 2. Only *Hippocrepina*, *Reophax* and *Bathysiphon* in addition to petrified plant material, shell fragments, fish remains and algal cysts were recorded from sample 1. *Ammobaculites*, *Miliammina* and *Saccammina* represent the foraminiferal assemblage from sample 3.

Facies 2: Conglomerate (3053.00 ft - 3052.8 ft)

Description: Facies 2 is represented by a thin, poorly sorted, matrix-supported conglomeratic bed with pebbles of maximum 1 cm in diameter (base of the unit). Well-rounded pebbles, mainly represented by white and black chert, are within a medium-to coarse-grained sandstone matrix. The lower contact is

sharp whereas the upper contact is probably bioturbated. No sedimentary or biogenic structures are recognized within the unit.

No samples have been taken for geochemical and micropaleontological analyses.

Facies 3: Intensively bioturbated silty mudstone with pebbles (3052.8 ft – 3052.00 ft)

Description: Facies 3 represent intensively bioturbated silty mudstone with some floating pebbles of about 0.3 cm in diameter that are more common at the base of the unit. *Terebellina*, *Thalassinoides* and *Chondrites* were recognized among the trace fossils.

No samples have been taken for geochemical and micropaleontological analyses.

Facies 4: Moderately to intensively bioturbated mudstone with siltstone and very fine-grained sandstone (3052.00 ft – 3047.50 ft)

Description: Facies 4 is sharp-based and consists of mudstone interbedded with siltstone and very fine-grained sandstone. The sandstone and siltstone laminae increase in frequency and thickness upwards resulting in a lighter color of the bulk rock. Where preserved, the sandstone laminae and beds are commonly sharp-based and contain low-angle, wavy cross-lamination and sub-parallel lamination (and lenticular bedding). Thicker sandstone beds commonly retain their original structure. Occasionally fining upward can be observed in siltstone and sandstone laminae. The sandstone and especially the mudstone beds are intensely to moderately bioturbated. Degree of bioturbation slightly decreases upwards with increase of the sand component. The trace-fossil assemblage is dominated by *Terebellina*, *Chondrites*, with some *Thalassinoides*.

Helminthopsis (?) and *Planolites*. *Skolithos* borrows appear within the sandy upper portion of the facies.

Geochemistry: Sample 4.

Foraminifera: Sample 4 has an abundant and diverse foraminiferal assemblage represented by 12 genera and 16 species and is dominated by *Gaudryina* and various species of *Miliammina*, *Trochammina*, *Verneuilinoides*.

Ammobaculites, *Ammomarginulina*, *Bathysiphon*, *Gravellina*, *Pseudobolivina*, *Textulariopsis*, *Reophax*, and *Saccamina* are present..

Facies 5: Bioturbated muddy sandstone with pebbles (3047.50 ft – 3040.50 ft)

Description: Facies 5 is more sandy than Facies 4 and is characterized by presence of small pebbles and granules within intensively bioturbated, interbedded, silty mudstone and fine-grained sandstone. Pebbles are most abundant within the lower part, while the upper part above the bentonite (3046.5 ft) carries smaller pebbles that appear only occasionally. It is hard to estimate the thickness of the beds or recognize any internal sedimentary structures within the unit due to the high degree of bioturbation. The trace-fossil assemblage is dominated by *Skolithos* and *Arenicolites*, with rare occurrences of *Planolites*, *Chondrites*, and *Diplocraterion* (within the pebbly lower part).

No samples have been taken for geochemical and micropaleontological analyses.

Facies 6: Poorly sorted medium-grained cross-bedded gravelly to clean sandstone (3040.50 ft – 3037.00 ft)

Description: Sandstone beds are predominantly poorly sorted and medium- to lower coarse-grained with sharp basal contacts. High-angle cross-bedding is dominant within sandstones, although few sandstone beds are structureless, possibly due to bioturbation or contain wavy low-angle cross-bedding. Trace fossils within the massive sandstone beds could not be identified due to the lack of contrast between hosting and infilling sediments. A sandstone bed, 17.5 cm thick, with small pebble and granular chert stringers on the foresets occurs in the lower part of the unit. Upwards, a more pebbles sporadically appear within the sandstone. The cross-bedded sandstone does not contain any evidence of bioturbation. The muddy siltstone/sandstone interval is moderately bioturbated and contains double mud drapes within thin mudstone laminae. Facies 6 grades into overlaying Facies 7.

Geochemistry: Sample 5.

Foraminifera: No foraminifera have been recovered from sample 5.

Facies 7: Fining upward sandstone and interbedded bioturbated mudstone (3037.00 ft – 3026.50 ft)

Description: Facies 7 is represented by a fining upward succession of interbedded sandstone and bioturbated mudstone with occasional pebbles. The lower contact with Facies 6 is gradational and is characterized by an upward increase in mudstone. Sandstone beds are sharp, scoured, and occasionally loaded at their bases, 2 to 5 cm thick and contain mudstone laminae that are either wavy or occur occasionally as flaser bedding. Sandstone beds vary in grain size from very fine to medium. Double mud drapes and petrified plant material are common within the unit. Thickness of the sandstone beds decreases upwards with increasing mud component. Where preserved, the sandstones show parallel bedding and lenticular bedding with asymmetrical ripple cross-lamination. Thicker sandstone beds are commonly bioturbated only at the top, while thinner beds and laminae can be totally reworked by organisms. The mudstone laminae are predominantly bioturbated by *Planolites*, *Chondrites* and *Teichichnus*. Within sandstone beds *Skolithos* and *Teichichnus* were recognized.

Geochemistry: Samples 6, and 7.

Foraminifera: Sample 6 is barren of foraminifera. Sample 7 contains only 2 specimens of *Verneulinoides* and 1 unidentified specimen.

Facies 8: Interlaminated mudstone and siltstone to very fine-grained sandstone (3026.50 ft – 2986.00 ft)

Description: Facies 8 sharply overlies Facies 7 and consists of black to dark gray fissile mudstone finely interbedded and interlaminated with sharp-based siltstone and very fine-grained sandstone. Lenticular to parallel bedded siltstones and sandstones occasionally show subtle color grading that indicates fining upward. Parallel lamination is dominated by asymmetrical ripple cross-lamination, especially within the thinner beds. Sediments are very slightly bioturbated mainly by *Planolites* at the lower part of the unit and become non-bioturbated upwards.

Geochemistry: Samples 8, 9, and 10.

Foraminifera: No foraminifera have been recorded within the entire interval.

Facies 9: Black mudstone with very fine-grained sandstone and siltstone (2986.00 ft – 2979.00 ft)

Description: Facies 9 consists of non-bioturbated massive to finely laminated mudstone with siltstone and very fine-grained sandstone laminae. Facies 9 is slightly sandier than the underlying unit, but has similar lithological characteristics. Facies 9 can be distinguished from Facies 8 by abundant fish and other vertebrate remains. On the geophysical well-logs the contact between the Westgate (Facies 8) and Fish Scales (Facies 9) formations, is a relatively easy pick and is expressed in a sharp increase of the gamma-ray and resistivity responses. In core a bentonite bed marks the contact between Facies 8 and Facies 9.

Geochemistry: Sample 11.

Foraminifera: The few foraminifera, recovered from Facies 9, are represented by *Gaudryina* spp., *Haplophragmoides postis goodrichi* and *Trochammina* spp..

10-25-07-20W4

Facies 1: Interbedded silty mudstone and sandstone (802.50 m - 801.71 m)

Description: Facies 1 consists of interbedded dark gray silty mudstone with very fine- to fine-grained whitish/gray sandstone. Shale laminae are 0.3 to 2 cm thick. Commonly sharp-based sandstone beds are 0.5 to 2 cm thick and increase upwards in frequency and thickness. According to the wire-line log Facies 1 represents the top portion of a coarsening-upward cycle. Low-angle, wavy cross-lamination and subhorizontal parallel lamination dominates within the sandstone beds. Primary sedimentary structures are preserved mainly within the thicker sandstone beds. A 17 cm thick, sharp-based, fine- to very fine-grained sandstone bed occurs at 802.30 m and clearly shows these types of structures. Bioturbation is more intensive in the lower part of the unit with higher mud content. Thicker sandstone beds usually have bioturbated upper contacts. Common trace fossils within the shale are *Planolites*, *Teichichnus*, *Terebellina* and *Helminthopsis*, while *Skolithos* is more common within the sandstone beds. No samples have been taken for geochemical and micropaleontological analyses.

Facies 2: Interbedded mudstone and very fine-grained sandstone (801.71 m - 797.10 m)

Description: Interbedded dark gray to gray mudstone and very fine-grained, light gray, silty sandstone of Facies 2 overlies with a sharp contact Facies 1. At the base the mudstone contains only a small amount of thin siltstone and very fine-grained sandstone laminae in small lenses. The sandstone laminae increase its frequency and thickness upwards, resulting in a lighter color of the bulk rock. Where preserved, the sandstone laminae and beds are commonly sharp-based and contain low-angle, ripple cross-lamination and sub-parallel lamination with the occasional presence of lenticular bedding. Original sedimentary structures are preserved within thicker sandstone beds, and destroyed by bioturbation within the thinner ones. Occasionally, upward fining can be observed in the siltstone and sandstone laminae. The sandstone and

especially the mudstone beds are intensely to moderately bioturbated and *Planolites*, *Chondrites*, *Terebellina*, *Rosselia*, *Teichichnus*, *Helminthopsis* and *Asterosoma* (?) could be locally identified. Degree of bioturbation decreases upwards. Facies 2 grades into Facies 1 at 797.10 m.

Geochemistry: Samples 1, 2, 3, 4, 5, and 6.

Foraminifera: Rich foraminiferal assemblages were recovered from all samples taken from Facies 2. Assemblages from samples 1 and 6 are represented by 11 genera. Samples 2, 4 and 5 contain 14 foraminiferal genera. The most abundant and diverse foraminiferal assemblage was recovered from Sample 3 and is represented by 315 specimens of 18 genera. The most common genera within Facies 2 are *Ammobaculites*, *Bathysiphon*, *Gaudryina*, *Miliammina*, *Reophax*, *Saccammina*, *Trochammina*, *Verneuilinoides*, *Hippocrepina*, *Hyperammina* and *Textularia*. *Miliammina manitobensis* and *Hyperammina emancerata* are the dominant species in sample 1. Sample 2 is characterized by abundant and diverse *Miliammina* (4 species), *Saccammina* (3 species) and *Trochammina* (3 species) with dominance of *M. manitobensis*, *Gaudryina canadensis* and *Saccammina lathrami*. Foraminiferal assemblages in samples 3, 4 and 5 are very abundant and are characterized by high numbers of *Ammobaculites*, *Uvigerinammina*, *Reophax*, *Miliammina* and *Gaudryina* with *Ammobaculites fragmentarius*, *Gaudryina canadensis*, *G. irenensis*, *Miliammina ischnia*, *M. manitobensis*, *Reophax vasiformis*, *R. sikanniensis* and *Uvigerinammina manitobensis* being the most abundant species. In sample 3 *Miliammina* and *Reophax* are represented by 5 and 6 species respectively. Also *Haplophragmoides* shows a relatively high abundance and diversity. In sample 4 the amount of *Miliammina* drops significantly. *Reophax* is very abundant and is represented by five species, and *Trochammina rutherfordi* and *Verneuilina canadensis* are present in high numbers. Sample 5 and 6 are characterized by high abundance and diversity of *Reophax*.

Facies 1: Interbedded silty mudstone and sandstone (797.10 m - 796.25 m)

Description: Facies 1 has a gradational lower boundary with underlying Facies 2. The Lithology of these sediments is very similar to those described above (see description of the Facies 1 at the interval 802.5 m - 801.71 m). Sediments differ from Facies 2 in increase of the sand component and more intense bioturbation.

No samples have been taken for geochemical and micropaleontological analyses.

Facies 3: Hummocky cross-stratified sandstone (796.25 m - 795.30 m)

Description: This facies predominantly consists of low-angle, wavy, cross-bedded, very fine- to fine-grained, whitish/gray sandstone with rare, thin, dark gray, wavy mudstone laminae. Sandstone beds are 1 cm to 15 cm thick, while mudstone laminae are around 0.2 to 0.5 cm thick. Amount of mudstone laminae is higher at the base and top of the unit. Facies 3 has a sharp contact with underlying Facies 1. The internal stratification of sandstone consists of subhorizontal parallel lamination and low angle wavy cross-lamination. Very few trace fossils such as *Cylindrichnus* and *Skolithos* are observed within the sandstone and occur mainly at the top of beds. Slight to moderate bioturbation in mudstone laminae is represented by *Planolites* and rarely by *Teichichnus*.

Geochemistry: Sample 7.

Foraminifera: The foraminiferal assemblage of sample 7 shows common abundance (33 specimens) and reduced diversity (10 genera) with *Verneuilinoides* and *Gaudryina* being the most abundant genera.

Facies 1: Interbedded silty mudstone and sandstone (795.30. m - 794.85 m)

Description: Facies 1 overlies Facies 3 with sharp contact. The lithology of these sediments is similar to those described above (see description of the Facies 1 at the intervals 802.5 m - 801.71 m. and 797.10 m - 796.25 m.

No samples have been taken for geochemical and micropaleontological analyses.

Facies 4: Medium-grained cross-bedded sandstone (794.85 m – 793.35 m)

Description: Sandstone beds are predominantly medium-grained with a sharp basal contact. At the basal part sandstone contains rip-up mud clasts bioturbated by *Planolites*. Internal sedimentary structures within sandstones are indistinct at the base probably due to bioturbation and become more recognizable upwards. High-angle cross-bedding is dominant within sandstone sets that are separated from each other by thin mudstone laminae. Thickness of sets and individual beds are around 30 cm and 1-2 cm respectively. Double mud drapes can be observed within mudstone laminae. Towards the top frequency of mudstone laminae increases, fining sandstone sets lose high angle cross-bedding stratification and decrease in thickness to 1 cm. Bioturbation of the sandstone was recorded at the base and top of the unit.

Geochemistry: Sample 8.

Foraminifera: No foraminifera have been recovered from sample 8.

Facies 5: Intensively bioturbated sandy siltstone (793.35 m – 793.15 m)

Description: Facies 5 overlies Facies 4 with a sharp contact and consists of sandy siltstone. Sedimentary structures or thickness of sandstone and siltstone laminae is difficult to determine due to the intense degree of bioturbation. No samples have been taken for geochemical and micropaleontological analyses.

Facies 6: Horizontally laminated mudstone, siltstone and fine-grained sandstone (793.15 m – 785.00 m)

Description: Facies 6 represents a coarsening upward cycle and consists of black mudstone with thin beds and laminae of siltstone and very fine-grained sandstone. A 1 cm thin bed of massive medium sandstone with sharp lower and upper contacts appears close to the base. Rare lenticular to parallel bedded siltstones and sandstones are 0.2 to 5 cm thick and increase in frequency and thickness up to 5 cm upwards. Subtle color grading within siltstones and sandstones indicates upward fining. Sandstone and siltstone beds are sharp-

based, scoured-based or show the evidence of loading at their basal contact. Parallel lamination characterizes the lower part whereas asymmetrical ripple cross-lamination is dominant in the the upper part of the facies. Sediments are not bioturbated to very slightly bioturbated by *Planolites* and *Terebellina* (rare). It the interval 790.70 m – 790.55 m sandy sediments are heavily bioturbated with a thin, medium-grained sandstone layer at the top. Facies 6 has similar characteristics as Facies 2 and mainly differs by presence of bioturbation.

Geochemistry: Samples, 9, 10, 11, 12, 13 and 14’.

Foraminifera: Foraminiferal assemblages, representing the Westgate Formation, were recovered within all samples from Facies 6 except sample 10”. In comparison with foraminiferal assemblages of the Bow Island Formation (samples 1-7) diversity and abundance are significantly lower. Only in samples 11 and 14 number exceed 100 specimens. The most common and abundant genera are *Gauchryina*, *Miliammina*, *Reophax* and *Ammobaculites*, while *Verneuilinoides* appears more sporadically. In samples 9, 10 and 11 *Miliammina* is represented with 4 to 5 species, while *Reophax* is the most diverse genus within samples 11 and 12. The most abundant and diverse foraminiferal assemblage was recovered from sample 11 (247 specimens representing 19 genera).

07-02-08-21W4

Facies 1: Interlaminated mudstone, siltstone and very fine-grained sandstone (870.00 m - 869.75 m)

Description: Facies 1 consists of interlaminated black mudstone, siltstone and silty very fine-grained sandstone. The sandstone and siltstone beds are sharp-based, occasionally scoured-based, 2 to 3 cm thick with parallel lamination, current ripple, combined flow ripple and oscillation ripple lamination. The mudstone appears as 2 to 3 cm thick parallel laminated tabular and wavy beds or as flaser bedding with occasional presence of double mud drapes. The facies is non-bioturbated to slightly bioturbated by *Planolites* mainly within mudstone beds.

Geochemistry: Samples 1 and 2.

Foraminifera: Foraminiferal assemblages are not abundant and diverse. In sample 1 a total of 37 foraminiferal specimens were recovered representing 7 genera with *Ammobaculites*, *Gaudryina* and *Reophax* being the most common. The assemblages in sample 2 is represented by *Gaudryina*, *Ammobaculites* and *Verneuilinoides* and contains only 17 specimens. Petrified plant material, small grains of amber and algal cysts were found.

Facies 2: Cross-stratified fine- to medium-grained sandstone (869.75 m - 867.35 m)

Description: The sharp-based Facies 2 is composed of well sorted fine- to medium-grained sandstone with dominance of trough cross-bedding with lesser amounts of planar-tabular bedding. Cross-bedding is well defined and occurs in continuously stacked sets, 4 to 30 cm thick. Reactivation surfaces are infrequently present within Facies 2. Very thin (0.5 mm) mud stringers were occasionally noticed within the sandstone beds. Two mudstone rip-up clasts were observed within the middle part of the unit. Few small petrified plant fragments occur on bedding surfaces. No bioturbation was observed within the Facies 2.

Geochemistry: Samples 3 and 4.

Foraminifera: No foraminifera have been recovered within Facies 2.

Facies 3: Black mudstone (867.35 m - 866.55 m)

Description: Facies 3 erosionally overlies Facies 2 and consists of black mudstone with rare siltstone and very fine-grained sandstone in thin beds and laminae. Commonly the mudstone is finely laminated, while the siltstone and sandstone beds show parallel lamination to small-scale cross-lamination. Petrified plant material, small shell fragments, fish and other vertebrate remains are common within the unit. Sediments are slightly to moderately bioturbated, although very few individual trace-fossils can be identified due to lack of the contrast between hosting and infilling sediments and, therefore, the degree of the bioturbation can be underestimated. *Planolites* and *Chondrites* were locally defined within the silty beds.

Geochemistry: Samples 5 and 6.

Foraminifera: Foraminiferal assemblages from samples 5 and 6 are abundant and diverse with 87 and 272 specimens respectively and are characterized by a number of first appearances of foraminiferal genera and species. *Miliammina*, *Gaudryina*, *Verneulinoides* and *Ammobaculites* are the most abundant and diverse among 12 genera in sample 5 and 19 genera in sample 6.

Verneulinoides perplexus, *V. borealis*, *Gaudryina canadensis* and *Ammobaculites fragmentarius* are the most abundant species in sample 5. *Gaudryina canadensis*, *Miliammina manitobensis*, *M. ischnia*, *M. inflata*, *Verneulinoides borealis* are the most representative species in sample 6.

Miscellaneous components contain petrified plant material, abundant fish and other vertebrate remains and shell fragments. Amber pieces and few pyritized diatoms were recovered from sample 6.

Facies 1: Interlaminated mudstone, siltstone and very fine-grained sandstone (866.55 m - 864.40 m)

Description: The lower contact of Facies 1 with underlying Facies 3 is gradational and based on the first appearance of a thick siltstone bed. Sedimentary structures are very similar to those described above (see Facies 1 from the interval 870.00 m - 869.75 m). The siltstone beds are thicker in the

lower part of the unit with lesser amount of mudstone that is mainly presented as thin mudstone laminae and beds less than 2 cm thick. Siderite concretions and pyrite nodules appear within the interval. Siltstone and very fine-grained sandstone beds are slightly to moderately bioturbated, while mudstone beds together with some thin siltstone and sandstone laminae can be almost homogenous due to the intense biological reworking of the sediment. Common trace fossils are *Planolites*, *Teichichnus*, *Chondrites*, *Thalassinoides*, with some *Palaeophycus*, *Arenicolites*, *Skolithos*, *Asterosoma*, *Helminthopsis* (?), and *Terebellina*.

Geochemistry: Sample 7.

Foraminifera: No foraminifera have been recovered within sample 7.

Facies 4: Interlaminated very fine- to fine-grained sandstone and muddy siltstone (864.40 m - 864.00 m)

Description: Facies 4 has a gradational lower contact and is characterized by interbedded sandstone and muddy siltstone. Sandstone beds are sharp-based and scoured and appear commonly as wavy or lenticular beds with current ripples, combined flow ripples and oscillation ripples. The mudstone laminae show wavy bedding to flaser bedding. Within this interval Facies 4 is interfingering with muddy siltstones of Facies 1. Sandstone beds are slightly bioturbated by *Palaeophycus*, *Arenicolites* and *Skolithos*. The trace-fossil assemblage within the mudstone laminae is characterized by *Planolites* and *Chondrites*. Sediments of Facies 4 have similarities with Facies 1 and may represent its more sandy variation.

No samples have been taken for geochemical and micropaleontological analyses.

Facies 5: Hummocky cross-stratified fine-grained sandstone (864.00 m - 861.55 m)

Description: This facies predominantly consists of sharp-based very fine- to fine-grained whitish/gray sandstone beds, 4 to 55 cm thick, with intervals of interlaminating mudstone and siltstone/very fine-grained sandstone and rare thin dark gray wavy mudstone laminae (0.5 – 3 cm thick). The internal

stratification of sandstones consists of planar to hummocky cross-stratification with low angle, inclined, intersecting surfaces. Few beds demonstrate fining upward successions with presence of oscillation ripples within siltier sediments. At the very top of the facies sediments are similar to those from Facies 4. The sandstones are non-bioturbated to slightly bioturbated with *Skolithos* and *Rosselia* borrows. Moderate to intense bioturbation within interlaminating mudstone and siltstone intervals is characterized by *Skolithos*, *Planolites*, *Teichichnus*, *Siphonites* and *Thalassinoides*. Slight to moderate bioturbation in mudstone laminae is represented mainly by *Planolites* and *Chondrites*.

Geochemistry: Samples 8, 9 and 10.

Foraminifera: Foraminifera was recovered from all three samples of Facies 5. Only 6 poorly preserved foraminifera were recovered from sample 9 with only one identified as *Verneulinoides borealis*. Samples 8 and 10 are similar and contain *Ammobaculites*, *Gaudryina*, *Miliammina*, *Verneulina* and *Verneulinoides* with relatively high amounts of unidentified foraminifera (39 and 26 specimens respectively). *Trochammina* is present in sample 8, sample 10 is characterized by the first appearance of *Uvigerinammina manitobensis* that is a dominant taxon within the sample. Petrified plant material was recorded within all samples, while algal cysts were recovered from sample 8, and shell fragments and small pyrite concretions were found only in sample 10.

Facies 6: Mixed conglomerate and muddy sandstone (861.55 m - 861.50 m)

Description: Facies 6 is represented by thin beds of the muddy, very fine-grained sandstone with randomly distributed, well rounded pebbles of predominantly chert, varying in size from 0.2 to 0.8 mm. The lower contact is scoured showing pebbly load casts. The highest concentration of pebbles occurs within relatively clean sandstone beds.

No samples have been taken for geochemical and micropaleontological analyses.

Facies 3: Black mudstone (861.50 m -860.20 m)

Description: Facies 3 has a sharp lower boundary and consists of black mudstone. Lithological and sedimentological characteristics of these sediments are similar to those described above (see description of the Facies 3 at the interval 867.35 m - 866.55 m).

Geochemistry: 11 and 12.

Foraminifera: Foraminifera from samples 11 and 12 are the most abundant and diverse within the core with 900 and 916 specimens respectively and are characterized by first appearances of a significant amount of new foraminiferal genera and species. Both samples have a similar fauna including *Ammobaculites*, *Bathysiphon*, *Gaudryina*, *Gravellina*, *Haplophragmoides*, *Hyperammina*, *Hippocrepina*, *Miliammina*, *Psamminopelta*, *Psammosphaera*, *Pseudoholivina*, *Reophax*, *Saccammina*, *Textularia*, *Textulariopsis*, *Trochammina*, *Verneuilina*, *Verneulinoides* and *Uvigerinammina*. In sample 11 *Ammobaculoides*, *Ammodiscus*, *Ammomarginulina*, *Ammotium*, *Spiroplectammina* and *Tritaxia* were also recorded. A single specimen of *Haplophragmium* was recovered in sample 12. *Ammobaculites*, *Gaudryina*, *Miliammina*, *Trochammina*, *Verneulinoides* and *Uvigerinammina* are the most diverse and/or abundant genera within both samples. Sample 11 is characterized by several species of *Saccammina* and *Trochammina*, and high numbers of *Miliammina* (mostly *M. manitobensis* and *M. ischnia*). A total of 174 specimens of *Uvigerinammina manitobensis* were recorded in sample 12. Few petrified plant pieces, fish remains and a single pyrite concretion were recovered from the sand-sized residue of sample 11.

Facies 1: Interlaminated mudstone, siltstone and very fine-grained sandstone (860.20 m - 859.45 m)

Description: Facies 1 has a gradational boundary with Facies 3 and are similar to Facies 1 described from the interval 866.55 m - 864.40 m (see above). Some pyrite nodules were recorded within the interval.

No samples have been taken for geochemical and micropaleontological analyses.

Facies 4: Interlaminated very fine- to fine-grained sandstone and muddy siltstone (859.45 m - 858.85 m)

Description: Sedimentological and lithological characteristics of these sediments are similar to Facies 4 described from the interval 864.40 m- 864.00 m (see above). Although sediments are sandier and contain few sandstone beds with planar to hummocky cross-stratification with low angle, inclined, intersecting surfaces. Bioturbation is more intense within the muddier intervals and is represented by *Planolites*, *Chondrites*, *Teichichnus*, *Thalassinoides* and *Skolithos*.

Geochemistry: Sample 13.

Foraminifera: The foraminiferal assemblage contains 11 genera, of which *Uvigerinammina*, *Verneuilinoides*, *Miliammina*, *Gaudryina* and *Ammobaculites* are the most dominant ones. *Uvigerinammina manitobensis*, *Miliammina manitobensis*, *Gaudryina canadensis* and *Verneuilinoides borealis* are the most common species. Petrified plant material and shell fragments are also present.

Facies 1: Interlaminated mudstone, siltstone and very fine-grained sandstone (858.85 m - 857.85 m)

Description: The contact between Facies 1 and underlying Facies 4 is intensively bioturbated. Sediments are very muddy and contain sedimentological and lithological characteristics of both Facies 1 and Facies 3. The trace-fossil assemblage is represented by *Chondrites*, *Planolites*, *Teichichnus*, *Terebellina*, *Thalassinoides*, *Siphonites*, *Trichichnus* and *Skolithos*.

No samples have been taken for geochemical and micropaleontological analyses.

Facies 4: Interlaminated very fine- to fine-grained sandstone and muddy siltstone (857.85 m - 856.15 m)

Description: Facies 4 has a gradational contact with underlying Facies 1 and consists of intensively bioturbated almost homogeneous muddy sandstone. Very few sandstone beds retain primary sedimentary structures such as small-scale cross-lamination. A lot of pyrite nodules were recorded within the interval. The

trace-fossil assemblage contains *Chondrites*, *Planolites*, *Teichichnus*, *Arenicolites*, *Skolithos*, *Terebellina*, *Trichichnus*, *Palaeophycus*, *Siphonites* and *Rosselia*.

Geochemistry: Sample 14 and 15.

Foraminifera: Sample 14 contains a relatively diverse and abundant foraminiferal assemblage (8 genera among 92 specimens) with *Uvigerinammina*, *Gaudryina*, *Miliammina*, *Verneulinoides*, and *Ammobaculites* being the most abundant genera. Only 9 specimens were recovered in sample 15.

Facies 6: Mixed conglomerate and muddy sandstone (856.15 m - 856.10 m)

Description: Facies 6 is represented by a poorly preserved bed of muddy sandstone with pebbles up to 2 cm in diameter. No sedimentary structures or bioturbation have been observed within this interval.

No samples have been taken for geochemical and micropaleontological analyses.

Facies 1: Interlaminated mudstone, siltstone and very fine-grained sandstone (856.10 m - 855.32 m)

Description: Facies 1 has a similar characteristics as Facies 1 described above (see above). The lower part of the facies is characterized by presence of small pebbles and granules floating within the intensively bioturbated interbedded silty mudstone and fine-grained sandstone.

Geochemistry: Sample 16.

Foraminifera: Only 16 foraminiferal specimens of 5 genera were recovered from sample 16. Petrified plant material and pyrite concretions were recorded within the sample.

Facies 4: Interlaminated very fine- to fine-grained sandstone and muddy siltstone (855.32 m - 854.65 m)

Description: Facies 4 is represented by a very sandy, moderately to intensively bioturbated interval with *Skolithos*, *Arenicolites* and some *Palaeophycus* and

Ophiomorpha trace fossils being present. Sandstone beds show a massive appearance due to the high degree of bioturbation.

Geochemistry: Sample 17.

Foraminifera: In sample 17 seven foraminiferal specimens from two genera were recovered together with petrified plant material and shell fragments.

Facies 1: Interlaminated mudstone, siltstone and very fine-grained sandstone (854.65 m - 853.73 m)

Description: Facies 1 is muddy and contains very similar characteristics described from the interval 858.85 m - 857.85 m (see above).

Geochemistry: Sample 18.

Foraminifera: The foraminiferal assemblage from sample 18 is represented by 10 genera with 120 foraminiferal specimens. *Miliammina manitobensis* forms the most dominant species.

Appendix 2

Foraminiferal Data

6-32-13-26W4

[illegible]

6-15-9-24W4

SAMPLE #	DEPTH (M)	FORMATION	Agglutinated	<i>Gaudryina canadensis</i>	<i>Miliammina awunensis</i>	<i>Miliammina manitobensis</i>	<i>Verneuilinoides perplexus</i>	Total amount of foraminifera	pyrite concretions	petrified plant material	amber	fish remains	algal cysts	shell fragments
20	1449.07	BOW ISLAND												
19	1449.75													
18	1452.75									1				
17	1455.05								1	1				
16	1456.7		1	1		1		3		1				
15	1456.81								1	3		1		2
14	1457.48					1		1	6	5				
13	1457.55									4	1	1		
12	1457.9												2	
11	1458		1		2	1	1	5						
10	1459.6											1		
9	1459.83									8	3			
8	1460.06								4					
7	1461.08													
6	1461.8													
5	1463.27													
4	1464.07													
3	1464.77													
2	1465.34								11					
1	1466.5								7					

11-33-11-26W4

[illegible]

<i>Verneuilinoides</i> spp	<i>Verneuilinoides cf. perplexus</i>	<i>Miliammina manitobensis</i>	<i>Trochammina</i> spp.	<i>Gaudryina irenensis</i>	<i>Gaudryina tailleuri</i>	<i>Verneuilina canadensis</i>	<i>Verneuilinoides borealis</i>	<i>Miliammina awunensis</i>	<i>Reophax troyeri</i>	<i>Textularia topagorukensis</i>	<i>Reophax sikanniensis</i>	<i>Pseudobolivina variana</i>	<i>Trochammina rutherfordi</i>	<i>Bathysiphon brosgiei</i>	<i>Ammobaculites petilus</i>	Total amount of foramilifera	petrified plant material	shell fragment	<i>Inoceramus</i> prisms	fish remains	pyrite concretions	diatoms	algal cysts
		2														2		2		4			
*	1	1														9				6			
																				28			
																1							
																	2			32			
																3	2		6	2			1
																3			1	1	7	4	1
1			1													8	1				2	1	1
																		1	10	18	7	1	
1	*	1												1	1	13			1	1	4	3	
	1		*	2			1						1			16	3				1		
				2								1				10		2			2	1	
	*		1		1		1									9		4					
	1										1					15	1						
	2		1				2	1	2	1						30	5	1					
	1	2			3	1	4	1								21	1	2					
1																7							
			1	1												6							
3	*	1														17	5				3		
																13							

6-16-6-22W4

[illegible]

11-17-10-21W4

[illegible]

11-28-9-21W4

[illegible]

10-25-7-20W4

SAMPLE #	DEPTH (M)	FORMATION	Agglutinated	Ammobaculites spp.	Ammobaculites fragmentarius	Ammobaculites tyrrelli	Bathysiphon spp.	Gaudryina spp.	Haplophragmium spp.	Haplophragmium cf. engleri	Hippocrepina spp.	Hippocrepina barksdalei	Hyperammina spp.	Hyperammina emancerata	Miliammina spp.	Miliammina ischnia	Miliammina inflata	Miliammina manitobensis	Reophax spp.	Reophax (Scherochorella) minuta	Psammospaera spp.	Saccammina spp.	Saccammina alexanderi	Saccammina lethrani
14'	785.02	WEST GATE	2				*	2							1				*	1		*	1	
14	785.6		42	13	8	3	*	3	2						2	2		4	2	2		*	1	
13	786.5		3	*	1	1	*	1										1	*			*	1	
12	788.1		20	2				*							*	2		6	2	2	1			
11"	789		4	1	2	1	*	*								1		2	*		1			
11'	789.1		5					*			*	1			*	1		1				*	1	
11	789.4		28	10	9	4	2	12			*	1	2		3	4	5	9	7	5	1	*	3	
10"	790.6																							
10'	790.62		17	1	1			*							*		1	2	*					
10	791.5		7	*	1		*	3							4	5	3	3	1					
9	792.3	BOW ISL.	18	1	4	3	*	1							7	2	10	4	1	1				
8'	792.6		32	4		2		*							1	4			*		1			
8	794																							
7	795.65		10	2				2	*	1					1		2		2					
6	797.85		31	17	11	14	*	7							2	2	1	1	5		1	*	6	
5	798.55		77	17	10	7	1	7					7		4	10		11	25	1		*	3	
4	799.2		90	12	9	4	*	6	1						4	1		2	29	1	1	*	11	
3	800.6		102	9	14	1	*	5	1		1		2	1	8	10	2	6	12	5	2	2	2	
2	801.15		24	4	2	3	*	4					*	1	8	4	1	9	*	2		*	2	
1	801.57		16	3	3	2	1	1	*	1	1	1	1	6	4	1	1	11	*	2	2	*	1	

[illegible]

[illegible]

<i>Reophax cf. peppercornensis</i>	<i>Reophax sikanniensis (small)</i>	<i>Reophax sikanniensis</i>	<i>Reophax troyeri</i>	<i>Reophax tundraensis</i>	<i>Uvigerinammina athabascensis</i>	<i>Uvigerinammina manitobensis</i>	<i>Vermeulinoides cf. fischeri</i>	<i>Ammotium spp.</i>	<i>Reophax cf. deskeri</i>	<i>Psammimopelta subcircularis</i>	<i>Textularia topogorukensis</i>	<i>Ammobaculites phaulus</i>	<i>Ammodiscus kiowensis</i>	<i>Glomospira glomerosa (?)</i>	<i>Gaudryina tailleuri</i>	<i>Gravellina chamneyi</i>	Total amount of foraminifera	fish remains	<i>Inoceramus</i> prisms	pyrite concretions	algal cysts	diatoms	petrified plant material
			1		1											1	10	1					2
	2			1												1	103	1		1			
	6		2			1								1	1		18						
	1					4											57	5	2				
																	21						
																	11						
	2	1	3	3		33			1	3		4	1				247	3	3				3
	2											1					34						
			1														39				1	1	
																	89					2	
	1							1		3	1						61	2		3	2	1	
					2			1									33						
	1	6	3	1		19		1	1								171	3		1			
1	1	10	9	2		17											269		1				
3	5	17	3			14											306						
1	12	1	1	3	3	28	1										315	2					
																	101						
																	60						

7-2-8-21W4

SAMPLE #	DEPTH (M)	FORMATION	Agglutinated	<i>Ammobaculites</i> spp.	<i>Ammobaculites fragmentarius</i>	<i>Ammobaculites petilus</i>	<i>Ammobaculites tyrrelli</i>	<i>Ammotium</i> spp.	<i>Gaudryina</i> spp.	<i>Gaudryina canadensis</i>	<i>Gaudryina irenensis</i>	<i>Miliammina</i> spp.	<i>Miliammina awunensis</i>	<i>Miliammina ischnia</i>	<i>Miliammina manitobensis</i>	<i>Reophax</i> spp.	<i>Reophax</i> cf. <i>sikanniensis</i>	<i>Reophax</i> cf. <i>tundraensis</i>	<i>Saccammina</i> spp.	<i>Saccammina lathrami</i>	<i>Verneuilina canadensis</i>	<i>Verneuilinoides</i> spp.	<i>Verneuilinoides borealis</i>	<i>Ammobaculites hymei</i>
18	854.21	BOW ISLAND	26	6	6		8		1	13		2	2	3	30				*	1	1	*	1	
17	855.05		4	*	1		1					*												
16	855.59		5	*		1			1	2		1		3										
15	856.6		2	2					3	2														
14	857.79		39	*	2				8	5		3		6	8	2						3		
13	859.03		74	5	1		4	2	11	19		8	2	3	11	2		*			1	5	9	
12	860.73		271	18	22		10		59	15	11	17	7	49	34	4		2	*		4	29	9	
11	861.4		238	25	12	3	19	2	38	31	14	47	21	58	94	1			*	1	4	30	11	
10	862.12		26	7					2	3	2	2			2						1	3	1	
9	862.77		5																		*	1		
8	863.95		39	2	6		4		9	6		5	1	4	5						2	7	7	
7	865.25																							
6	866.85		52	8	3		7	1	18	15	1	14	6	19	29	*			*	3	9	6	14	
5	867.3		10	5	4	1	1		5	9	3	*	2	2	3				*		3	2	8	1
4	868.15																							
3	869.35																							
2	869.75		5	2	1				2	1	4											1	1	
1	869.9		4	*	2	2	9	3	1	4	3	*	1	1	1	*	3	1	*	1	1			

[illegible]

Appendix 3

Geochemical Data

6-32-13-27W4

DEPTH M	T _{max} C°	S ₁ mgHC/ g rock	S ₂ mgHC/ g rock	S ₃ mgHC/ g rock	PI	S ₂ /S ₃	TOC mgHC/ gTOC	HI wt%	OI mgCO ₂ / gTOC
2075.30	433	1.05	2.58	0.51	0.29	5.05	1.04	248	49
2075.30	434	1.02	2.73	0.56	0.27	4.87	1.05	260	53
2076.00	437	1.90	12.32	0.42	0.13	29.33	3.10	397	13
2076.00	437	1.96	12.75	0.40	0.13	31.87	3.23	394	12
2076.55	433	1.38	8.07	0.44	0.15	18.34	2.38	339	18
2076.55	434	1.37	7.85	0.42	0.15	18.69	2.41	325	17
2077.00	436	1.04	3.12	0.40	0.25	7.80	1.38	226	28
2077.00	437	1.04	3.37	0.37	0.24	9.10	1.37	245	27
2077.55	438	1.42	6.68	0.38	0.18	17.57	1.90	351	20
2077.55	440	1.34	6.40	0.23	0.17	27.82	1.83	349	12
2078.15	430	0.26	0.52	0.04	0.33	13.00	0.24	216	16
2078.15	433	0.21	0.45	0.05	0.32	9.00	0.22	204	22
2078.75	442	0.23	1.63	0.09	0.12	18.11	1.09	149	8
2078.75	442	0.23	1.64	0.10	0.12	16.40	1.06	154	9
2079.75	441	0.19	1.40	0.13	0.12	10.76	1.09	128	11
2079.75	441	0.18	1.28	0.16	0.12	8.00	1.05	121	15
2080.75	442	0.19	1.66	0.17	0.10	9.76	1.18	140	14
2080.75	446	0.16	1.19	0.28	0.12	4.25	1.06	112	26
2081.75	438	0.72	6.71	0.25	0.10	26.84	2.39	280	10
2081.75	437	0.73	6.91	0.16	0.10	43.18	2.28	303	7
2082.25	426	0.27	0.22	0.14	0.56	1.57	0.16	137	87
2082.25	429	0.25	0.22	0.20	0.54	1.10	0.16	137	125
2083.40	443	0.32	2.56	0.21	0.11	12.19	1.34	191	15
2083.40	439	0.33	2.49	0.15	0.12	16.60	1.33	187	11
2083.60	440	0.22	0.24	0.15	0.48	1.60	0.21	114	71
2083.60	435	0.21	0.23	0.21	0.48	1.09	0.20	115	105
2083.90	434	0.55	1.48	0.52	0.27	2.84	0.98	151	53
2083.90	435	0.55	1.40	0.49	0.28	2.85	0.98	142	50
2084.15	438	0.64	1.22	0.49	0.34	2.48	0.82	148	59
2084.15	434	0.66	1.22	0.49	0.35	2.48	0.82	148	59
2084.85	435	0.65	2.72	0.67	0.19	4.05	1.64	165	40
2084.85	434	0.63	2.62	0.07	0.19	37.42	1.56	167	4
2085.25	436	0.12	1.98	0.50	0.06	3.96	0.79	250	63
2085.25	437	0.12	2.20	0.62	0.05	3.54	0.79	278	78
2085.55	432	0.34	1.42	0.72	0.19	1.97	0.99	143	72
2085.55	432	0.30	1.50	0.61	0.17	2.45	0.98	153	62
2086.15	436	0.41	2.36	0.55	0.15	4.29	1.10	214	50
2086.15	436	0.41	2.10	0.55	0.16	3.81	1.08	194	50
2086.65	435	0.47	1.57	0.59	0.23	2.66	0.91	172	64
2086.65	436	0.45	1.31	0.49	0.26	2.67	0.88	148	55
2087.00	377	0.72	0.52	0.53	0.58	0.98	0.22	236	240
2087.00	377	0.78	0.52	0.44	0.60	1.18	0.22	236	200
2087.30	395	0.41	0.10	0.67	0.82	0.14	0.18	55	372
2087.30	386	0.42	0.12	0.78	0.78	0.15	0.19	63	410
2087.80	429	1.11	18.23	1.11	0.06	16.42	7.88	231	14
2087.80	432	1.16	18.50	1.49	0.06	12.41	7.93	233	18
2088.50	0	0.37	0.08	1.02	0.84	0.07	0.13	61	784
2088.50	384	0.38	0.07	0.31	0.86	0.22	0.13	53	238
2089.30	0	0.17	0.01	0.20	0.94	0.05	0.27	3	74
2089.30	0	0.16	0.02	0.26	0.89	0.07	0.27	7	96

2089.70	0	0.45	0.07	0.27	0.87	0.25	0.31	22	87
2089.70	0	0.43	0.06	0.28	0.90	0.21	0.31	19	90
2090.90	0	0.02	0.00	0.28	1.00	0.00	0.20	0	140
2090.90	0	0.02	0.00	0.18	1.00	0.00	0.20	0	90
2091.90	0	0.03	0.00	0.13	1.00	0.00	0.15	0	86
2091.90	0	0.03	0.00	0.16	1.00	0.00	0.15	0	106
2093.00	0	0.02	0.00	0.15	1.00	0.00	0.16	0	93
2093.00	0	0.03	0.00	0.20	1.00	0.00	0.16	0	125
2094.10	0	0.22	0.02	0.26	0.92	0.07	0.05	40	520
2094.10	0	0.21	0.00	0.21	1.00	0.00	0.04	0	525
2094.70	0	0.40	0.04	0.26	0.91	0.15	0.08	50	325
2094.70	0	0.38	0.04	0.08	0.90	0.50	0.08	50	100
2095.90	0	0.23	0.05	0.33	0.82	0.15	0.41	12	80
2095.90	0	0.21	0.06	0.39	0.81	0.15	0.41	14	95
2096.85	345	0.38	0.12	0.45	0.76	0.26	0.32	37	140
2096.85	355	0.37	0.14	0.15	0.74	0.93	0.30	46	50

6-15-9-24W4

DEPTH M	T _{max} C°	S ₁ mgHC/ g rock	S ₂ mgHC/ g rock	S ₃ mgHC/ g rock	PI	S ₂ /S ₃	TOC mgHC/ gTOC	HI wt%	OI mgCO ₂ / gTOC
1449.07	0	0.00	0.00	0.00	0.00	0.00	0.07	0	0
1449.07	394	0.18	0.05	0.00	0.82	0.00	0.09	55	0
1449.75	429	0.14	0.21	0.00	0.41	0.00	0.32	65	0
1449.75	427	0.13	0.19	0.03	0.41	6.33	0.32	59	9
1452.75	429	0.22	1.18	0.11	0.16	10.72	1.29	91	8
1452.75	429	0.20	1.10	0.12	0.15	9.16	1.24	88	9
1455.05	434	0.14	0.87	0.00	0.14	0.00	0.92	94	0
1455.05	433	0.15	0.79	0.02	0.16	39.50	0.87	90	2
1456.70	434	0.14	4.87	0.11	0.03	44.27	2.59	188	4
1456.70	434	0.13	4.54	0.07	0.03	64.85	2.60	174	2
1456.81	434	0.06	2.10	0.01	0.03	210.00	1.81	116	0
1456.81	435	0.07	2.09	0.03	0.03	69.66	1.78	117	1
1457.48	433	0.19	1.15	0.05	0.14	23.00	1.19	96	4
1457.48	434	0.18	1.05	0.06	0.15	17.50	1.21	86	4
1457.55	432	0.10	1.34	0.03	0.07	44.66	1.23	108	2
1457.55	434	0.11	1.29	0.03	0.08	43.00	1.25	103	2
1457.90	432	0.06	0.61	0.01	0.09	61.00	0.92	66	1
1457.90	433	0.06	0.58	0.03	0.09	19.33	0.91	63	3
1458.00	434	0.07	0.61	0.34	0.10	1.79	0.96	63	35
1458.00	430	0.10	0.62	0.50	0.14	1.24	0.91	68	54
1459.60	439	0.08	1.23	0.05	0.06	24.60	1.45	84	3
1459.60	438	0.07	1.11	0.04	0.06	27.75	1.39	79	2
1459.83	439	0.02	0.43	0.04	0.05	10.75	1.12	38	3
1459.83	439	0.02	0.40	0.04	0.05	10.00	1.14	35	3
1460.06	439	0.09	0.71	0.07	0.11	10.14	1.67	42	4
1460.06	439	0.09	0.73	0.08	0.11	9.12	1.68	43	4
1461.08	0	0.04	0.00	0.02	1.00	0.00	0.17	0	11
1461.08	303	0.05	0.01	0.02	0.83	0.50	0.16	6	12
1461.80	0	0.03	0.00	0.01	1.00	0.00	0.02	0	50
1461.80	0	0.04	0.00	0.01	1.00	0.00	0.02	0	50
1463.27	0	0.07	0.00	0.04	1.00	0.00	0.12	0	33
1463.27	0	0.07	0.00	0.10	1.00	0.00	0.12	0	83
1464.07	0	0.00	0.00	0.15	0.00	0.00	0.01	0	1500
1464.07	0	0.00	0.00	0.21	0.00	0.00	0.01	0	2100
1464.77	0	0.00	0.00	0.08	0.00	0.00	0.13	0	61
1464.77	0	0.01	0.00	0.11	0.00	0.00	0.13	0	84
1465.34	0	0.00	0.00	0.01	0.00	0.00	0.12	0	8
1465.34	0	0.07	0.00	0.27	1.00	0.00	0.04	0	675
1466.50	405	0.07	0.01	0.28	0.87	0.03	0.06	16	466
1466.50	0	0.07	0.00	0.29	1.00	0.00	0.06	0	483

11-33-11-26W4

DEPTH M	T _{max} C°	S ₁ mgHC/ g rock	S ₂ mgHC/ g rock	S ₃ mgHC/ g rock	PI	S ₂ /S ₃	TOC mgHC/ gTOC	HI wt%	OI mgCO ₂ / gTOC
1806.00	429	0.81	7.21	0.28	0.10	25.75	2.09	344	13
1806.00	430	0.78	6.26	0.18	0.11	34.77	1.98	316	9
1807.00	427	0.85	5.00	0.42	0.15	11.90	1.61	310	26
1807.00	429	0.83	4.83	0.34	0.15	14.20	1.65	292	20
1808.10	426	1.77	21.11	0.70	0.08	30.15	4.54	464	15
1808.10	425	1.93	22.90	0.73	0.08	31.36	4.59	498	15
1809.00	426	1.38	13.06	0.54	0.10	24.18	3.09	422	17
1809.00	424	1.39	12.79	0.35	0.10	36.54	3.08	415	11
1810.05	425	0.27	1.07	0.48	0.20	2.22	0.49	218	97
1810.05	425	0.26	1.18	0.51	0.18	2.31	0.48	245	106
1811.00	423	0.26	1.10	0.26	0.19	4.23	0.56	196	46
1811.00	423	0.28	1.17	0.23	0.19	5.08	0.56	208	41
1812.00	433	0.14	1.50	0.26	0.09	5.76	0.98	153	26
1812.00	430	0.15	1.41	0.32	0.10	4.40	0.97	145	32
1812.70	432	0.18	1.78	0.25	0.09	7.12	1.14	156	21
1812.70	432	0.18	1.51	0.29	0.11	5.20	1.11	136	26
1814.80	428	0.34	2.35	0.42	0.13	5.59	1.25	188	33
1814.80	430	0.34	2.44	0.39	0.12	6.25	1.26	193	30
1815.60	432	0.32	1.95	0.38	0.14	5.13	1.58	123	24
1815.60	432	0.33	1.95	0.47	0.14	4.14	1.57	124	29
1815.85	423	0.20	1.30	0.26	0.13	5.00	1.01	128	25
1815.85	427	0.18	1.23	0.26	0.13	4.73	1.00	123	26
1816.80	428	0.31	1.39	0.30	0.18	4.63	1.22	113	24
1816.80	430	0.31	1.30	0.27	0.19	4.81	1.19	109	22
1817.00	427	0.20	0.41	0.24	0.33	1.70	0.52	78	46
1817.00	432	0.20	0.45	0.26	0.31	1.73	0.57	78	45
1818.05	431	0.41	0.69	0.22	0.37	3.13	0.64	107	34
1818.05	432	0.39	0.63	0.29	0.38	2.17	0.65	96	44
1819.00	430	0.17	0.63	0.33	0.21	1.90	0.79	79	41
1819.00	428	0.16	0.65	0.23	0.20	2.82	0.79	82	29
1819.85	436	0.26	0.91	0.00	0.22	0.00	0.82	110	0
1819.85	434	0.28	0.90	0.00	0.24	0.00	0.93	96	0
1821.00	434	0.21	0.88	0.16	0.19	5.50	0.80	110	20
1821.00	435	0.20	0.84	0.19	0.19	4.42	0.78	107	24
1822.00	437	0.25	0.84	0.14	0.23	6.00	0.97	86	14
1822.00	437	0.24	0.89	0.16	0.21	5.56	0.97	91	16
1823.10	436	0.22	0.86	0.14	0.20	6.14	0.95	90	14
1823.10	437	0.21	0.64	0.10	0.25	6.40	0.94	68	10
1824.00	436	0.23	1.50	0.18	0.13	8.33	1.12	133	16
1824.00	436	0.22	1.35	0.10	0.14	13.50	1.10	122	9

6-16-6-24W4

DEPTH M	T _{max} C°	S ₁ mgHC/g rock	S ₂ mgHC/g rock	S ₃ mgHC/g rock	PI	S ₂ /S ₃	TOC mgHC/gT OC	HI wt%	OI mgCO ₂ / gTOC
970.00	436	0.23	0.62	0.14	0.27	4.42	0.35	177	40
970.00	438	0.24	0.67	0.24	0.27	2.79	0.34	197	70
970.70	426	0.58	7.39	0.51	0.07	14.49	2.64	279	19
970.70	428	0.55	7.50	0.47	0.07	15.95	2.69	278	17
972.80	429	0.35	2.98	0.34	0.11	8.76	1.23	242	27
972.80	431	0.36	2.99	0.31	0.11	9.64	1.23	243	25
974.20	427	0.61	9.39	0.41	0.06	22.90	2.62	358	15
974.20	429	0.61	9.56	0.37	0.06	25.83	2.62	364	14
975.70	427	0.82	8.41	0.45	0.09	18.68	2.48	339	18
975.70	426	0.80	8.37	0.47	0.09	17.80	2.48	337	18
976.80	423	0.75	9.23	0.54	0.08	17.09	2.67	345	20
976.80	423	0.70	8.73	0.54	0.07	16.16	2.66	328	20
978.40	423	0.50	4.99	0.39	0.09	12.79	1.76	283	22
978.40	423	0.51	5.39	0.39	0.09	13.82	1.78	302	21
982.50	424	0.88	11.59	0.59	0.07	19.64	3.47	334	17
982.50	424	0.91	11.50	0.52	0.07	22.11	3.48	330	14
984.50	434	0.14	2.10	0.13	0.06	16.15	1.50	140	8
984.50	437	0.11	1.51	0.17	0.07	8.88	1.46	103	11
985.50	438	0.18	2.22	0.16	0.07	13.87	1.67	132	9
985.50	437	0.16	2.47	0.17	0.06	14.52	1.61	153	10
988.65	390	0.08	0.06	0.11	0.57	0.54	0.06	100	183
988.65	377	0.07	0.04	0.12	0.70	0.33	0.06	66	200
989.40	426	0.12	0.04	0.09	0.75	0.44	0.11	36	81
989.40	429	0.13	0.05	0.07	0.72	0.71	0.11	45	63
992.40	436	0.18	0.14	0.06	0.56	2.33	0.18	77	33
992.40	432	0.19	0.20	0.09	0.50	2.22	0.19	105	47
993.40	433	0.17	0.80	0.08	0.18	10.00	1.10	72	7
993.40	432	0.16	0.73	0.04	0.18	18.25	1.07	68	3
994.00	433	0.41	0.91	0.08	0.31	11.37	0.73	124	10
994.00	433	0.42	0.94	0.05	0.31	18.80	0.73	128	6
995.45	438	0.40	1.72	0.14	0.19	12.28	1.23	139	11
995.45	434	0.42	1.80	0.16	0.19	11.25	1.25	144	12
996.55	436	0.12	1.04	0.14	0.10	7.42	0.88	118	15
996.55	436	0.12	0.94	0.19	0.11	4.94	0.85	110	22
997.45	434	0.12	1.85	0.13	0.06	14.23	1.47	125	8
997.45	437	0.12	1.94	0.11	0.06	17.63	1.28	151	8
998.55	436	0.39	1.60	0.09	0.20	17.77	1.19	134	7
998.55	437	0.39	1.76	0.08	0.18	22.00	1.34	131	5
998.85	437	0.12	3.52	0.28	0.03	12.57	2.20	160	12
998.85	434	0.15	3.69	0.29	0.04	12.72	2.36	156	12
999.95	435	0.25	1.03	0.07	0.20	14.71	0.85	121	8
999.95	433	0.25	1.06	0.07	0.19	15.14	0.85	124	8
1000.85	437	0.16	0.74	0.04	0.18	18.50	0.54	137	7
1000.85	437	0.16	0.76	0.08	0.17	9.50	0.54	140	14
1002.25	438	0.22	2.70	0.32	0.08	8.43	1.52	177	21
1002.25	437	0.19	2.25	0.30	0.08	7.50	1.53	147	19
1003.75	438	0.15	0.50	0.16	0.23	3.12	0.46	108	34
1003.75	437	0.12	0.39	0.18	0.24	2.16	0.44	88	40
1004.95	396	0.07	0.01	0.16	0.87	0.06	0.04	25	400
1004.95	0	0.08	0.00	0.21	1.00	0.00	0.04	0	525

11-17-10-21W4

DEPTH Ft	T _{max} C°	S ₁ mgHC/g rock	S ₂ mgHC/g rock	S ₃ mgHC/g rock	PI	S ₂ /S ₃	TOC mgHC/gT OC	HI wt%	OI mgCO ₂ / gTOC
3061.5	432	0.09	1.56	0.14	0.05	11.14	1.33	117	10
3061.5	432	0.09	1.42	0.12	0.06	11.83	1.32	107	9
3072	431	0.07	1.36	0.22	0.05	6.18	1.37	99	16
3072	432	0.06	1.29	0.2	0.04	6.45	1.34	96	14
3081.5	434	0.16	1.13	0.24	0.12	4.7	1.26	89	19
3081.5	433	0.17	1.12	0.26	0.13	4.3	1.25	89	20
3089	433	0.05	1.31	0.16	0.04	8.18	1.34	97	11
3089	435	0.04	1.3	0.14	0.03	9.28	1.37	94	10
3090	430	0.18	0.88	0.44	0.17	2	1	88	44
3090	426	0.2	0.84	0.45	0.19	1.86	1	84	45
3091	434	0.07	1.13	0.13	0.06	8.69	1.38	81	9
3091	433	0.09	1.27	0.14	0.07	9.07	1.4	90	10
3092	431	0.09	2.55	0.26	0.03	9.8	1.87	136	13
3092	432	0.09	2.64	0.28	0.03	9.42	1.87	141	14
3092.5	432	0.13	2.4	0.26	0.05	9.23	1.7	141	15
3092.5	432	0.13	2.48	0.4	0.05	6.2	1.71	145	23
3099.5	436	0.29	3.02	0.35	0.09	8.62	2.21	136	15
3099.5	435	0.29	3	0.34	0.09	8.82	2.21	135	15
3103	433	0.36	1.45	0.22	0.2	6.59	1.29	112	17
3103	434	0.35	1.29	0.21	0.21	6.14	1.27	101	16
3105.5	438	0.25	0.94	0.14	0.21	6.71	0.6	156	23
3105.5	437	0.3	1.03	0.22	0.23	4.68	0.61	168	36
3110	440	0.12	27.69	0.41	0	67.53	4.13	670	9
3110	439	0.12	27.8	0.31	0	89.67	4.16	668	7
3114.5	436.00	0.28	0.43	0.14	0.40	3.07	0.53	81	26
3114.5	433.00	0.28	0.44	0.13	0.39	3.38	0.54	81	24
3115.5	436.00	0.53	2.22	0.24	0.19	9.25	1.26	176	19
3115.5	433.00	0.56	2.23	0.31	0.20	7.19	1.28	174	24
3120.0	438.00	0.17	3.13	0.32	0.05	9.78	2.28	137	14
3120.0	438.00	0.16	3.13	0.32	0.05	9.78	2.3	136	13
3123.0	439.00	0.63	1.86	0.13	0.25	14.30	0.98	189	13
3123.0	438.00	0.63	1.84	0.13	0.26	14.15	0.98	187	13

11-28-9-21W4

DEPTH Ft	T _{max} C°	S ₁ mgHC/g rock	S ₂ mgHC/g rock	S ₃ mgHC/g rock	PI	S ₂ /S ₃	TOC mgHC/gT OC	HI wt%	OI mgCO ₂ / gTOC
2980.00	412	0.23	1.74	0.34	0.12	5.11	1.10	158	30
2980.00	412	0.23	1.56	0.43	0.13	3.62	1.08	144	39
3000.00	426	0.05	1.03	0.38	0.05	2.71	1.30	79	29
3000.00	425	0.05	0.91	0.36	0.05	2.52	1.23	73	29
3020.50	425	0.08	1.07	0.69	0.07	1.55	1.31	81	52
3020.50	429	0.08	1.15	0.65	0.07	1.76	1.33	86	48
3024.00	433	0.05	1.93	0.52	0.03	3.71	1.59	121	32
3024.00	428	0.03	1.31	0.55	0.02	2.38	1.51	86	36
3027.00	432	0.07	1.61	0.60	0.04	2.68	1.63	98	36
3027.00	434	0.07	1.43	0.61	0.05	2.34	1.63	87	37
3033.00	430	0.19	0.67	0.54	0.22	1.24	0.87	77	62
3033.00	432	0.19	0.66	0.69	0.23	0.95	0.86	76	80
3039.00	426	0.10	0.23	0.57	0.31	0.40	0.44	52	129
3039.00	425	0.10	0.22	0.39	0.31	0.56	0.44	50	88
3050.00	433	0.16	0.87	0.24	0.16	3.62	1.09	79	22
3050.00	435	0.14	0.79	0.26	0.15	3.03	1.08	73	24
3053.50	438	0.06	3.23	0.28	0.02	11.53	2.33	138	12
3053.50	439	0.06	3.41	0.26	0.02	13.11	2.32	146	11
3058.50	435	0.10	3.09	0.43	0.03	7.18	2.53	122	16
3058.50	434	0.09	2.89	0.46	0.03	6.28	2.54	113	18
3060.50	433	0.16	3.80	0.54	0.04	7.03	2.91	130	18
3060.50	436	0.15	3.84	0.61	0.04	6.29	2.94	130	20

10-25-7-20W4

DEPTH M	T _{max} C°	S ₁ mgHC/g rock	S ₂ mgHC/ g rock	S ₃ mgHC/ g rock	PI	S ₂ /S ₃	TOC mgHC/ gTOC	HI wt%	OI mgCO ₂ / gTOC
785.02	433	0.17	2.15	0.29	0.07	7.41	1.52	141	19
785.02	433	0.18	2.06	0.31	0.08	6.64	1.51	136	20
786.50	433	0.32	3.00	0.32	0.10	9.37	1.81	165	17
786.50	435	0.26	2.82	0.31	0.08	9.09	1.78	158	17
788.10	434	0.19	1.99	0.23	0.09	8.65	1.36	146	16
788.10	432	0.19	1.84	0.21	0.09	8.76	1.38	133	15
789.40	434	0.06	1.80	0.21	0.03	8.57	1.59	113	13
789.40	434	0.06	1.85	0.22	0.03	8.40	1.60	115	13
791.50	434	0.07	1.58	0.22	0.04	7.18	1.39	113	15
791.50	431	0.05	1.34	0.23	0.04	5.82	1.39	96	16
792.30	432	0.10	1.48	0.24	0.06	6.16	1.39	106	17
792.30	431	0.13	1.73	0.26	0.07	6.65	1.40	123	18
794.00	424	0.09	0.69	0.24	0.12	2.87	0.85	81	28
794.00	425	0.09	0.64	0.27	0.12	2.37	0.87	73	31
795.65	428	0.14	0.52	0.29	0.21	1.79	0.80	65	36
795.65	425	0.13	0.48	0.22	0.22	2.18	0.79	60	27
797.85	432	0.18	1.64	0.32	0.10	5.12	1.56	105	20
797.85	432	0.19	1.81	0.48	0.09	3.77	1.57	115	30
798.55	431	0.09	0.70	0.22	0.12	3.18	0.95	73	23
798.55	434	0.07	0.58	0.26	0.11	2.23	0.95	61	27
799.20	432	0.11	0.78	0.19	0.12	4.10	1.11	70	17
799.20	432	0.09	0.65	0.19	0.12	3.42	1.10	59	17
800.60	433	0.15	1.22	0.24	0.11	5.08	1.42	85	16
800.60	434	0.12	1.03	0.22	0.11	4.68	1.28	80	17
801.15	435	0.15	1.28	0.24	0.11	5.33	1.28	100	18
801.15	433	0.13	1.30	0.17	0.09	7.64	1.27	102	13
801.57	435	0.10	2.26	0.33	0.04	6.84	2.17	104	15
801.57	436	0.09	2.27	0.33	0.04	6.87	2.14	106	15

7-2-8-21W4

DEPTH M	T _{max} C°	S ₁ mgHC/ g rock	S ₂ mgHC/ g rock	S ₃ mgHC/ g rock	PI	S ₂ /S ₃	TOC mgHC/ gTOC	HI wt%	OI mgCO ₂ / gTOC
854.21	431	0.23	0.82	0.10	0.22	8.20	0.91	90	10
854.21	429	0.28	0.9	0.11	0.23	8.72	0.94	102	11
855.05	426	0.27	1.03	0.18	0.21	5.72	1.15	89	15
855.05	423	0.28	1.08	0.17	0.21	6.35	1.14	94	14
855.59	427	0.18	0.48	0.20	0.27	2.40	0.56	85	35
855.59	428	0.17	0.49	0.19	0.26	2.57	0.56	87	33
856.60	427	0.11	0.32	0.13	0.26	2.46	0.50	64	26
856.60	429	0.10	0.27	0.14	0.28	1.92	0.49	55	28
857.79	424	0.07	0.44	0.14	0.14	3.14	0.69	63	20
857.79	428	0.06	0.41	0.19	0.13	2.15	0.69	59	27
859.03	430	0.25	0.43	0.00	0.37	0.00	0.62	69	0
859.03	430	0.24	0.41	0.06	0.37	6.83	0.62	66	9
860.73	434	0.25	1.00	0.14	0.20	7.14	1.12	89	12
860.73	432	0.26	0.96	0.15	0.21	6.40	1.11	86	13
861.40	434	0.17	1.32	0.27	0.11	4.88	1.31	100	20
861.40	435	0.16	1.29	0.19	0.11	6.78	1.31	98	14
862.12	432	0.17	2.76	0.38	0.06	7.26	2.26	122	16
862.12	434	0.18	2.78	0.30	0.06	9.26	2.34	118	12
862.77	434	0.20	2.29	0.19	0.08	12.05	2.13	107	8
862.77	433	0.22	2.46	0.24	0.08	10.25	2.13	115	11
863.95	427	0.28	1.69	0.14	0.14	12.07	1.39	121	10
863.95	432	0.25	1.38	0.17	0.15	8.11	1.38	100	12
865.25	432	0.19	1.39	0.12	0.12	11.58	1.07	129	11
865.25	435	0.17	1.33	0.31	0.11	4.29	1.06	125	29
866.85	436	0.21	0.54	0.13	0.28	4.15	1.29	41	10
866.85	434	0.23	0.60	0.12	0.28	5.00	1.29	46	9
867.30	434	0.07	0.60	0.09	0.11	6.66	1.16	51	7
867.30	434	0.07	0.62	0.12	0.10	5.16	1.17	52	10
868.15	322	0.17	0.09	0.05	0.65	1.80	0.15	60	33
868.15	392	0.18	0.06	0.04	0.75	1.50	0.16	37	25
869.35	327	0.15	0.04	0.07	0.83	0.57	0.04	100	175
869.35	367	0.16	0.05	0.06	0.80	0.83	0.05	100	120
869.75	434	0.22	1.40	0.28	0.14	5.00	2.17	64	12
869.75	434	0.22	1.40	0.24	0.14	5.83	2.17	64	11
869.90	426	0.15	0.61	0.25	0.20	2.44	1.20	50	20
869.90	433	0.12	0.51	0.29	0.19	1.75	1.18	43	24