SEDIMENTOLOGY, ORGANIC PETROLOGY, ORGANIC GEOCHEMISTRY, AND PETROLEUM POTENTIAL OF THE MIDDLE DEVONIAN WINNIPEGOSIS FORMATION IN SOUTHWESTERN MANITOBA, CANADA

By

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Submitted to the Faculty of Graduate Studies
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for the Degree of

MASTER OF SCIENCE

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BY

David McDonald

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirement of the degree

MASTER OF SCIENCE

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ABSTRACT

The Middle Devonian Winnipegosis, Elm Point, and Ratner formations are parts of the Elk Point Group, which is a cyclical succession of carbonate and evaporite rocks that were deposited within the Hume-Dawson sequence in the Western Canada Sedimentary Basin. In Manitoba, these formations occur in the subsurface in the southwestern part of the province and are partly exposed in the Devonian outcrop belt along the eastern erosional margin of the Elk Point Basin. The lower and upper members of the Winnipegosis Formation are composed of ramp and isolated reef/platform units respectively. Within the study area, the western platform margin is approximately coincident with the Birdtail-Waskada Axis, which reflects the Precambrian Superior Boundary Zone, and the northern margin is approximately coincident with the contact between the Precambrian Uchi and English River domains, which raise the issue of tectonically controlled basin differentiation. At the end of Winnipegosis time, the Elk Point Basin became restricted and the basin was filled by interlaminated carbonate and anhydrite of the Ratner Formation followed by the deposition of anhydrite, halite, and bittern salts (Muskeg and Prairie Evaporite formations) as a result of evaporative drawdown.

Based on detailed core examination, fifteen lithofacies have been recognized in the Winnipegosis, Elm Point, and Ratner formations in the study area: A) non-fossiliferous mudstone, B) mottled-nodular skeletal wackestone-mudstone, C) nodular-patterned mudstone, D) bituminous laminite, E) interlaminated mudstone-anhydrite, F) massive-

mottled mudstone, G) septarian-type nodular skeletal packstone, H) bedded-mottled peloidal packstone, I) intraclast floatstone, J) bituminous skeletal wackestone-floatstone, K) peloidal-udoteacean packstone, L) stromatoporoid floatstone, M) coral-stromatoporoid rudstone-framestone, N) laminated mudstone-peloidal packstone, and O) microbial bindstone. These lithofacies have been grouped into five lithofacies associations: ramp, platform interior, platform slope, isolated reef, and basinal salina. The ramp association (lithofacies A, B, C, D) comprises the Lower Winnipegosis Member/Elm Point Formation and includes deposits of inner to mid-ramp settings as well as off-shore tidal flat islands. The platform interior association (lithofacies D, H, I, O) and platform slope association (lithofacies D, F, G, H, I, M, N, O) comprise the Upper Winnipegosis Member and include deposits of open to slightly restricted lagoonal and lower to upper slope settings respectively. The isolated reef association (lithofacies I, J, K, L, M, N, O) occurs in the Upper Winnipegosis Member isolated reef deposits and includes proto-reef, lagoonal, fore-reef, reef-crest, and reef flat deposits. The basinal salina association (lithofacies D, E) comprises the Ratner Formation.

Bituminous laminites (lithofacies D) occur in the ramp-to-platform and ramp-to-basin transitions, platform interior and platform slope successions, and in basinal successions. Based on examination of representative samples of these bituminous laminites using white and ultra-violet incident light microscopy, organic facies indicative of either normal or elevated phytoplankton productivity (blooms) were interpreted based on the maceral assemblages present. Bituminous laminites in the study area were deposited primarily as a result of elevated phytoplankton productivity; three bloom facies were identified: BL1, cyanophyte blooms; BL2, cyanophyte and Prasinophyte blooms; and

BL3, calcisphere-producing phytoplankton blooms. They are best developed in stratigraphic intervals associated with changes in depositional regime including the transition from ramp-to-platform/basin and from an open to restricted basin at the end of Winnipegosis time.

Organic geochemical analyses were also conducted to evaluate the kerogen type, extent of thermal maturation, and the petroleum generative potential of the bituminous laminites. Data from Rock Eval pyrolysis analyses, which were plotted on modified van Krevelen diagrams, indicate that bituminous laminites within the study area are geochemically varied, but most samples plot between Type II and Type III kerogen fields. Additionally, all analyzed bituminous laminites are thermally immature with respect to hydrocarbon generation; however, one laminite in the Lower Winnipegosis Member, which is the most southwestern and deepest one in the study area, has approached the onset of catagenesis.

The Winnipegosis Formation is best known for its isolated reef petroleum plays in Saskatchewan; however at least three other plays exist: platform margin, platform interior, and basin laminites (Ratner Formation). In the study area, previously documented and newly found oil shows from cores and cuttings indicate that an unknown quantity of petroleum has migrated through parts of the study area. However, there has been no petroleum production from the Winnipegosis Formation in Manitoba to date.

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CHAPTER 1: INTRODUCTION

1.1 Prologue

The occurrence of Devonian reefs in the subsurface of the Western Canadian Sedimentary Basin has been of paramount significance to the economy of western Canada as the Devonian System historically has been the most prolific conventional oil-producing interval in Western Canada (e.g., Wendte, 1992).

The impetus for hydrocarbon exploration in reefs in the Middle Devonian Winnipegosis Formation of southern Saskatchewan and North Dakota was the reef discoveries in the Keg River Formation of the Rainbow-Zama trend in northwestern Alberta (Precht, 1986). The Keg River reefs are coeval with the Winnipegosis reefs. According to early estimates, these Keg River reefs had total hydrocarbon reserves greater than $159x10^6$ m^3 with per well recoverable reserves often in excess of $159x10^3$ m^3 (Barss et al., 1970). After many dry wells, discoveries during the 1980's in southeastern Saskatchewan included the Hitchcock area isolated reefs, as well as the Tableland isolated reef, which had estimated recoverable hydrocarbon reserves of $2.5x10^5$ m^3, and the Temple Field in the western platform margin of North Dakota, which had defined recoverable hydrocarbon reserves of $1.03x10^6$ m^3 (Ehrets and Kissling, 1987; Martindale and MacDonald, 1989).

In comparison to the Winnipegosis Formation in Saskatchewan, North Dakota, and the equivalent Keg River Formation in Alberta, the Winnipegosis Formation and other Devonian strata in Manitoba have received little study and their full economic potential is

poorly known. This study focuses on the sedimentology, organic petrology and organic geochemistry of the Winnipegosis Formation and associated Elm Point and Ratner formations at the eastern margin of the Elk Point Basin in the southwest corner of Manitoba.

1.2 Geologic Setting

Devonian strata of the Western Canadian Sedimentary Basin (WCSB) occur in a widespread belt extending from the Arctic Ocean and the Alaska-Yukon border to southwestern Manitoba, and continue into the north-central United States (e.g., Perrin, 1987; Wendte, 1992). These strata include a diverse variety of depositional facies with recurring lateral and vertical relationships (e.g., Wendte, 1992). Rudimentary facies belts include platform carbonates and evaporites, reefal carbonates, and basin-filling shales, limestones and evaporites.

Generally, Devonian deposition in the WCSB is interpreted to be characterized by steady transgression interrupted by brief regressive pulses (e.g., Moore, 1988). Consequently, Devonian strata are divided by discontinuities into five sequences: (1) Delorme sequence, (2) Bear Rock sequence, (3) Hume-Dawson sequence, (4) Beaverhill-Saskatchewan sequence, and (5) Palliser sequence. Each sequence began with an influx of siliciclastics, followed by deposition of platform carbonates and mound building; reef-building was only attained during the third and fourth sequences.

The Hume-Dawson sequence was deposited during the Middle Eifelian to Middle Givetian (e.g., Moore, 1988). During this time, the northern region of western Canada had deepened to form an open platform and the Keg River Barrier (Presqu'ile Barrier) had built across the area northeastward of the Peace River Arch. The elongated, intracratonic Elk Point Basin formed behind the barrier where sub-basins had coalesced and extended from northeastern British Columbia and the District of Mackenzie southeastward into the Williston Basin of southern Saskatchewan and Manitoba, and northern North Dakota and Montana (e.g., Norris et al., 1982; Moore, 1988; Meier-Drees, 1994) (Fig. 1.1). Carbonate rocks in the Hume-Dawson sequence deposited in this basin are assigned to the Keg River Formation in Alberta and the Winnipegosis Formation in Saskatchewan, North Dakota, and Montana, and to the Winnipegosis and Elm Point formations in Manitoba (e.g., Norris et al., 1982; Perrin, 1987; Moore, 1988).

As the sea transgressed to its maximum extent, the Elk Point Basin differentiated into two regions: a shallow fringing carbonate platform and a bathymetrically deeper basin (Perrin, 1982). In Manitoba, this differentiation appears to be at least partially tectonically controlled as the platform margin lies coincident with the Birdtail-Waskada Axis, which is a trend manifested as structural and isopach anomalies in Phanerozoic strata that overlie the Precambrian Superior Boundary Zone (e.g., McCabe, 1971) (Fig. 1.2). Swarms of isolated reefs grew up to 200 m high in response to deepening sub-tropical to tropical waters (e.g., Moore, 1988; 1989a). At the end of Winnipegosis time, the Elk Point Basin became restricted and the basin was filled by laminated/ interlaminated carbonate and anhydrite (Ratner Formation) followed by the deposition of

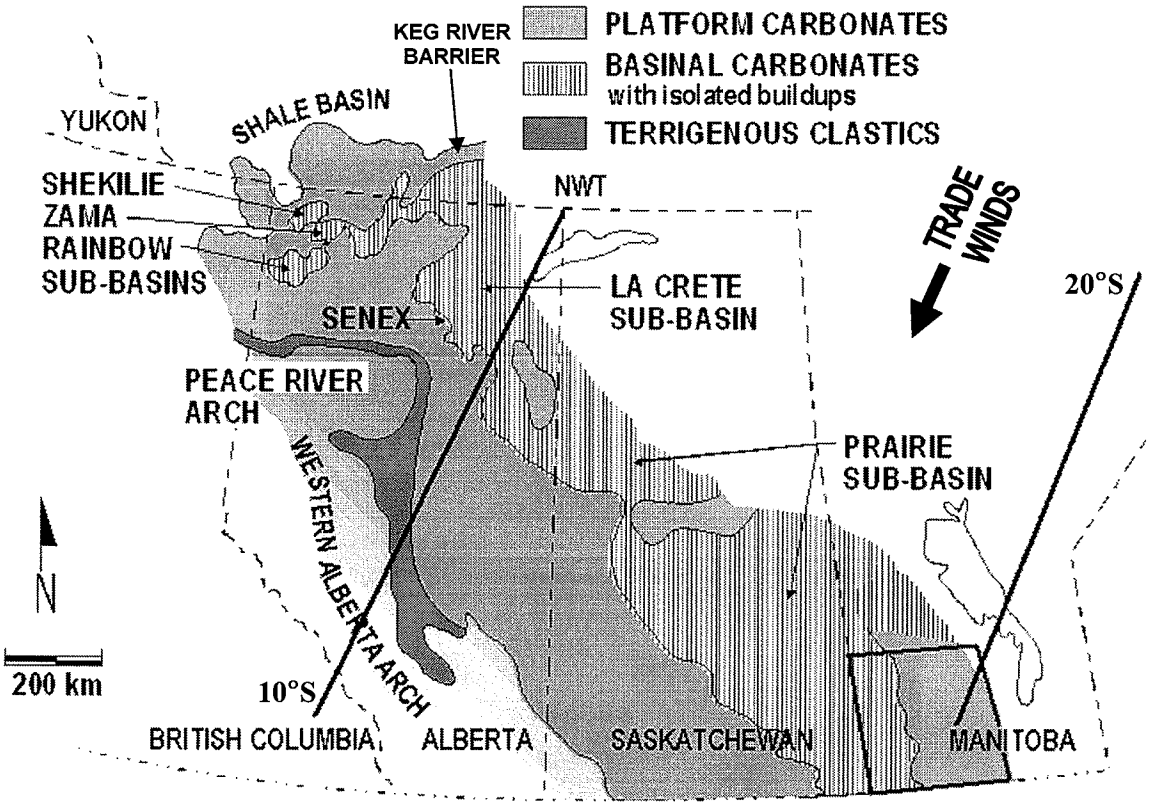


Figure 1.1: Paleogeographic map of the Elk Point Basin during Winnipegosis Formation deposition with the study area outlined in red (modified from Chow et al., 1995). Paleolatitude lines and tradewind direction from Heckel and Witzke (1979).

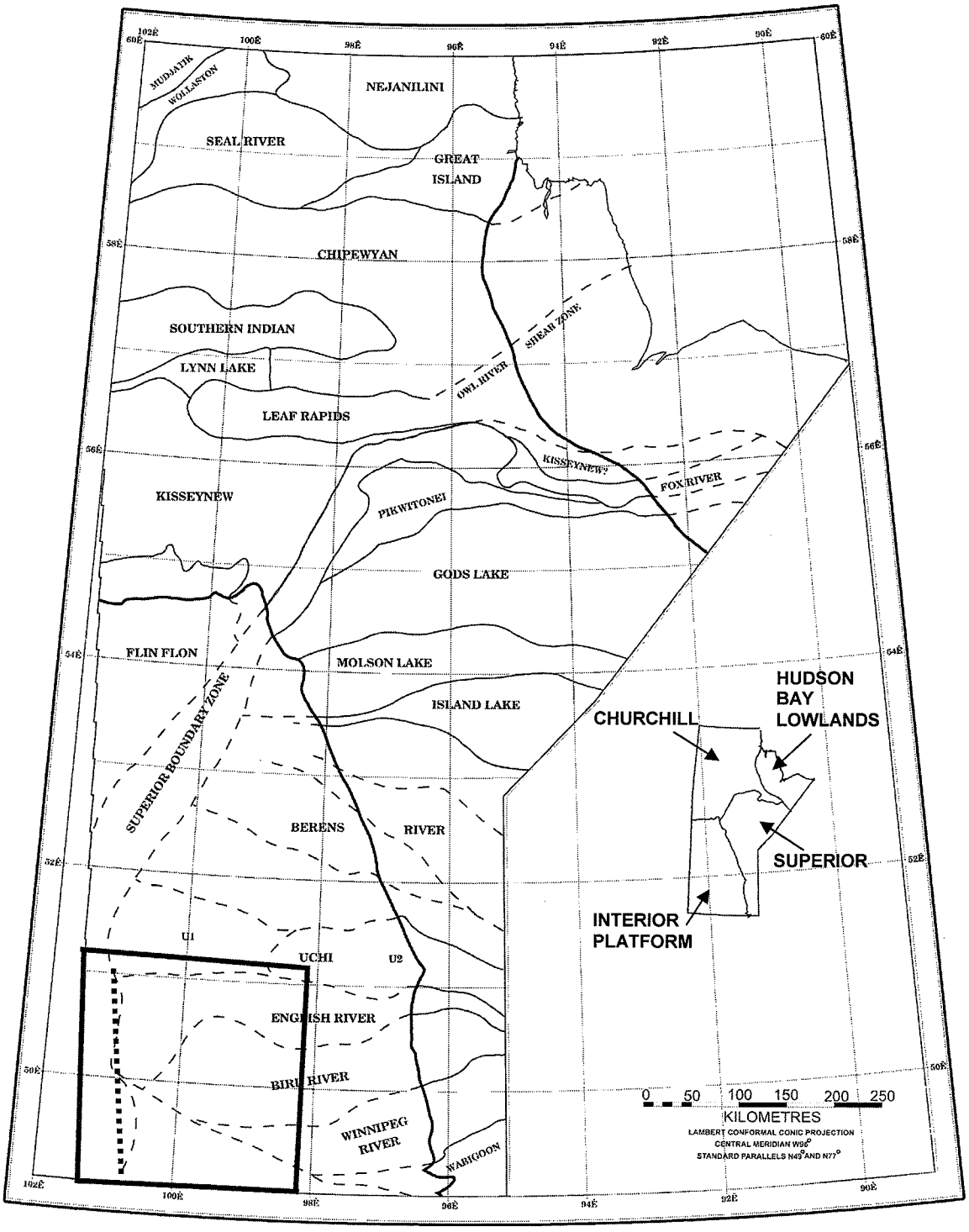


Figure 1.2: Map showing basement domains in Manitoba interpreted from magnetic and gravity potential field data (modified from Pilkington and Thomas, 2001). Location of Birdtail-Waskada Axis (blue dashed line) from Martiniuk (1992); study area is outlined in red.

anhydrite, halite, and potassium and magnesium salts (Muskeg and Prairie Evaporite formations) as a result of evaporative drawdown (e.g., Maiklem, 1971; Kent and Christopher, 1994; Jin and Bergman, 2001). By the Mississippian, the Elk Point Basin was eliminated by the upwarp of the Saskatchewan Shelf and Sweetgrass Arch, and the Williston Basin became prominent again (e.g., Kent and Christopher, 1994). As a consequence of this shift in tectonic/depositional framework, the Winnipegosis Formation in Manitoba presently dips southwestwards towards the ellipsoidal Williston Basin centered in North Dakota (Fig. 1.3; 1.4).

An unknown portion of the northeastern Elk Point Basin, up to one third by some estimates, has been removed by erosion, and outcropping Devonian rocks at its erosional edge, including the Winnipegosis Formation, form a northwest-trending linear belt in southwestern Manitoba (e.g., Norris et al., 1982; Williams, 1984; McCabe, 1988). This belt measures approximately 350 km long, up to 80 km wide, and extends from the southeast end of Lake Manitoba in the south to the northwest end of Lake Winnipegosis in the north (e.g., Norris et al., 1982) (Fig. 1.4; 1.5).

1.3 Previous Studies

The Winnipegosis Formation has been the subject of many studies spanning more than a century and has also been included in regional or broad-scoped overviews. Rocks equivalent to the Winnipegosis Formation were originally identified by Tyrrell (1892) in the Manitoba outcrop belt and he named them the Winnipegosan Formation. Kindle (1914) introduced the Elm Point Limestone in the Manitoba outcrop belt near the

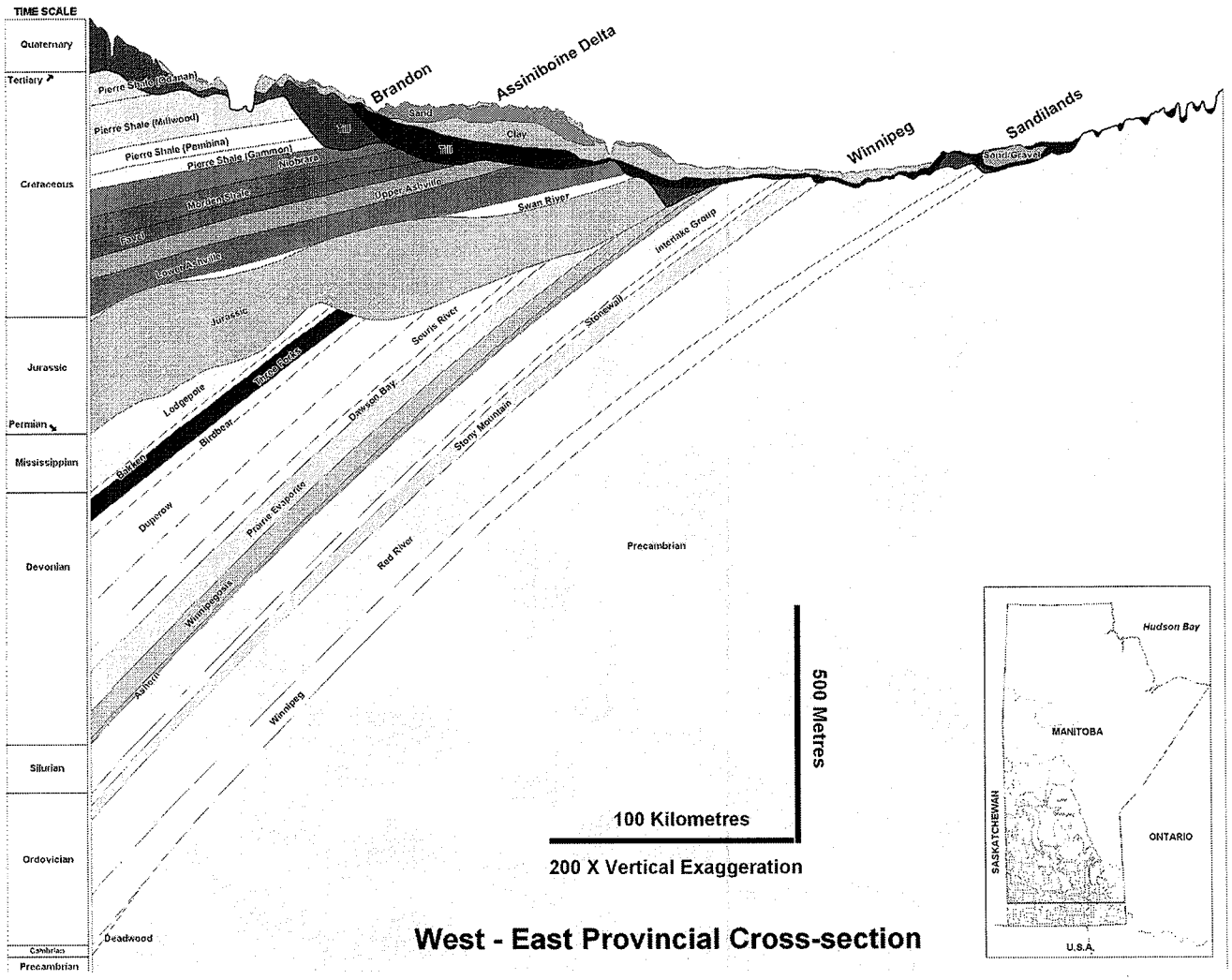


Figure 1.3: Structural W-E cross section across southern Manitoba showing the westward-dipping Phanerozoic succession (pers. comm., G. Matile, 2006).

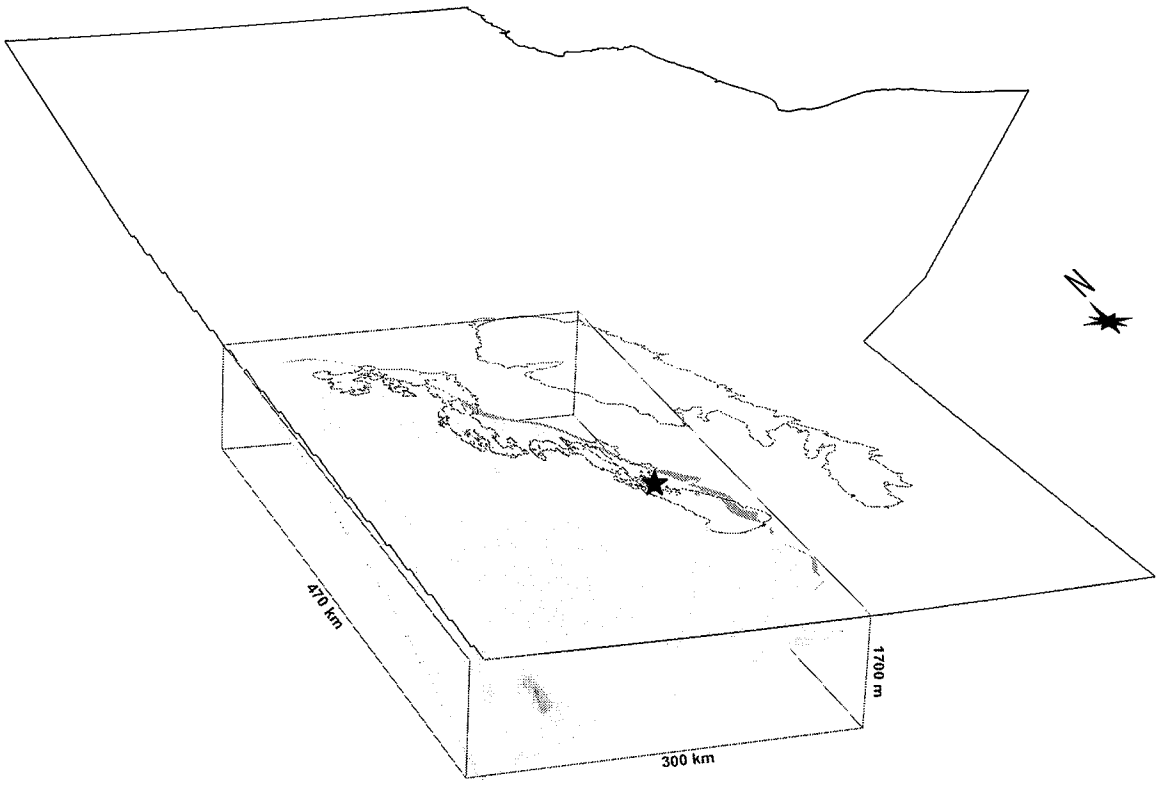


Figure 1.4: Three dimensional diagram illustrating the outline of the province of Manitoba and present configuration of the Winnipegosis Formation dipping southwestward towards the Williston Basin depocenter in North Dakota (pers. comm., G. Keller and G. Matile, 2006). The brown area indicates the erosional surface at the eastern margin, the prominent indentation towards the southwest corner is the Hartney structure (possible meteorite impact), and the red star marks the Lake Manitoba Narrows. V.E. 50X.

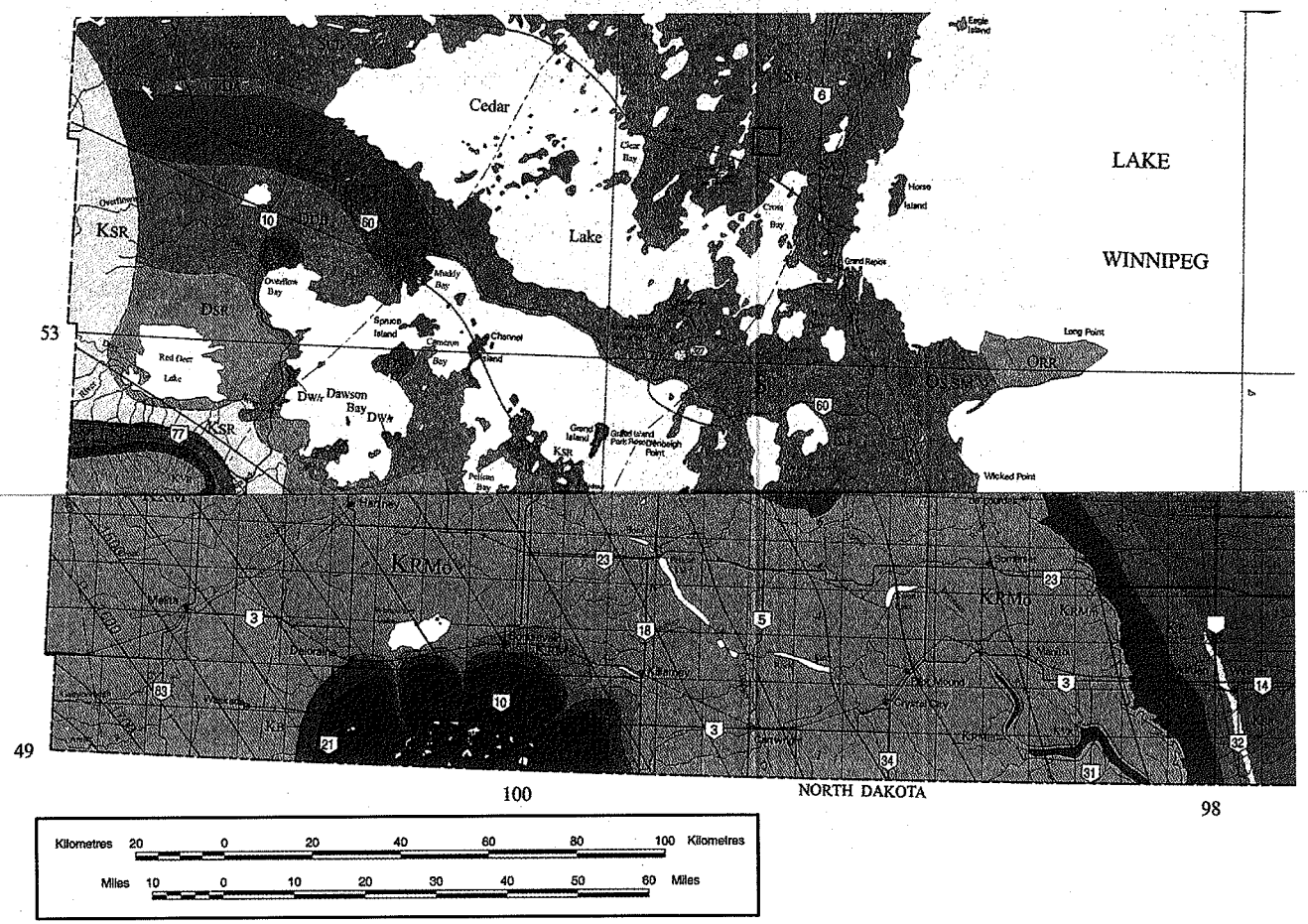


Figure 1.5: Geological map showing the distribution of the Elm Point and Winnipegosis formations (brown colored, labeled D_{EP} and orange colored, D_W) in the Devonian outcrop belt relative to other Phanerozoic strata in southern Manitoba (modified from Manitoba Geological Survey, ftp://ftp.em.gov.mb.ca/pub/ mb_geol.pdf, accessed March 27, 2006).

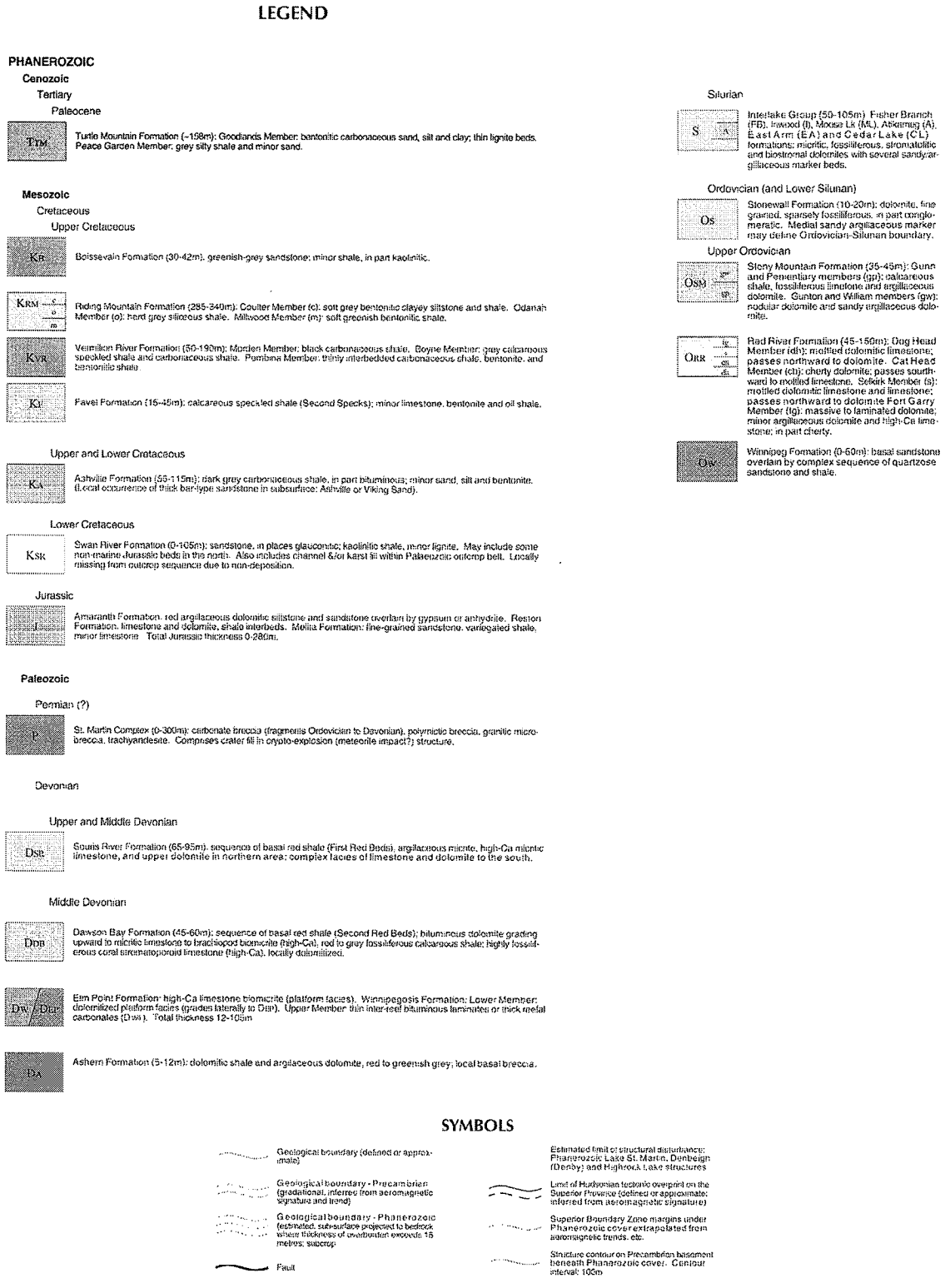


Figure 1.5: Continued.

northeast end of Lake Manitoba, which was later renamed the Elm Point Formation by Baillie (1951). Baillie (1953; 1955) proposed a revised classification of the Elk Point Group in the Williston Basin and identified bioherm and interbioherm facies in Tyrrell's (1892) Winnipegosan Formation and re-named it the Winnipegosis Formation with the intent of avoiding a time connotation.

1.3.1 Basin-Scale Studies

Kent (1964) and Moore (1988; 1989a) provided overviews of the geological history of the Devonian System in the WCSB. Wendte (1992) summarized Devonian strata in the subsurface of the WCSB using a sequence-stratigraphic approach. Meijer-Drees (1994) provided an overview of the Elk Point Group in western Canada, which includes the Winnipegosis Formation, and Williams (1984) discussed enigmatic depositional features of the Elk Point Basin. More topic-specific studies included Moore (1989b), which outlined the occurrence and history of Devonian reefs in Canada, and Davies and Ludlam (1973), which addressed the origin of basinal laminites in the Elk Point Basin. Maiklem (1971) studied post-Winnipegosis evaporative drawdown and diagenesis in the Elk Point Basin.

1.3.2 Manitoba Studies

Regional-scale work documented the tectonic framework of Paleozoic formations in Manitoba including the Winnipegois Formation (McCabe, 1967) and provided a comprehensive description of the sedimentology and stratigraphy of Devonian strata in the Manitoba outcrop belt, including micropaleontology (Norris et al., 1982). McCabe

and Barchyn (1982), Bezys and McCabe (1996), and Bezys and Bamburak (2004) provided overviews of the Manitoba outcrop belt in a series of field trip guide books. Martiniuk (1992) and Martiniuk and Barchyn (1993) reported on the stratigraphy and petroleum potential of the Lower Paleozoic in the subsurface of southwestern Manitoba. Rosenthal (1988) studied the sedimentology of the Winnipegosis Formation from cores and outcrops from the Devonian outcrop belt and developed a model with implications for subsurface exploration.

Studies of Winnipegosis reefs include McCabe (1988), which proposed a reef model for the outcrop belt and made comparisons to the Keg River reefs, and Teare (1990), which examined the sedimentology of isolated reefs in the Dawson Bay area. Kent and Minto (1991) and Minto (1996) studied the sedimentology, paleoecology, and morphology of reefs at the Bluff in the Dawson Bay area. Chow and Longstaffe (1995) studied controls on early dolomitization of the Elm Point Formation.

1.3.3 Saskatchewan Studies

Jones (1965) completed a comprehensive study on the Winnipegosis Formation in Saskatchewan and subdivided the unit into lower and upper members. A number of studies focused on Winnipegosis reefs/mounds, detailing their form and distribution (Gendzwill and Wilson, 1987), sedimentology and diagenesis (Martindale and MacDonald, 1989; Stanford, 1989; Fu et al., 2004; Fu et al., 2006), and reservoir quality and source rocks (Martindale et al., 1991; Yurkowski, 1995). Organic petrology of the

Winnipegosis Formation source rocks in Saskatchewan was conducted by Stasiuk (1993; 1994; 1999) and Stasiuk and Fowler (2004).

Shearman and Fuller (1969) examined the origin and diagenesis of Winnipegosis basinal laminites in Saskatchewan. Kendall (1975) suggested that the bituminous laminites were coeval with the Winnipegosis isolated reefs and the Ratner Member postdated the reefs. Wardlaw and Reinson (1971) and Reinson and Wardlaw (1972) discussed the Winnipegosis Formation-Prairie Evaporite transition, re-evaluated Jones' (1965) subdivisions, and named the laminated inter-reef carbonates the Ratner Member. Jin and Bergman (1999) studied the sequence stratigraphy of the Winnipegosis Formation-Prairie Evaporite transition and Jin and Bergman (2001) revised the stratigraphy of this interval, elevating the Ratner Member to formation status and formalized the Brightholme Member. Jin and Bergman (1998) examined the occurrences of the Ratner laminite in southern Saskatchewan.

1.3.4 North Dakota Studies

Perrin (1982; 1987) and Perrin and Precht (1985) discussed the sedimentology, paleoecology, and diagenesis of the Winnipegosis Formation in North Dakota. Fisher and Burke (1987) provided a synoptic overview of pinnacle reefs, and Erets and Kissling (1987) and Precht (1986) examined the sedimentology and reservoir development of platform margin and pinnacle reef reservoirs. Kostelnyk (1998) studied diagenesis in the Winnipegosis Formation.

1.4 The Study

1.4.1 Objectives

The primary aim of this study is to describe and interpret the sedimentology, organic petrology, and organic geochemistry of the Winnipegosis and Elm Point formations in southwestern Manitoba with secondary emphasis on the Ratner Formation. This work addresses knowledge of the evolution of the Elk Point Basin at its eastern margin and provides insight into the petroleum potential of the Winnipegosis Formation.

The specific objectives are as follows:

1. Describe and interpret the lithofacies and lithofacies associations in the Elm Point, Winnipegosis, and Ratner formations using cores and well logs.
2. Construct isopach maps of the lower and upper members of the Winnipegosis Formation to assist with depositional interpretations.
3. Describe and characterize the organic facies of bituminous laminites present in the cores in order to interpret the primary controls on sedimentary organic matter accumulation and preservation and the depositional origin of associated carbonate units.
4. Use organic geochemistry to characterize and determine the thermal maturity of the bituminous laminites.
5. Investigate the hydrocarbon potential of the study area by making comparisons with producing areas elsewhere in the Elk Point Basin.

1.4.2 Study Location

The study area encompasses ~56,000 km^2 in southwestern Manitoba from the Canada-United States border to just north of Dauphin (Township 1 to 25) and from just east of Portage la Prairie to the Saskatchewan border (Range 6 to 29W1) (Fig. 1.6). The Winnipegosis Formation crops out in the Lake Manitoba Narrows area in the northeast corner of the study area and occurs at greater than 1723 m in the subsurface in the southwestern corner (Fig. 1.4).

1.5 Methodology

1.5.1 Selection, Examination, and Description of Core

The study included all 23 petroleum well cores that penetrated the Winnipegosis Formation in the study area (Fig. 1.6). In addition, five stratigraphic test cores from the Lake Manitoba Narrows area in the outcrop belt were examined; they are closely spaced and cover the complete Elm Point-Winnipegosis interval, facilitating short distance correlations (Fig. 1.7). The cores totaled approximately 422 m in length and were studied and photographed during the summer of 2004 at the core and sample library of Manitoba Industry, Economic Development, and Mines (currently Manitoba Science, Technology, Energy and Mines) in Winnipeg (Appendix B).

Lithological logs were created for all cores and documented color, lithology, sedimentary structures and textures, allochems, porosity types, and accessory minerals (Appendices B and C). Where it was not previously done, cores were cut and the slabbed surfaces were

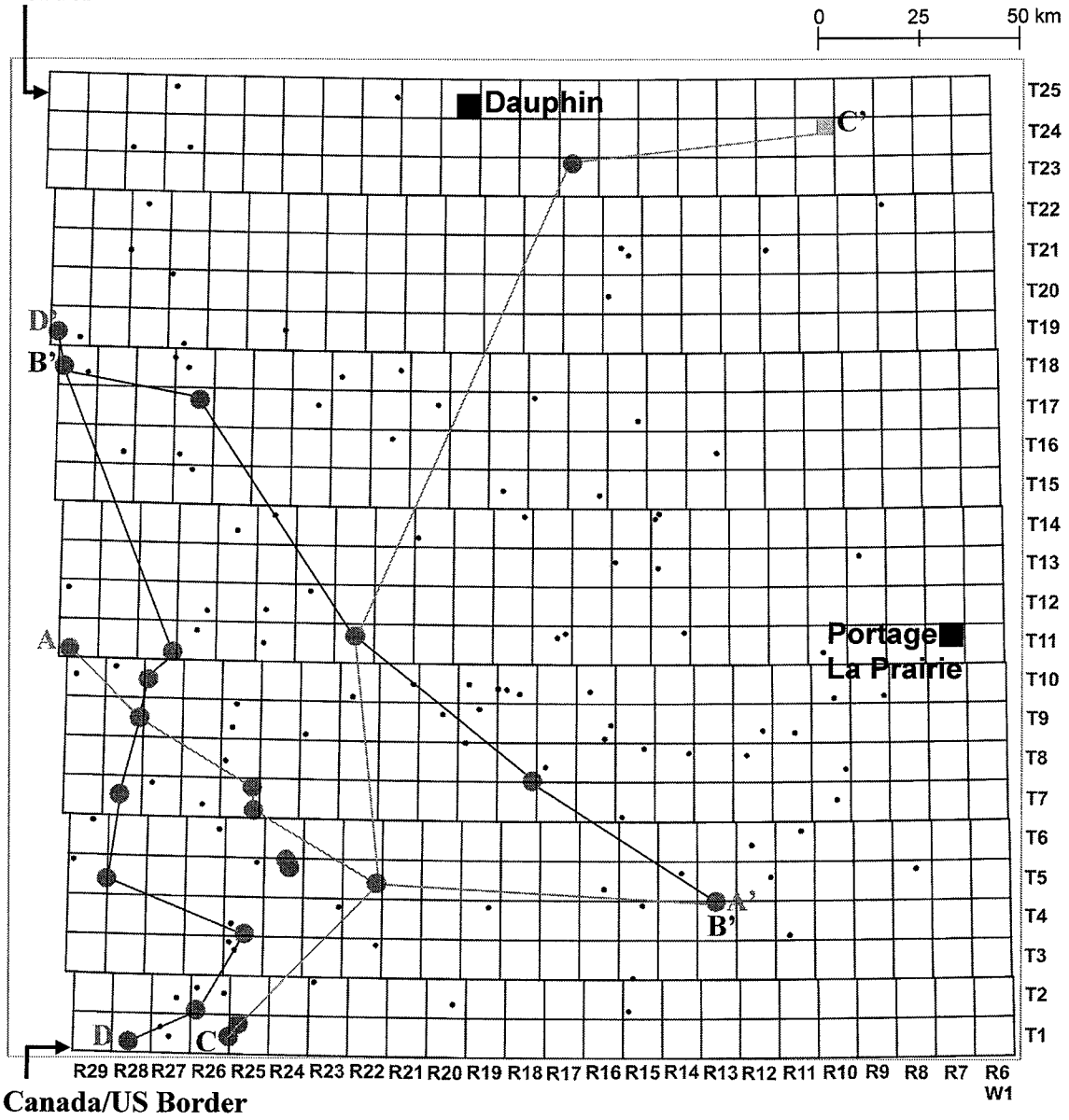


Figure 1.6: Map showing the location of cores used in the study and section lines of the regional cross sections. The red dots indicate the locations of wells for which petroleum cores were available. The blue square indicates the general location of five stratigraphic test cores in the Lake Manitoba Narrows area in the outcrop belt used in the study. Black dots indicate the locations of wells that penetrate at least the Upper Winnipegosis Member and were not studied because of lack of core.

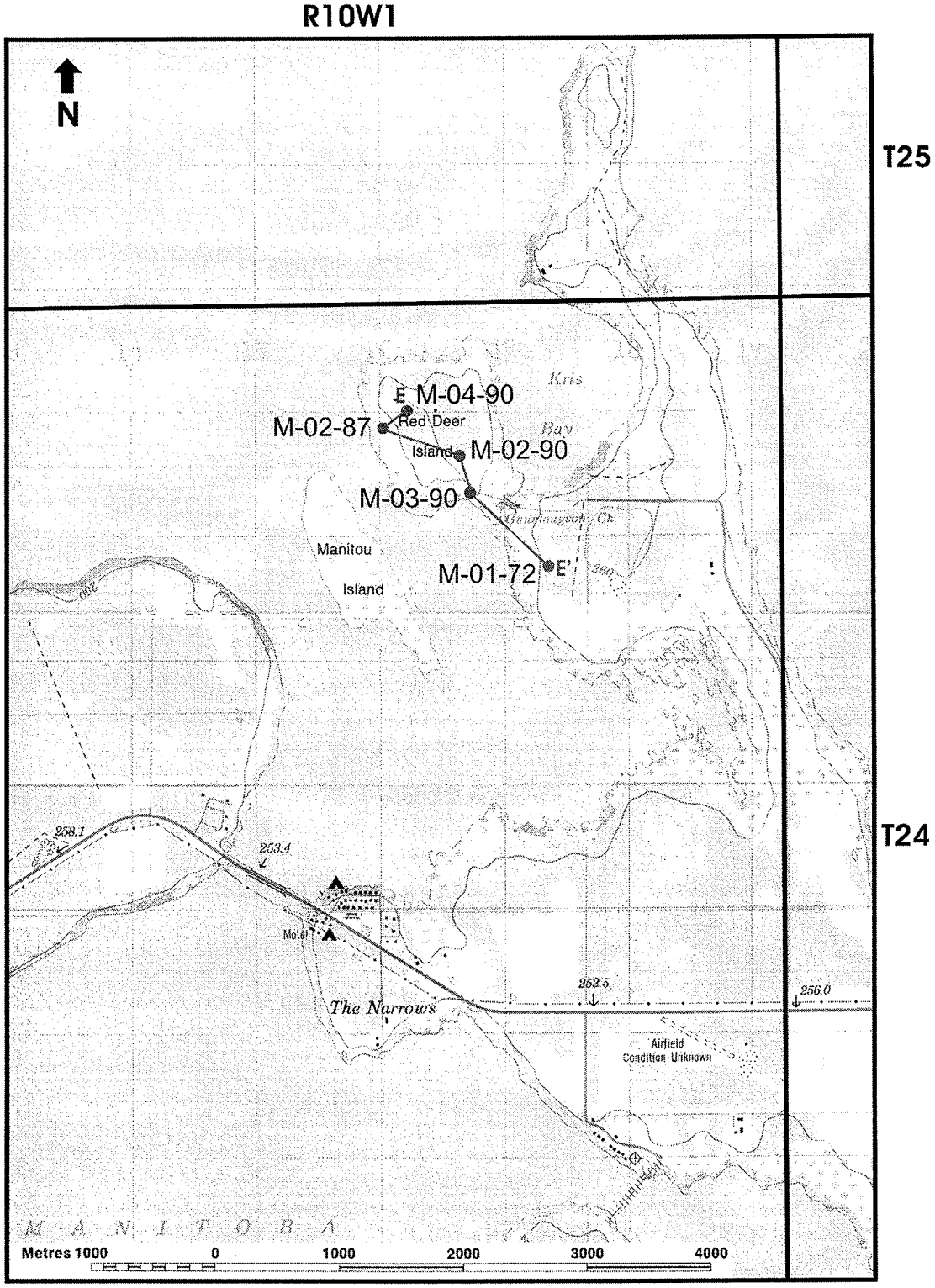


Figure 1.7: Topographic map of the Lake Manitoba Narrows area in the Devonian outcrop belt showing the location of stratigraphic cross section E-E' (modified from Ebb and Flow Lake topographic map, Canada Center for Mapping, Department of Energy, Mines, and Resources, 1993).

examined wet to enhance textural definition. Where possible, core depths were corrected to petrophysical log depth by matching prominent lithological changes to log responses. Limestone was differentiated from dolostone using dilute (10%) hydrochloric acid. Dilute hydrochloric acid was also used to etch limestone and dolomitic intervals to clean the surfaces. A binocular microscope was used to assist with identifying small constituents where required. Lithologies were classified according to Dunham's (1962) classification of carbonate rocks as modified by Embry and Klovan (1971) (Fig. 1.8A). The prefix "dolo" was assigned to the names of lithologies that are exclusively dolomitized and the prefix "(dolo)" was assigned to lithologies that occur as both limestone and dolostone. Porosity was described based on the classification of Choquette and Pray (1970) with the addition of using the term "pinpoint" for describing sub-millimeter scale, round pores (Fig. 1.8B). After core logging and photography were completed, the cores were sampled for thin sections, organic petrology, and organic geochemistry.

1.5.2 Cross Section Construction

Five stratigraphic cross sections were created to assist in determining the lateral and vertical relationships of the various lithofacies within the study area. The section lines were aligned as much as possible to trend either parallel or perpendicular to regional dip in the Elk Point Basin. The wells were spaced proportionately and petrophysical log profiles were included where available. The top of the Ashern Formation was used as a datum because of its low relief and the fact that it is unaffected by salt dissolution

A

ALLOCHTHONOUS LIMESTONE Original components not organically bound during deposition						AUTOCHTHONOUS LIMESTONE Original components organically bound during deposition		
Less than 10% >2 mm components				Greater than 10% >2mm components		By organisms that build a rigid framework	By organisms that encrust and bind	By organisms that act as baffles
Contains lime mud (<0.03mm)			No lime mud					
Mud-supported		Grain-supported		Matrix-supported	>2 mm component-supported			
Less than 10% grains (>0.03 mm <2 mm)	Greater than 10% grains							
						BOUNDSTONE		
MUD-STONE	WACKE-STONE	PACK-STONE	GRAIN-STONE	FLOAT-STONE	RUD-STONE	FRAME-STONE	BIND-STONE	BAFFLE-STONE

B

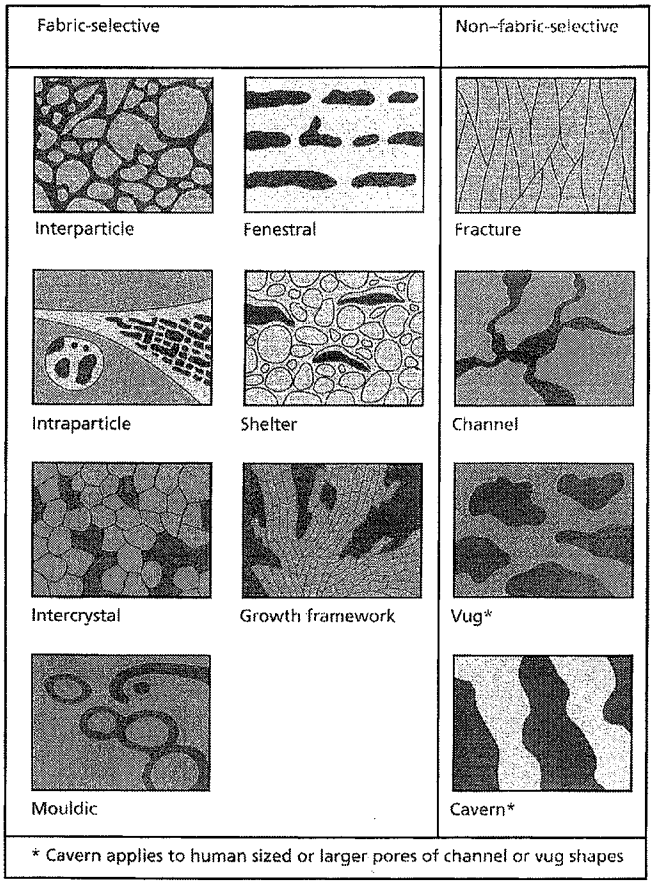


Figure 1.8: A) Dunham's (1962) classification of limestones as modified by Embry and Klovan (1971). B) Choquette and Pray's (1970) classification of porosity in carbonate rocks (modified from Adams and MacKenzie, 1998); porosity in dark blue.

(e.g., Ehrets and Kissling, 1987; Rosenthal, 1988; Martindale et al., 1991; Jin and Bergman, 1999; Zhang et al., 2004).

Four of the cross sections are small-scale, spanning most of the study area (Fig. 1.6; Encls. 1-4). These sections include all of the cored petroleum wells with the exception of two wells from the Hartney area (Township 5, Range 24W1), where a post-Mississippian to pre-Jurassic impact crater and extreme thrust faulting make it impossible to place the cores stratigraphically (cf. Martiniuk, 1992; Grieve et al., 1998). Additionally, one of the small-scale cross sections (Encl. 3) ties into one of the stratigraphic test cores in the Lake Manitoba Narrows area of the outcrop belt. The fifth stratigraphic cross section is large-scale and includes five stratigraphic test cores from the Lake Manitoba Narrows area (Fig. 1.7; Encl. 5).

1.5.3 Spatial Analysis of Isopach Data and Map Construction

Isopach maps of both the Lower Winnipegosis Member/Elm Point Formation and the Upper Winnipegosis Member/Ratner Formation were constructed to assist with depositional interpretation (Encls. 8, 9). These members/formations were combined to provide as much continuity of data across the study area as possible. Computerized mapping with Golden Software's Surfer application was employed to minimize human bias in contouring. A geostatistical method called kriging, which attempts to express trends present in data sets, was used to generate the isopach maps. More specifically, ordinary (point) kriging was used because it is considered to be the best linear unbiased estimator (B.L.U.E.), and is distinguished from other point estimation methods by its

minimization of the error variance (Issaks and Srivastava, 1989). Additionally, ordinary kriging interpolates the unknown values at specific locations while fitting observed values exactly (Golden Software Inc., 2002), a feature that was considered to be desirable for the isopach maps because there is very little uncertainty in the data at those locations.

Isopach values for Manitoba were calculated from formation tops obtained in 2004 from the stratigraphic database of the then-named Manitoba Industry, Economic Development and Mines, which is derived from petrophysical log picks in petroleum wells and core descriptions from stratigraphic test holes (Appendix A). Adjustments were made, where required, for the wells and stratigraphic test cores examined in this study. Additional data were obtained for wells that penetrated the Winnipegosis and Ratner formations in the four ranges west of the Manitoba-Saskatchewan border from Saskatchewan Industry and Resources and in the four townships south of the Manitoba-North Dakota border from the North Dakota Geological Survey so that contouring results near the western and southern boundaries of the study area would be as accurate as possible (Appendix A). A total of 222 data points were used for the isopach map of the Lower Winnipegosis Member/Elm Point Formation and 226 data points were used for the isopach map of the Upper Winnipegosis Member/Ratner Formation (Fig. 1.9). The UTM (Universal Transverse Mercator) system was used for well location co-ordinates with a NAD83 geodetic datum.

The kriging method uses a variogram model for interpolation (e.g., Golden Software Inc., 2002). Variogram models were produced for this study by generating an omni-directional, experimental variogram, which is a quantitative descriptive statistic that can

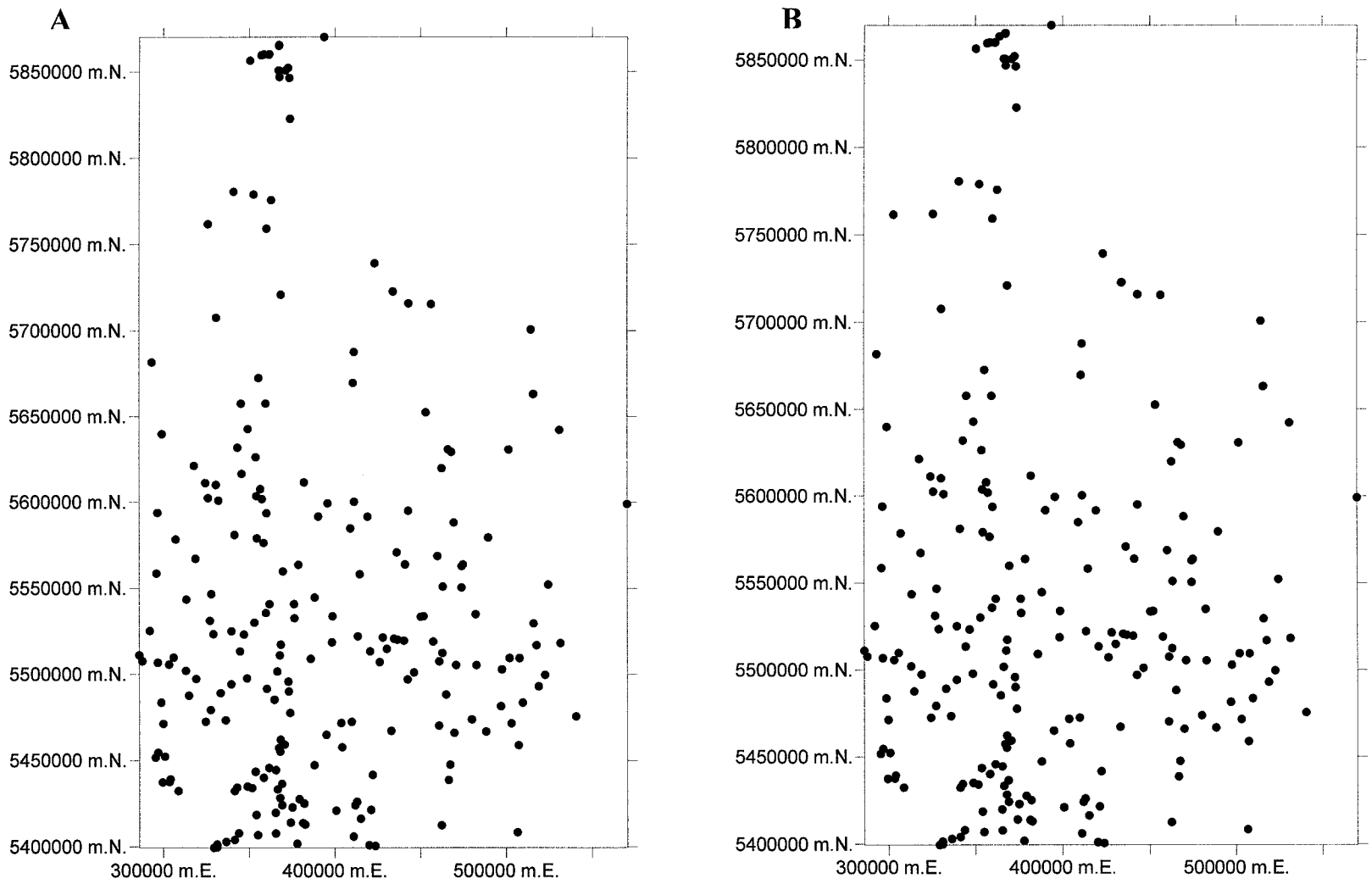


Figure 1.9: Distribution of data points used for interpolating the isopach contour maps. A) Data points for the Lower Winnipegosis Member/ Elm Point Formation. B) Data points for the Upper Winnipegosis Member/Ratner Formation.

be represented graphically to characterize the spatial continuity of a dataset, for each of the Lower Winnipegosis Member/Elm Point Formation and Upper Winnipegosis Member/Ratner Formation datasets. Variogram models were then fitted to the experimental variograms.

1.5.4 Carbonate Petrography

In total, 139 thin-sections were prepared and then stained with a 2:3 solution of Alizarin Red-S and potassium ferricyanide ($K_3[Fe(CN)_6]$) to distinguish calcite from dolomite and ferroan from non-ferroan carbonates respectively (Dickson, 1966). Thin-sections were examined and photographed using a Nikon OPTIPHOT-POL microscope with a phototube and a Nikon COOLPIX 4500 digital camera (Appendix D). Epi-fluorescence microscopy was done using the same microscope with an epi-fluorescence attachment and a Hg lamp (Model HB-10101AF) light source; this setup permitted concurrent transmitted light and epi-fluorescence microscopy. The thin-sections were examined using ultraviolet (UV; 330-380 nm excitation filter, 420 nm barrier filter), violet (V; 380-425 nm excitation filter, 450 nm barrier filter), blue-violet (BV; 400-440 nm excitation filter, 470 nm barrier filter), and blue (B; 450-490 nm excitation filter, 520 nm barrier filter) light filters to search for remnants of allochems in diagenetically altered samples (Dravis and Yurewicz, 1985); however, epi-fluorescence did not prove useful for this purpose but did reveal microscopic oil staining in pore spaces. Diffused plane-polarized light microscopy, which involves placing a piece of white paper between the microscope stage and thin section so as to diffuse condensed plane polarized light, was also used to accentuate obscured allochems in diagenetically altered samples (Dravis, 1991).

Volume percentage estimates for constituents and porosity observed in thin-section were done visually with the assistance of comparison charts from Baccelle and Bosellini (1965) (Appendix D). The crystal size of authigenic constituents was described using the classification of Folk (1962) with the modification of using the term "micrite" for calcite grains $\leq$ 5 μm rather than aphanocrystalline (Fig. 1.10A). Neomorphic calcite was described as either microspar (4-30 μm) or pseudospar (>30μm) using the classification of Folk (1965). Dolomite was described using the textural classification of Sibley and Gregg (1987) (Fig. 1.10B).

1.5.5 Scanning Electron Microscopy

Scanning electron microscope (SEM) analysis was used for semi-quantitative elemental analysis of opaque minerals in carbonate samples where they were of interest for depositional interpretation. Two thin sections were selected using carbonate petrography for SEM analysis and were carbon coated. The instrument used was a Cambridge Stereoscan 120 with the electron beam operating at an accelerating voltage of 20 kV, which was fitted with a backscattered electron (BSE) detector to differentiate mineral phases with contrasting atomic weights as represented by different grey levels. Once minerals of interest were identified, their elemental composition was determined using an energy dispersive X-ray analysis system (EDAX Genesis Program), which collected emissions from a spot with a 2 μm diameter.

A CLASSIFICATION	SIZE
Extremely coarsely crystalline	>4 mm
Very coarsely crystalline	1-4 mm
Coarsely crystalline	0.25-1 mm
Medium crystalline	0.062-0.25 mm
Finely crystalline	0.016-0.062 mm
Very finely crystalline	0.004-0.016 mm
Aphanocrystalline	<0.004 mm

B

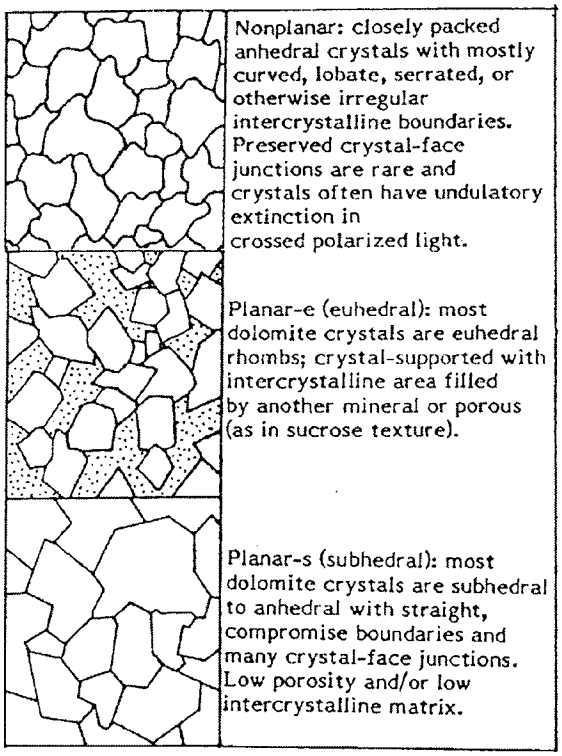


Figure 1.10: A) Size scale for authigenic constituents in carbonate rocks (modified from Folk, 1962). B) Classification of dolomite textures (modified from Sibley and Gregg, 1987).

1.5.6 Organic Petrology

In total, 13 representative samples from 12 bituminous laminites in nine cores were selected for organic petrology, which was conducted at the Organic Petrology Laboratory at the Geological Survey of Canada in Calgary under the supervision of Dr. Lavern Stasiuk (Appendix E). These samples were fragmented with a mortar and pestle into coarse and fine size fractions, which were embedded in 2.5 cm diameter epoxy resin pellets. Fragments from the coarser fraction (as large as 1 cm^3) were oriented by hand to be either perpendicular or parallel to bedding with respect to the pellet surface while the finer fraction was oriented randomly to provide as many vantage points as possible. A portion was also saved for the purpose of Rock-Eval pyrolysis. Once hardened, the pellets were polished to provide a smooth reflective surface. The pellets were then mounted to standard glass slides using plasticine and leveled using a calibrated press. The samples were examined using a Zeiss Axioplan II Universal incident and transmitted light microscope (total magnification 100 to 2500x) with both a white (halogen 12v, 100w) light source and a UV (HBO 100w Hg) light source coupled with an ultraviolet G 365 nm excitation filter, 395 nm beam splitter and 420 nm barrier filter; a high-precision, semi-automatic scanning stage; and oil-immersion objectives. Observed macerals were identified based on a combination of morphology, UV-fluorescence, and reflected white light properties. Photomicrographs of macerals were taken using an AxioVision camera-image capture system.

1.5.7 Rock-Eval Pyrolysis

Each of the 13 samples selected for organic petrology was also used for organic geochemical analysis using a Rock-Eval 6 pyroanalyzer at the Organic Geochemistry Laboratory at the Geological Survey of Canada in Calgary (Appendix F). The samples were trimmed to remove as much non-bituminous carbonate material as possible and then powdered using a mortar and pestle. Temperature programmed heating of the sample in an inert atmosphere enabled determination of free hydrocarbon content and the quantity of hydrocarbons and compounds containing oxygen in the form of CO_2 that were generated during thermal cracking of kerogen in the sample (Appendix F) (e.g., Lafargue et al., 1998). Additionally, the residual organic carbon following pyrolysis was oxidized in a second oven to determine the total organic carbon (TOC) content of the sample. The Rock-Eval pyrolysis data were used to create a hydrogen index (HI vs. OI) plot, also known as a modified van Krevelen diagram, and a hydrogen index vs. maximum temperature (HI vs. T_{max}) plot to determine the type of kerogen present, thermal maturity, and petroleum generating potential of each sample (e.g., Peters, 1986).

CHAPTER 2: STRATIGRAPHY

2.1 Elk Point Group

In Manitoba, the Elk Point Group comprises all Devonian strata between the Silurian Interlake Group and the base of the Mafeking Member (Second Red Beds) of the Dawson Bay Formation in the Manitoba Group (Norris et al., 1982). The Elk Point Group was originally subdivided into four formations by Baillie (1953) but now consists of five; in ascending order, they are: Ashern, Elm Point, Winnipegosis, Ratner, and Prairie Evaporite (Fig. 2.1).

2.2 Ashern Formation

Baillie (1953) defined the Ashern Formation from the Manitoba Devonian outcrop belt as poorly bedded, brownish-red to brick-red, argillaceous dolostone and silty dolomitic shale that unconformably overlie the Silurian Interlake Group at a low angle. Within the study area, the upper contact with the Lower Winnipegosis Member and Elm Point Formation is sharp and unconformable (Baillie, 1951). The Ashern Formation in Manitoba ranges between 3 and 12.2 m thick with variability resulting from the infilling of a variably eroded Silurian surface (Norris et al., 1982). The Ashern Formation has been variably interpreted as an intertidal to supratidal deposit of re-worked residual soil which formed during erosion in the late Silurian to early Devonian (Norris et al., 1982), and as a subaerial or shallow hypersaline loess sequence (Kendall, 1975).

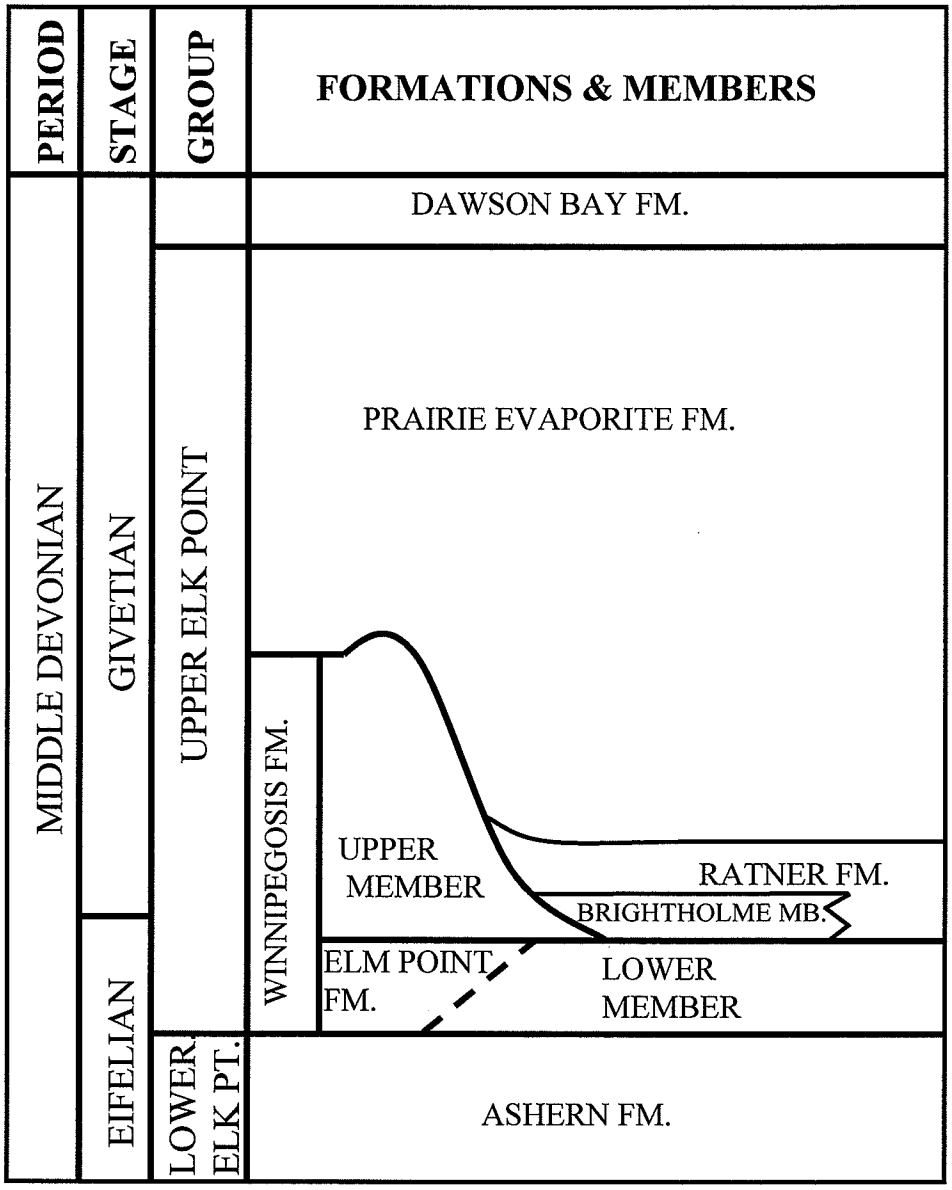


Figure 2.1: Stratigraphic column of the Elk Point Group (modified from Reinson and Wardlaw, 1972; Norris et al., 1982; Jin and Bergman, 2001).

2.3 Elm Point Formation

The Elm Point Formation is found in the southern three-quarters of the Manitoba Devonian outcrop belt where it overlies the Ashern Formation and is overlain by the Upper Winnipegosis Member (Norris et al., 1982). Lithologically, the Elm Point Formation consists of distinctive, variably dolomitized and mottled/nodular limestone. The Elm Point Formation is the limestone facies of the Lower Winnipegosis Member and grades laterally to dolostone in the northern quarter of the outcrop belt and in the subsurface to the west where the two units cannot be distinguished. The Elm Point Formation and the Lower Winnipegosis Member represent a compositional continuum where an arbitrary lower limit of 25% calcium carbonate is used to differentiate the Elm Point Formation from the Lower Winnipegosis Member; however, the Elm Point Formation is considered to be a mappable unit. Norris et al. (1982) reported that the contact between the Elm Point Formation and the underlying red, argillaceous dolostone and dolomitic shale of the Ashern Formation is usually sharp, akin to a paraconformity. According to Perrin (1982) the contact in North Dakota is usually characterized by a brecciated zone or shows other evidence of exposure. The upper contact with the Upper Winnipegosis Member is sharp to gradational.

Complete sections of the Elm Point Formation are not visible in outcrop; however, the formation occurs up to 24.4 m thick in the subsurface of the study area (Encl. 1-5). The Elm Point Formation is marked by its lateral continuity and is interpreted to represent a carbonate ramp deposit (e.g., Chow and Longstaffe, 1995).

2.4 Winnipegosis Formation

In the southern part of the Manitoba Devonian outcrop belt, the Winnipegosis Formation includes all of the beds between the Elm Point Formation and the argillaceous beds of the Mafeking Member (Second Red Beds) of the Dawson Bay Formation in the Manitoba Group (Norris et al., 1982). In the northern part of the outcrop belt, as well as locally in the south, the Elm Point Formation has been dolomitized and all strata between the Ashern and Dawson Bay formations are assigned to the Winnipegosis Formation. The upper contact of the Upper Winnipegosis Member with the overlying Dawson Bay Formation is unconformable and represents a horizon of major salt solution and collapse. The Elm Point Formation is also sparse in the subsurface to the west and the Winnipegosis Formation includes all strata between the top of the Ashern Formation and the base of the evaporites of the Prairie Evaporite Formation where they have not been removed by dissolution. Jones (1965) introduced the concept of dividing the Winnipegosis Formation into lower and upper members in the subsurface of Saskatchewan with the intention of distinguishing a lower carbonate ramp unit and an upper shelf and reef/inter-reef complex. However the inter-reef unit has since been assigned to the Ratner Formation (see below).

Within the study area, the Lower Winnipegosis Member is a ramp succession, consisting of tan and brown, mottled to nodular, sparsely fossiliferous dolostone that ranges between 3 and 20.7 m thick (Fig. 2.2; Encl. 1-5). The Upper Winnipegosis Member consists of highly variable dolostone and within the study area occurs as a basin-fringing platform to the east which ranges between 5.6 and 39.8 m thick where it is unaffected by

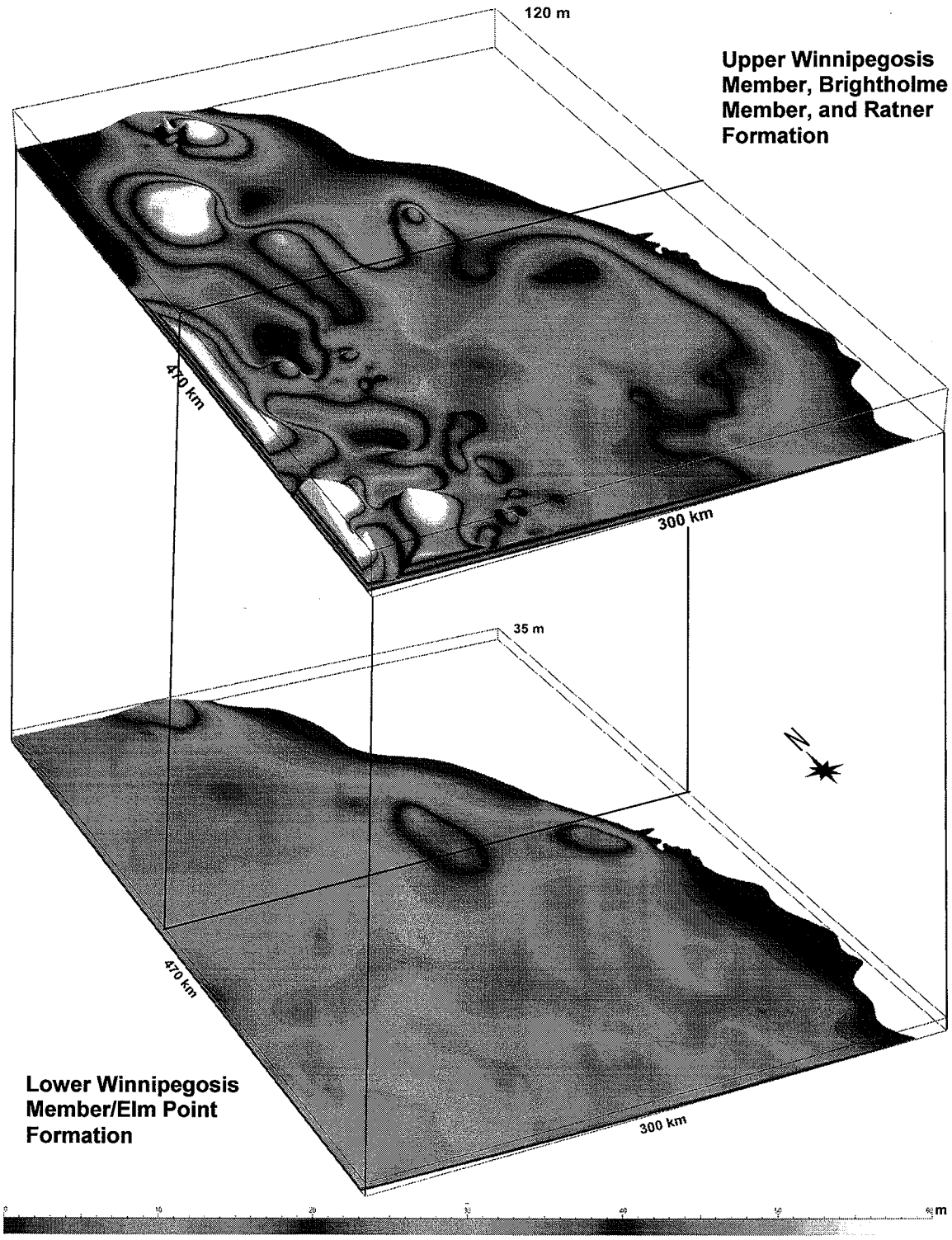


Figure 2.2: Three dimensional figure showing the distribution and thickness of the Lower Winnipegosis Member/Elm Point Formation ramp and the Upper Winnipegosis Member platform and basinal areas with isolated reefs in Manitoba (study area is the southern half). Where present, the Brightholme Member and the Ratner Formation occur in depressions to the north and west of the platform shown in dark orange in the upper map (pers. comm., G. Keller and G. Matile, 2006).

erosion, and isolated reefs, up to 63.2 m thick, in the western basinal area (Fig. 2.2; Encl. 1-5).

The Brightholme Member was first informally proposed in southeastern Saskatchewan by Stoakes et al. (1987) and was named after the Britalta Brightholme 5-29-47-3W3 well in which it is found. This member is characterized by thin, black bituminous laminites, typically less than 1 m thick, that occur above the Lower Winnipegosis Member and are interpreted to represent coeval basinal equivalents of the Upper Winnipegosis Member reefs and basin-fringing platform. In close proximity to reefs, the bituminous laminites are interdigitated with reef-derived skeletal debris that is interpreted to be tempestites. Historically, these laminites have been included with the Upper Winnipegosis Member in Manitoba (e.g., Norris et al., 1982; Rosenthal, 1988), with the Lower Winnipegosis Member in Saskatchewan (e.g., Jones, 1965) or not specifically assigned to any member (e.g., Kendall, 1975). The Brightholme Member was formalized by Jin and Bergman (2001) who concurred with the original proposal of Stoakes et al. (1987); however, they suggested that the Dome Silver Park 16-13-42-19W2 well be considered the type section because the member is well defined and contains less reefal contamination. In Manitoba, the Brightholme Member occurs in inter-reef positions north of the study area, where it is 2-5 m thick and may contain reefal carbonate interbeds (Rosenthal, 1988; Teare, 1990). It is not known if the Brightholme Member is present in basinal areas within the study area because it is not present in core; however, bituminous laminites that onlap the Upper Winnipegosis Member platform may be laterally continuous into the basin and thus would constitute the Brightholme Member.

2.5 Ratner Formation

The Ratner Formation was originally defined as the Ratner Member of the Winnipegosis Formation by Wardlaw and Reinson (1972) with the type section in the California Standard 1-15-48-17W2 well in Saskatchewan. This formation is a brining-upward transitional unit that consists of thinly interlaminated carbonate rocks and anhydrite with bituminous partings and is dominantly carbonate rocks at the base and anhydrite at the top (Jin and Bergman 1998; 2001). It may have up to three cycles where well developed in Saskatchewan. The Ratner Formation occurs in basinal areas above the Lower Winnipegosis Member or the Brightholme Member and below the Prairie Evaporite Formation (Fig. 2.2) (Jin and Bergman, 2001). It thickens in close proximity to isolated reefs of the Upper Winnipegosis Member and may also drape drowned reefs.

Historically, laminites equivalent to the Ratner Formation have been assigned either to the lowermost Prairie Evaporite Formation (e.g., Baillie, 1953; Kendall, 1975) or to the Upper Winnipegosis Member (e.g., Rosenthal, 1988; Teare, 1990; Kostelnyk, 1998). However, Jones (1965) suggested these laminites belonged neither to the Winnipegosis Formation nor the Prairie Evaporite and should be considered a separate, transitional formation. The Ratner Member was elevated to formation status by Jin and Bergman (2001). Formation status was justified because the laminites lack reef-derived debris, occur over drowned reefs, and show a brining-upward trend suggesting they postdate carbonate deposition of the Winnipegosis Formation. Where present in the study area, the Ratner Formation ranges from 0.2 to 6.5 m thick and was found to onlap the Upper Winnipegosis Member platform (Encl. 1-4).

2.6 Prairie Evaporite Formation

The Prairie Evaporite Formation consists of evaporite deposits located between the Winnipegosis Formation and the Mafeking Member (Second Red Beds) of the Dawson Bay Formation (Baillie, 1953). In Saskatchewan the Prairie Evaporite Formation is divided into lower and upper units (Reinson and Wardlaw, 1972). The lower part of the formation consists of the Whitkow Member and the Shell Lake Member. The Whitkow Member consists of a lower anhydrite unit that thickens proximal to Upper Winnipegosis Member reefs and an upper halite unit that dominates away from reefs. The Shell Lake Member, also know as the "Middle Anhydrite", consists predominantly of nodular-mosaic and massive anhydrite and may contain a thin carbonate unit known as the Quill Lake Marker Beds. The upper part of the formation consists predominantly of halite that is interbedded with the Esterhazy, Belle Plaine, and Patience Lake members, which consist of potash (Zhang et al., 2004).

Within the study area, the Prairie Evaporite Formation ranges from a maximum thickness of 152 m at the Saskatchewan border to less than 12 m where it extends eastwards over the Upper Winnipegosis Member platform as a lobe-like solution remnant (Bannatyne, 1960; Norris et al., 1982). At its thickest, the Prairie Evaporite Formation consists mostly of coarsely crystalline halite with potash interbeds near the top and rapidly changes laterally to anhydrite as it thins eastwards (Bannatyne, 1960). Where it has been dissolved in the outcrop belt, the Prairie Evaporite is replaced with a collapse breccia, which consists of limestone and dolostone clasts in a clay-shale matrix, likely derived from insoluble residues (Norris et al., 1982; Rosenthal, 1988). Localized evaporite

dissolution and ensuing collapse are known to have occurred above some Upper Winnipegosis Member isolated reefs in Saskatchewan (e.g., Gendzwill and Wilson, 1987) and evidence for these processes was also observed within the study area.

2.7 Lateral Extent and Thickness of the Winnipegosis, Elm Point, and Ratner Formations

Isopach maps for both the Lower Winnipegosis Member/Elm Point Formation and the Upper Winnipegosis Member/Ratner Formation were constructed using the kriging method as outlined in Section 1.5.3. The Lower Winnipegosis Member/Elm Point Formation experimental variogram was successfully fitted with a linear variogram model (Fig. 2.3A). The results indicate that variability in isopach values increases constantly as a function of increasing lag distances (distance between pairs of locations) and that there is still some correlation between points separated by the maximum lag distance of 180 km. This response suggests that the deposition of the unit involved some processes with spatial scales exceeding 180 km. It is an expected response for a blanket type deposit like a ramp. Although an optimal fit would have involved a non-zero intercept (nugget effect), a zero intercept was used in the model to avoid possible discontinuities in the predicted surface at sample locations (e.g., Golden Software Inc., 2002).

Acceptable contouring results were obtained for the Upper Winnipegosis Member/Ratner Formation only after the isopach data from the platform area (100 data points) were separated from the isopach data from the basinal area. The variograms for the two areas have different forms with the basinal area data characterized by shorter spatial scales,

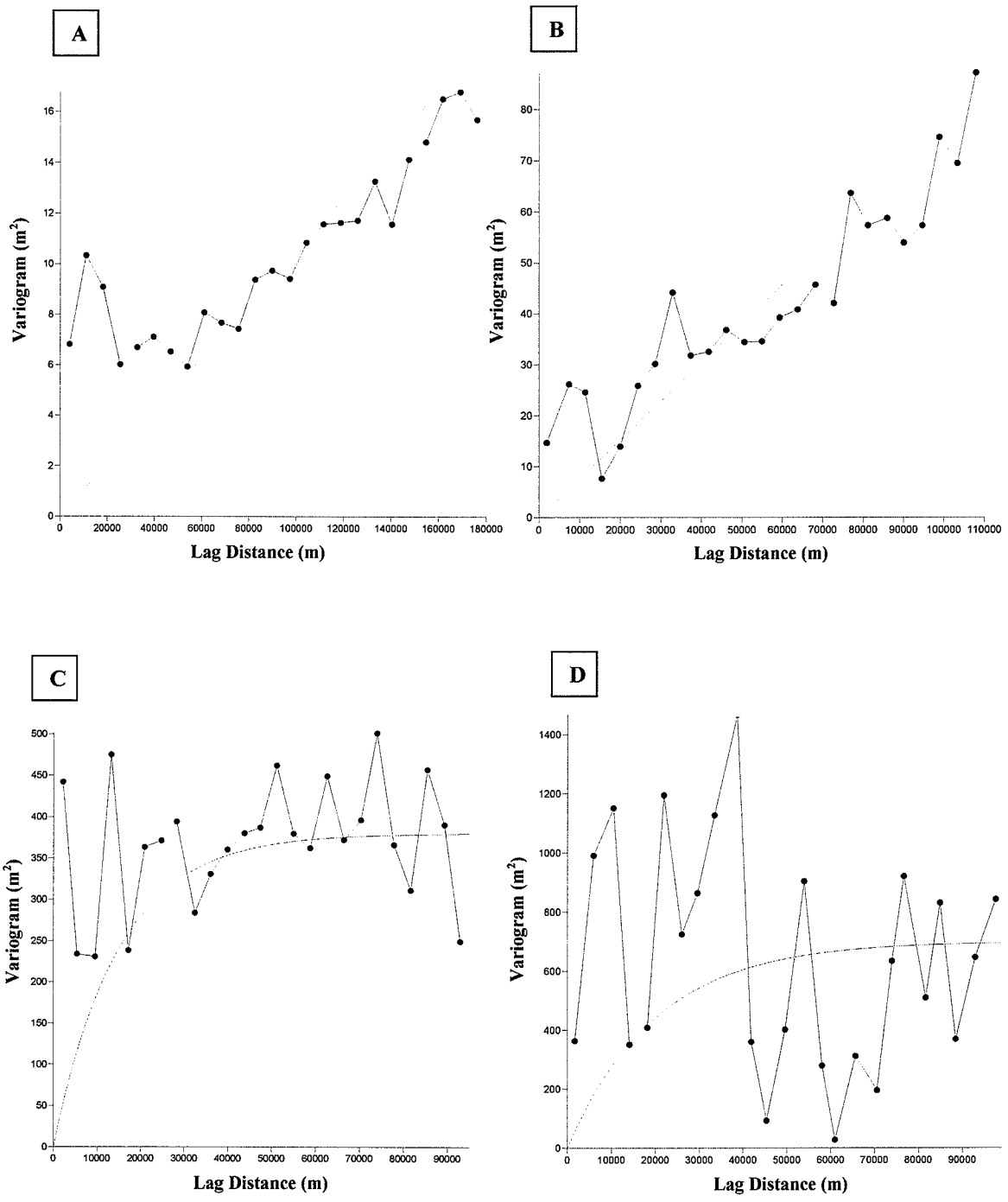


Figure 2.3: Variograms used for interpolation of isopach maps. Experimental variograms are shown in black and variogram models are shown in blue. A) Lower Winnipegosis Member/Elm Point Formation. B) Platform area of the Upper Winnipegosis Member. C) Western basinal area of the Upper Winnipegosis Member/Ratner Formation. D) Northern basinal area of the Upper Winnipegosis Member/Ratner Formation.

which is interpreted to be due to the presence of isolated reefs. Kriging the entire study area using a single variogram model failed to yield well-defined depositional features. The boundary between platform and basinal areas was defined using a combination of isopach values and information from previously published isopach maps for the Winnipegosis Formation (e.g., Norris et al., 1982). Due to software limitations that restricted analyses to rectangular areas, isopach data for the basinal area were further sub-divided into western and northern rectangular areas, with 92 and 38 data points respectively, and a variogram model was fitted to an experimental variogram generated for each area (Fig. 2.4).

The experimental variogram for the platform area was fitted with a linear variogram model indicating that variability in isopach values increases constantly as a function of increasing lag distances (Fig. 2.3B). This result is similar to that obtained for the Lower Winnipegosis Member/Elm Point Formation and is what would be expected in a blanket type deposit, in this case a platform. The experimental variogram for the western basinal area suggests the deposition was dominated by short spatial scale processes of less than 35 km (Fig. 2.3C). There were insufficient data points at small lags to tightly define the exact scale of the processes. In order to proceed with the contouring the data were fitted using an exponential model with a 25 km exponential distance scale, which best fit the available data points. Due to the paucity of sample points for the northern basinal area, the points do not define a smooth variogram curve (Fig. 2.3D). Consequently, a variogram model was forced to the experimental variogram for the northern area data set with the assumption that the spatial statistics would be similar for both basinal areas.

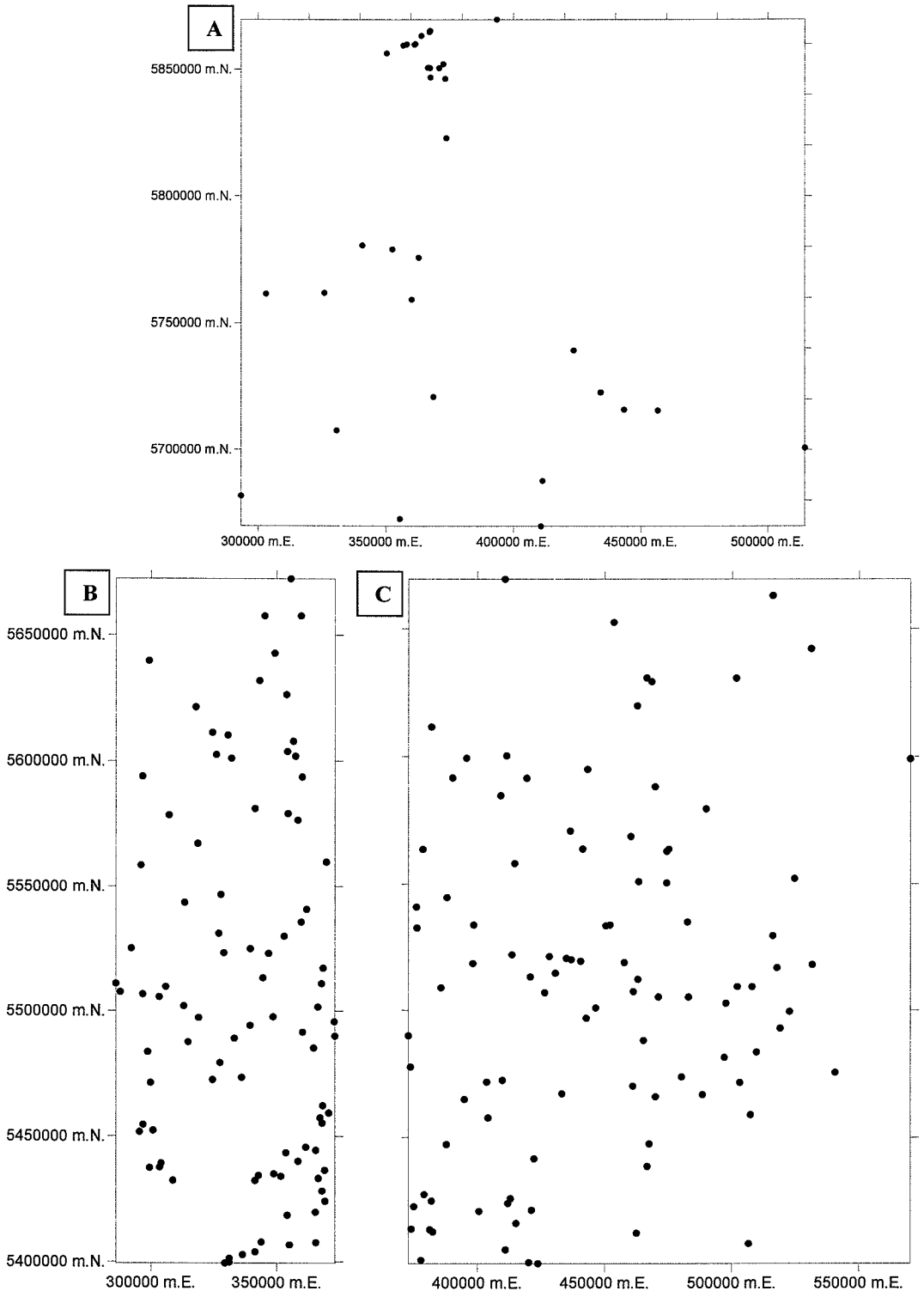


Figure 2.4: Subdivision of the Upper Winnipegosis Member/Ratner Formation data points for independent interpolation. A) Distribution of the northern basinal area data points. B) Distribution of the western basinal area data points. C) Distribution of the platform area data points.

This step introduced some human bias but was necessary to enable the isolated reefs in the northern area to be represented as discrete entities by contour lines in the final map. As a consequence, the aerial extent of some of the isolated reefs may be portrayed with incorrect spatial extent.

Once the variogram model for the Lower Winnipegosis Member/Elm Point Formation and the three variogram models for the Upper Winnipegosis Member/Ratner Formation were defined, they were used with kriging interpolation to create four grid files. The three grid files for the Upper Winnipegosis Member/Ratner Formation data were then converted to data files, which were merged in a worksheet and re-gridded using the Nearest Neighbor method, which prevents additional interpolation, to create a composite grid file (Barnes, 2005).

The grid files for the Lower Winnipegosis Member/Elm Point Formation and the Upper Winnipegosis/Ratner Formation were then used to create two isopach maps using 5 m contour intervals. This interval was chosen so as to adequately display all of the spatial features in the data. Once the contour maps were generated, blanking files were created to mask the northern corners because they did not contain any data points and had little control from the data points in adjacent areas. Finally, both isopach maps were imported into Corel Draw and a township and range grid was overlaid and the study area was outlined. Contoured areas adjacent to the study area in North Dakota, Saskatchewan, and to the north were included so as to provide broader context.

The final Lower Winnipegosis Member/Elm Point Formation isopach map generally shows broad, gentle gradients on the surface of the ramp deposit as evidenced by broadly spaced contour lines (Encl. 8). However, localized, anomalous thicks and thins appear to be scattered randomly throughout the map area.

The final Upper Winnipegosis Member/Ratner Formation isopach map shows both basinal and platform areas (Encl. 9). The platform area is found in the southeast corner of the map and is characterized by broad, widely spaced contour lines, except on the northern and western platform slopes where the contour lines tighten where well control is sufficient. The northern platform slope trends approximately E-W and occurs between Townships 23 and 25. The northern platform slope appears to be much broader than the western slope; however, there is much less well control. The western platform slope is irregular but generally trends N to slightly NW and occurs between Ranges 24 and 25 in the southern part of the study area and Ranges 26 to 27 near the northern end of the study area. The thickest parts of the platform occur parallel to the platform margins as discontinuous, elongate thicks; however, the discontinuity may be the result of poor well control. The platform extends southward of the study area into North Dakota and thinning of the platform along the eastern edge is likely a combination of depositional thinning and erosion since portions of the thin area are still overlain by the Prairie Evaporite (cf. Norris et al., 1982).

The basinal area is characterized by isolated thick "bulls eyes", which represent isolated reefs, and intervening depressions representing the basin floor where the Ratner

Formation is found. Some smaller isolated reefs appear to lie coincident with the western platform slope. The basinal area occurs west of the western platform margin within the study area and extends westwards into Saskatchewan, south and southwestward into North Dakota, and also occurs north of the study area.

The Winnipegosis Formation has been removed by erosion in the northeast corner of the study area, as well as in the area to the northeast of the study area. The masked area in the northwest corner of the maps simply represents an absence of data.

CHAPTER 3: LITHOFACIES

3.1 Introduction

A total of fifteen lithofacies were recognized in the Winnipegosis Formation within the study area, based on detailed core descriptions (Appendix B), thin section descriptions (Appendix D), and petrophysical well logs (Table 3.1). Three of these lithofacies comprise the ramp succession in the Lower Winnipegosis Member and its lateral outcrop equivalent, the Elm Point Formation: A) non-fossiliferous mudstone, B) mottled-nodular skeletal wackestone-mudstone, and C) nodular-patterned mudstone. Eleven lithofacies occur in the platform-basin succession in the Upper Winnipegosis Member: E) interlaminated mudstone-anhydrite, F) massive-mottled mudstone, G) septarian-type nodular skeletal packstone, H) bedded-mottled peloidal packstone, I) intraclast floatstone, J) bituminous skeletal wackestone-floatstone, K) peloidal-udoteacean packstone, L) stromatoporoid floatstone, M) coral-stromatoporoid rudstone-framestone, N) laminated mudstone-peloidal packstone, and O) microbial bindstone. Lithofacies D, bituminous laminite, is common to both the Elm Point Formation/Lower Winnipegosis Member and the Upper Winnipegosis Member and its organic petrology is discussed in Chapter 5. Most lithofacies do not have characteristic petrophysical log signatures; however, those that do are noted.

3.2 Lithofacies A: Non-Fossiliferous Mudstone

3.2.1 Description

This lithofacies consists of varicolored off-white, light gray and light purple, non-fossiliferous dolomudstone which is slightly calcareous in places (Fig. 3.1). It is thickly

Table 3.1: Summary of lithofacies.

	LITHOFACIES NAME	THICKNESS	LOWER CONTACT	UPPER CONTACT	COLOR	LITHOLOGY	SEDIMENTARY STRUCTURES/TEXTURES	ALLOCHEM ABUNDANCE	MAJOR ALLOCHEM CONSTITUENTS
A	Non-fossiliferous mudstone	0.4-0.7 m	sharp, overlying Ashern Fm.	gradational	off-white, light grey, light purple	dolomudstone, minor intraclastic dolorudstone beds/dolopackstone laminae (3-5 mm thick with sharp contacts), and patterned dolomudstone	thick laminae to med. beds (1-18 cm thick), massive/mottled, *Skolithos*-like burrows (2 to 4 mm wide and 1.5 to 3 cm long)	0-90%	none
B	Mottled-nodular skeletal wackestone-mudstone	0.5-23.95 m	gradational	gradational to sharp	tan, light brown, brown, light grey	(dolo)mudstone to skeletal (dolo)wackestone with rare intraclastic-skeletal packstone/rudstone	non-bedded, mottled to nodular, *Planolites*	0-30%	brachiopods, crinoids
C	Nodular-patterned mudstone	0.9- >4.5 m?	gradational	gradational	tan, light brown, light purple, maroon	argillaceous dolomudstone, minor skeletal dolowackestone & intraclast dolofloatstone	thick to very thick bedded (30 cm to 2 m thick), nodular, patterned	0-10%	none
D	Bituminous laminite	0.003- >0.77 m?	sharp/rapidly gradational	sharp/rapidly gradational	black, dark brown (tan interbeds)	mudstone, (dolo)packstone/grainstone, bituminous	thinly laminated	0-85%	peloids, styliolinids, calcispheres
E	Interlaminated mudstone-anhydrite	0.2-6.5 m	sharp	gradational	tan, light-med brown, white	(dolo)mudstone, anhydrite, calcitized/dolomitized anhydrite	thin laminated to med. bedded, enterolithic in part	0-<1%	none
F	Massive-mottled mudstone	0.2-4 m	sharp to gradational	sharp to gradational	tan, light brown	(dolo)mudstone, rare skeletal floatstone	massive to mottled, rarely faintly laminated	<1-8%	none
G	Septarian-type nodular skeletal packstone	0.45- >5.8m?	gradational to sharp	gradational to sharp	tan, light & dark brown	variably bituminous skeletal dolopackstone	thin to very thickly bedded, nodules with septarian structure	>70%?	crinoids, brachiopods, unidentifiable fragments
H	Bedded-mottled peloidal packstone	0.2- >26 m?	sharp to gradational	sharp to gradational	tan, light-dark brown, light grey or light yellow	variably bituminous peloidal (dolo)packstone to dolograinstone, rare dolomudstone and skeletal dolofloatstone	thickly laminated to thickly bedded, or mottled/crudely bedded, *Planolites*	80-85%	peloids
I	Intraclast floatstone	0.2->1.5 m?	sharp to rapidly gradational	sharp to rapidly gradational	tan, light/dark grey	intraclast dolofloatstone with dolomudstone, peloidal dolopackstone, or peloidal-skeletal dolopackstone matrix	isolated medium to very thick beds	13-25% (exclusive of matrix)	dolomudstone to dolograinstone intraclasts (0.01->5 cm), sub-angular to rounded
J	Bituminous skeletal wackestone-floatstone	0.15-2.9 m	gradational or sharp to rapidly gradational	gradational or sharp to rapidly gradational	black/dark brown, white (bioclasts)	bituminous skeletal dolowackestone to floatstone	medium to very thick beds	10-20%	*Amphipora*, thamnoporid corals, crinoids
K	Peloidal-udoteacean packstone	0.2- >18.6 m?	gradational, rapidly gradational	sharp, rapidly gradational	tan, light brown	dolopackstone to dolograinstone, rare skeletal dolofloatstone	very thin to very thickly bedded, mostly med. bedded, also mottled	60-85%	peloids, udoteacean algae
L	Stromatoporoid floatstone	0.3-2.6 m	sharp	sharp	tan, light brown, brown, light grey, white	skeletal dolofloatstone with peloidal/skeletal dolopackstone matrix	mottled to crudely thin or medium bedded	10-20% (exclusive of matrix)	bulbous, encrusting or tabular stromatoporoid fragments
M	Coral-stromatoporoid rudstone-framestone	0.04- >3.13 m?	sharp	sharp	tan, light brown, bone white	dolorudstone and/or doloframestone +/- peloidal/skeletal or skeletal dolopackstone matrix	thin to very thick beds	80-95%	bulbous/massive tabulate corals including favositids, encrusting/tabular stromatoporoids (up to >8 cm)
N	Laminated mudstone-peloidal packstone	0.23- >11.13 m?	sharp	?	tan, light & dark brown	dolopackstone and dolomudstone	thinly laminated to thinly bedded, horizontal to inclined, small-scale normal faults	0-85%	peloids
O	Microbial bindstone	0.40- >1.2 m?	sharp	sharp	tan, yellow, light brown	microbial dolobindstone	thin laminae, stromatolitic-crenulated in part	0-10%?	none

Table 3.1 cont.

	MINOR CONSTITUENTS	DOLOMITE	POROSITY	DEPOSITIONAL ENVIRONMENT	FACIES ASSOCIATION
A	sub-angular to rounded, equant to elongate intraclasts (1 mm-3 cm)	100% - aphanocrystalline to very finely crystalline, non-planar; minor fine crystalline planar-e	nil	low-energy, intertidal/ shallow subtidal, restricted-high salinity	ramp
B	tabular stromatoporoids, halysitid tabulate corals, solitary septate corals, gastropods, bryozoans, calcispheres, ostracods, cricoconarids, *Rothpletzella*, udoteacean & dasycladacean calcareous algae, trilobite fragments, *Girvanella*, intraclasts, oncoids, peloids	0-100% - fine crystalline, non-planar; fine to medium crystalline, planar-s; fine to coarse crystalline, planar-e	<1-15% (intercrystalline, vuggy, moldic, fracture)	low-energy, subtidal, below fair-weather wave base, open normal marine	ramp
C	brachiopods, intraclasts, clay, hematite, anhydrite laths	100% - very fine to fine crystalline, planar-s, non-planar, and planar-e	1-5% (intercrystalline, moldic, vuggy, fracture)	low-energy, intertidal-supratidal, high salinity, oxic	ramp
D	fish bones, tentaculitids, intraclasts, ostracods, crinoids, tubular calcareous algae, tabulate coral fragments, quartz silt, anhydrite laths	0-100% - aphanocrystalline; fine to medium crystalline, planar-e and planar-s	0-25% (fracture, intraparticle, intercrystalline, interparticle, moldic, vuggy)	low-energy, shallow to deep subtidal, open to restricted, intermittently anoxic	ramp, platform interior, platform slope, basinal salina
E	gastropods	<5-100% - aphanocrystalline; fine to medium crystalline, planar-e, planar-s, non-planar	0-5% (intercrystalline, rare fenestral)	low-energy, subtidal, restricted, hypersaline	basinal salina
F	brachiopods, crinoids, thamnoporid corals, cricoconarids, ostracods, gastropods, udoteacean calcareous algae, oncoids, intraclasts, peloids	5-100% - aphanocrystalline; fine to medium-crystalline, non-planar, planar-s and planar-e	0-7% (intercrystalline, vuggy, moldic)	low energy, deep subtidal, dysoxic	platform slope
G	ostracods	100% - aphanocrystalline; very fine to medium crystalline, non-planar, planar-s, and planar-e	5-15% (intercrystalline, moldic, vuggy, fracture)	low energy, deep subtidal, dysoxic-anoxic	platform slope
H	rugose & thamnoporid corals, tabular & wafer stromatoporoids, *Amphipora*, ostracods, crinoids, brachiopods, gastropods, calcispheres, *Stachyodes*?, cricoconarids, intraclasts	30-100% - aphanocrystalline; fine to coarse crystalline, planar-e; fine to medium crystalline, planar-s and non-planar	1-35% (intercrystalline, moldic, vuggy, fracture)	low energy, shallow subtidal, oxic to dysoxic	platform slope, platform interior
I	crinoids, brachiopods, udoteacean algae	100% - aphanocrystalline; very fine to medium crystalline, non-planar, planar-s, and planar-e	5-15% (intercrystalline, vuggy, fracture, moldic)	subtidal, high-energy, event beds-tempestite/sediment gravity flow	platform interior, platform slope, isolated reef
J	brachiopods, intraclasts	100% - fine to medium crystalline, non-planar	<1% (intercrystalline, pinpoint)	low-energy, subtidal, restricted, dysoxic, lagoonal	isolated reef
K	thamnoporid corals, tabular tabulate corals, halysitoid corals, solitary rugose corals, *Amphipora*, oncoids, brachiopods? styliolinids? ostracods? tabular stromatoporoids? intraclasts	100% - aphanocrystalline; very fine to coarse crystalline, non-planar, planar-s, and planar-e	3-20% (intercrystalline, vuggy, moldic, intra-skeletal, fracture)	low to moderate-energy, subtidal, below fair-weather wave base, normal open marine	isolated reef
L	stringocephalid brachiopods, solitary septate corals, *Amphipora*	100% - aphanocrystalline; fine to medium crystalline, planar-s and planar-e	0-8% (intercrystalline, pinpoint, intraskeletal, fracture, anhydrite cement)	open, low to moderate energy, shallow subtidal, normal open marine	isolated reef
M	syringoporid corals (up to 1 cm long & 5 mm wide), *Amphipora* (1.5-3 mm), thamnoporid corals (8mm-1.5 cm)	100% - aphanocrystalline; fine to medium crystalline, non-planar, planar-s, and planar-e	3-15% (intercrystalline, moldic, fracture, vuggy, interparticle, intraskeletal, anhydrite cement)	high-energy, subtidal, above fair-weather wave base	isolated reef, platform slope
N	tabular stromatoporoids (>8 cm)	100% - aphanocrystalline; fine to medium crystalline, planar-s, planar-e, and non-planar	5-30% (intercrystalline, vuggy, moldic, fracture)	low energy, subtidal, moderate depth, variably inclined depositional surface, elevated salinity or dysoxic	isolated reef, platform slope
O	solitary rugose coral, peloids?	100% - aphanocrystalline; fine to medium crystalline, planar-s and planar-e	10-15% (fenestral, vuggy, intercrystalline)	low-energy, intertidal-supratidal	isolated reef, platform slope, platform interior

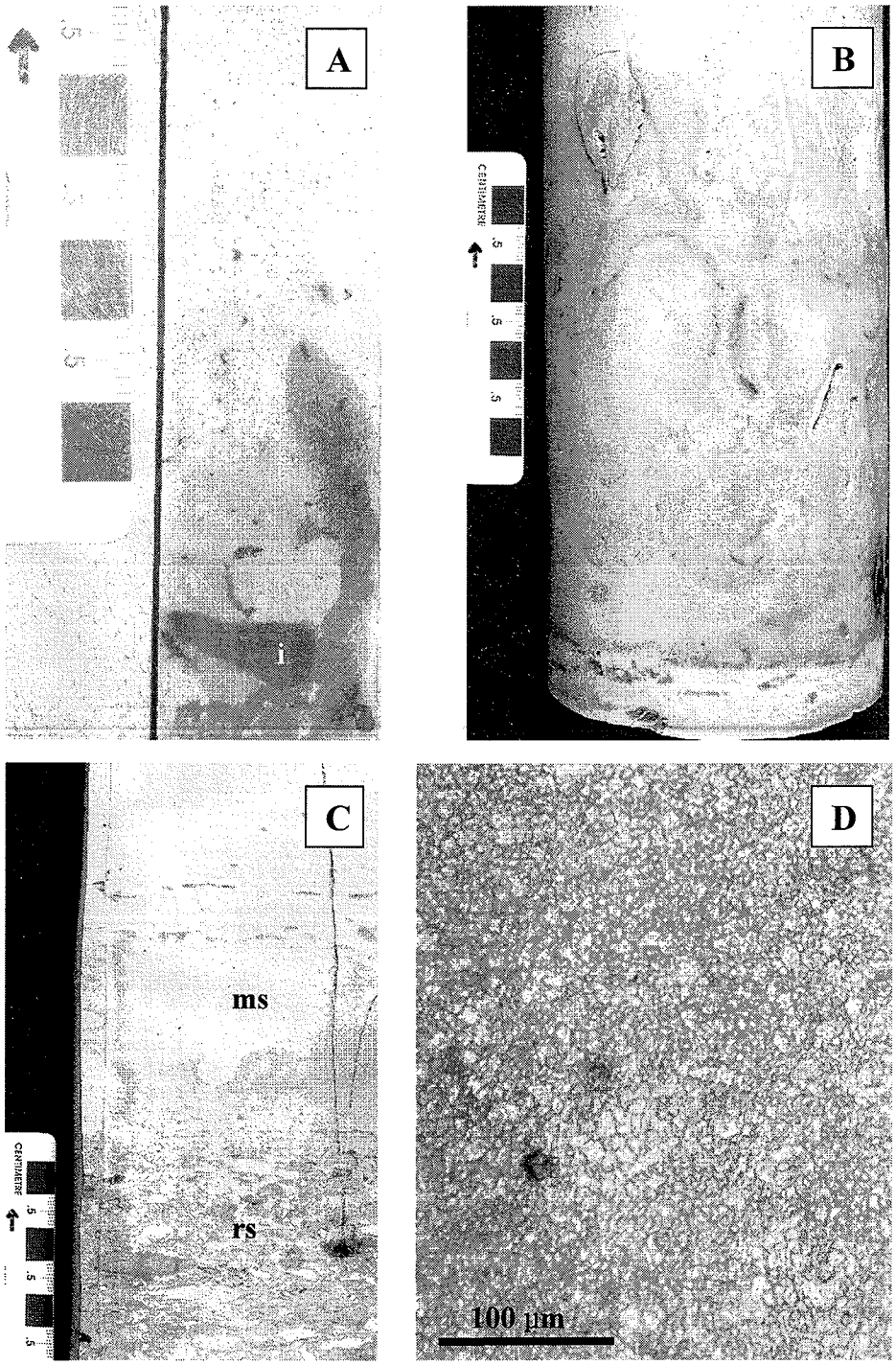


Figure 3.1 Lithofacies A: non-fossiliferous mudstone. A) Core photograph showing massive dolomudstone and argillaceous mudstone intraclast (i), likely derived from the underlying Ashern Formation. 5-35-24-10W1, 42.20 m (138.5'). B) Core photograph of *Skolithos*-like burrows in dolomudstone. 14-13-009-28W1, 1320.90 m (4333.6'). C) Core photograph showing basal dolorudstone (rs) overlain by thin bedded dolomudstone (ms). 14-13-009-28W1, 1321.3 m (4334.9'). D) Photomicrograph of aphanocrystalline to very finely crystalline, non-planar dolomite. Plane polarized light. 16-26-24-10W1, 47.20 m (154.85').

laminated to medium bedded and lower beds are generally massive becoming progressively mottled upwards. Rare thin beds of purple patterned dolomudstone (see lithofacies C; Section 3.4.1) and rare laminae of intraclastic dolopackstone punctuate the dolomudstone. *Skolithos*-like burrows were observed in the uppermost bed of this lithofacies in well 14-13-009-28W1, 1320.90 m (4333.6') (Fig. 3.1B). Most burrows are filled and accentuated by tan dolomudstone, while some remain open.

The lower half of lithofacies A may contain scattered rounded intraclasts of red, argillaceous mudstone; 0.5 to 3 mm, and rarely up to 2 cm, in diameter; and similar in lithology to the underlying Ashern Formation (Fig. 3.1A). In places, the basal portion of this lithofacies is an intraclast dolopackstone or dolorudstone bed (8-22 cm thick) with a gradational upper contact (Fig. 3.1C). Intraclasts are light grey to dark purple, argillaceous dolomudstone and sub-angular to rounded. They are poorly sorted, ranging from 1 to 30 mm in diameter, and some of are fractured. The matrix is a light grey to light purple, argillaceous dolomudstone, which contains minor disseminated opaque minerals, trace angular to sub-rounded quartz silt, and rare anhydrite laths and molds.

Lithofacies A is essentially tight with rare vertical fractures and trace pinpoint porosity visible in core. Lithofacies A shows a very clean gamma-ray and fast sonic response directly above the argillaceous Ashern Formation. This lithofacies is not found in all wells suggesting the lithofacies is laterally discontinuous.

3.2.2 Interpretation

Lithofacies A is interpreted to have been deposited in a low-energy, restricted, intertidal to shallow-subtidal environment. Low-energy conditions are indicated by the predominance of mudstone and the shallow-water setting is suggested by the local occurrence of a patterned texture (refer to Section 3.4.2). Rare intraclast beds suggest intermittent high-energy events, such as storms (cf. Jones and Desrochers, 1992). Restricted conditions, as indicated by the conspicuous absence of benthos, may have stemmed from high salinity and/or low oxygen content; the occurrence of anhydrite laths at the base of the lithofacies support elevated salinity. However, the presence of localized burrows and mottling that is interpreted to be burrow-mottling in the upper half of the lithofacies suggests that the environment was hospitable for benthic infauna during the later stages of lithofacies A deposition and certainly by its end.

The erosional lower contact and the presence of intraclasts that are similar in lithology to the Ashern Formation in the lower half of the lithofacies support the interpretation of a post-Ashern hiatus and suggest that the Ashern Formation was not ubiquitously buried during early deposition of lithofacies A. The laterally discontinuous nature of this lithofacies further suggests that deposition was localized, possibly in paleotopographic lows on the surface of the Ashern Formation. In summary, lithofacies A is interpreted to represent an initial marine transgression over the Ashern surface followed by a transition from restricted to open marine conditions.

Perrin (1982; 1987) recognized a laterally discontinuous lithofacies of mottled and laminated dolomudstone in the Winnipegosis Formation in North Dakota that is compositionally similar and probably stratigraphically equivalent to lithofacies A. She interpreted this lithofacies to have been deposited by a renewed transgression over the Ashern Formation following a brief hiatus. It was considered to represent restricted subtidal through lower-supratidal conditions in a coastal sabkha which was subjected to syndepositional reflux dolomitization.

3.3 Lithofacies B: Mottled-Nodular Skeletal Wackestone-Mudstone

3.3.1 Description

Lithofacies B consists of non-bedded, mottled to nodular, dolomitic limestone to dolostone, ranging from skeletal wackestone to mudstone (Fig. 3.2). Where this lithofacies is largely limestone (Elm Point Formation), the nodules consist of light to dark brown, skeletal wackestone, and range from 1 to >6 cm in diameter (many nodules are larger than the diameter of the core) with round, ovoid, and very irregular amoeboid forms. The nodules remain largely undolomitized, containing abundant micrite, and have sharp to gradational boundaries (Fig. 3.2D). The nodules are rarely fractured across their diameter and the fractures are occluded by radial fibrous and/or coarse crystalline, equant calcite. The internodular matrix is tan to light brown mudstone to skeletal wackestone. The argillaceous and bituminous content is variable but generally increases upwards and occurs either as clusters of fine wispy microstylolites which commonly show compactional drape around nodules and terminate laterally with horsetail structures, or are finely disseminated. The wackestone matrix contains micrite, microspar and less

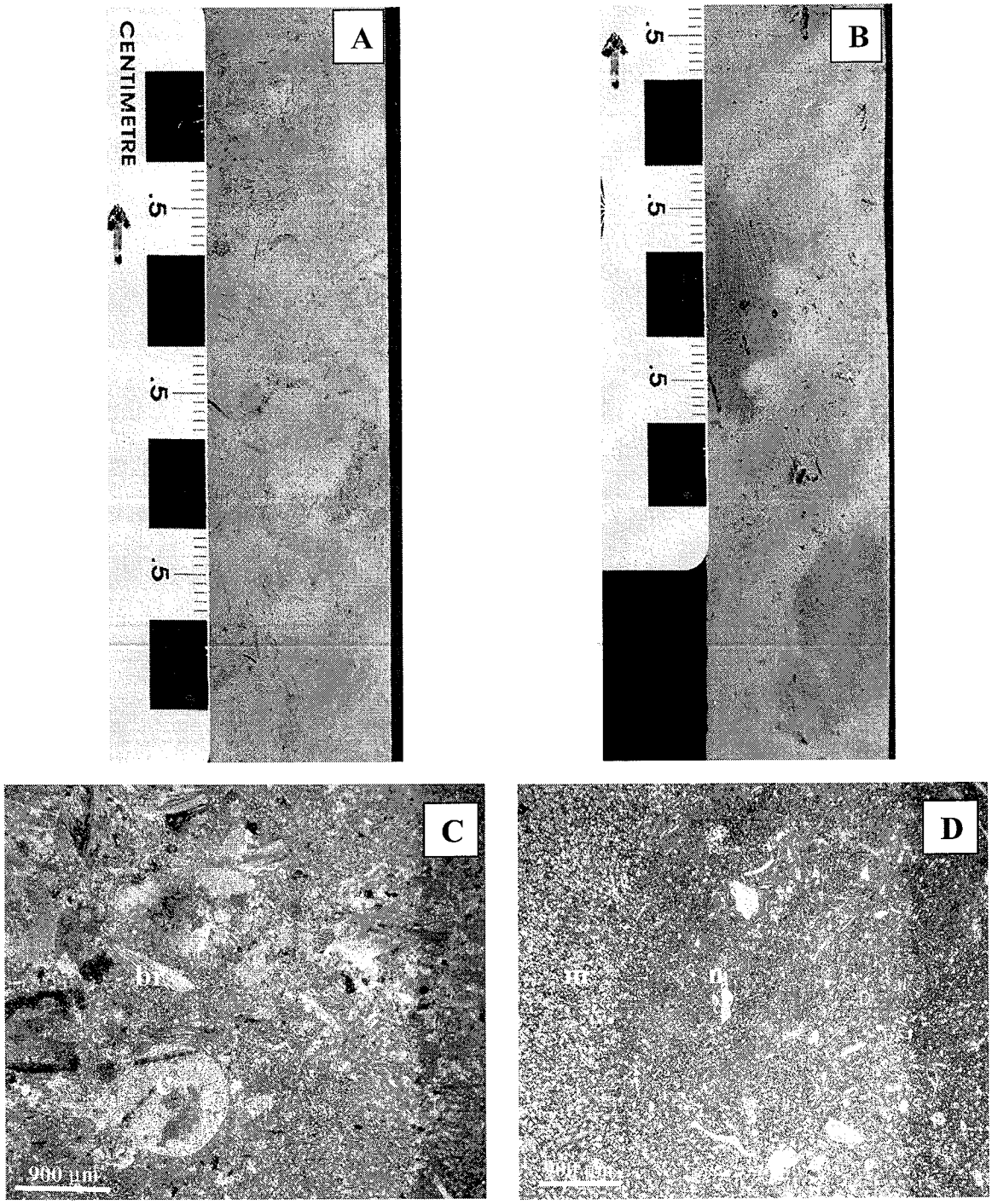


Figure 3.2 Lithofacies B: mottled-nodular skeletal wackestone-mudstone (limestone). A) Core photograph showing mottled skeletal wackestone. 12-35-24-10W1, 41.11 m (134.8'). B) Core photograph showing mottled-nodular skeletal wackestone. 12-35-24-10W1, 28 m (91.8'). C) Photomicrograph showing skeletal wackestone with crinoids (c), brachiopods (br), and unidentifiable comminuted fossil fragments in the internodular matrix. Crossed nicols. 3-35-24-10W1, 41.3 m (135.49'). D) Photomicrograph showing an undolomitized nodule (n) in partly dolomitized, internodular matrix (m). Plane polarized light. 16-26-24-10W1, 44.54 m (146.1').

commonly pseudospar, which has been variably replaced by fine crystalline planar-s, non-planar, and planar-e dolomite.

Allochems constitute 0-30% of lithofacies B (Fig. 3.2C). Fragmented bioclasts are found within both nodules and the internodular matrix, and most are <1 mm to 3 mm in size but range up to 3 cm. Bioclasts consist predominantly of brachiopods, including stringocephelids, and crinoids, including articulated crinoid stems. Crinoids generally become more abundant upwards through the lithofacies. Identifiable subordinate bioclasts include gastropods, bryozoans, calcispheres, ostracods, cricoconarids, and udoteacean and possible dasycladacean calcareous algae. In-situ, thin tabular stromatoporoids occur locally and may be encrusted by *Rothpletzella* calcareous algae or bryozoans. Rare oncoids, 2 to 3 cm in diameter, have brachiopod valves as nuclei, and typically show concentric fenestral or vuggy porosity. However in well 02-21-007-28W1, 1448.4 m, oncoids are fairly common at the top of lithofacies B. Where lithofacies B is dolomitic limestone, bioclasts may be recrystallized to pseudospar but are rarely dolomitized. Non-skeletal allochems are relatively rare and include peloids (2-40%) and rounded intraclasts of lime mudstone or skeletal wackestone (5-10%), which rarely have a thin pyritized rim.

Where lithofacies B is completely dolomitized (Lower Winnipegosis Member), nodules are tan colored and generally consist of fine to medium crystalline, planar-e dolomite (Fig. 3.3A). A light brown, internodular matrix consists of dominantly fine to medium crystalline, planar-s dolomite and fine crystalline, non-planar dolomite. Although nodule

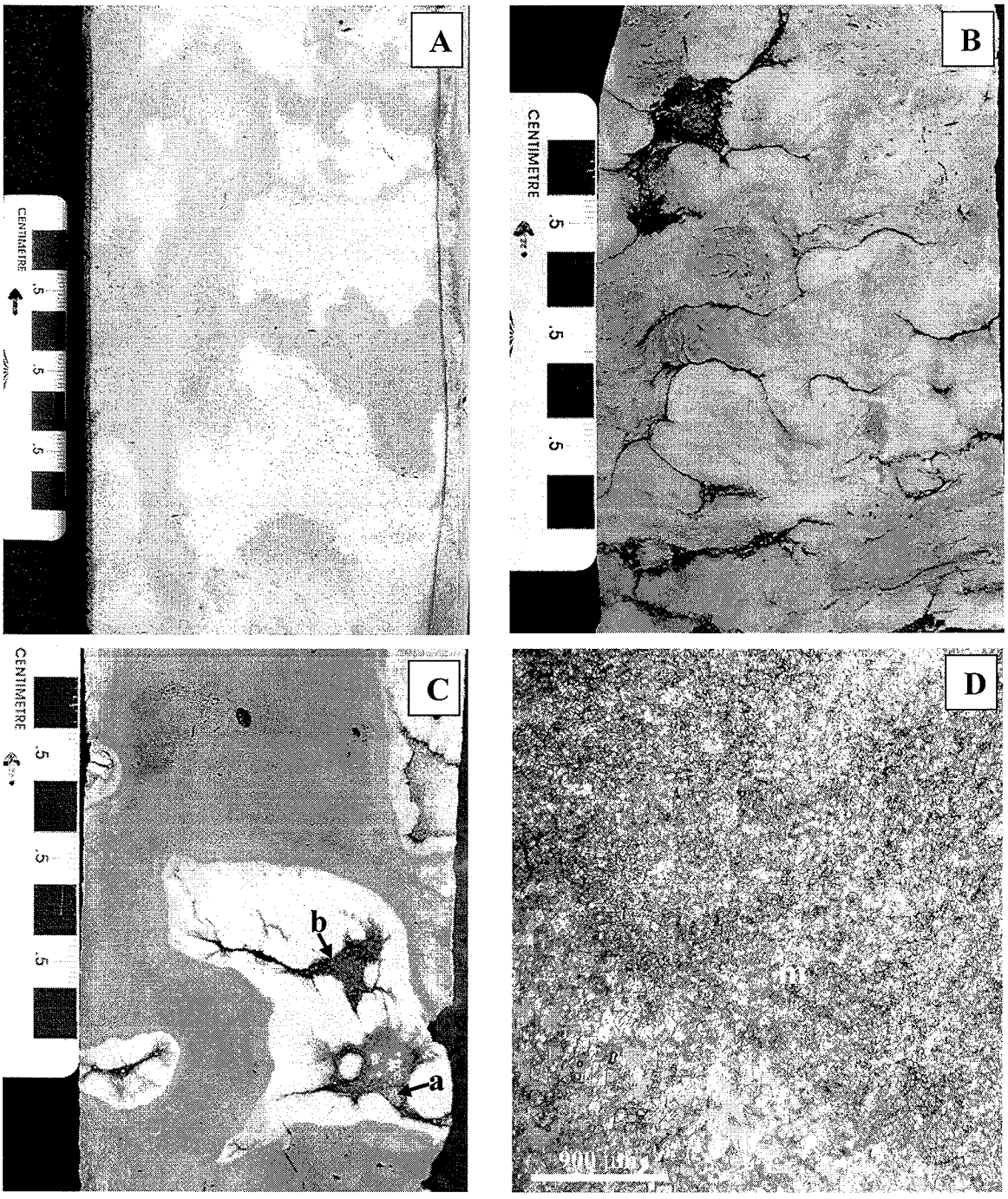


Figure 3.3 Lithofacies B: mottled-nodular skeletal wackestone-mudstone (pervasively dolomitized). A) Core photograph showing nodular dolomudstone. 14-13-009-28W1, 1318.20 m (4324.8'). B) Core photograph showing ill-defined nodules accentuated by bituminous/argillaceous seams in skeletal dolowackestone. 15-18-010-27W1, 1272.5 m (4175'). C) Core photograph showing septarian nodules with bituminous fill (b) and small internal anhydrite nodules (a) in dolomudstone. 103/03-12-011-27W1, 1180.80 m (3874'). D) Photomicrograph showing internodular matrix (m) and nodule (n) in dolomudstone. Plane polarized light; porosity is shown by blue epoxy. 14-13-009-28W1, 1317.80 m (4323.49').

morphologies in the limestone and dolostone lithofacies are generally similar, there are features distinct to dolostones. These features include irregularly shaped nodules that have partly coalesced and are separated by thin, argillaceous or bituminous seams (Fig. 3.3B). There are also rare nodules with septarian structures (see Section 3.8) typified by an irregular, central void and connecting radiating fractures which have a bituminous and/or argillaceous fill and locally small anhydrite nodules (Fig. 3.3C). In some cases the dolostone nodules are partly or completely replaced by anhydrite.

Lithofacies B contains rare, thin to medium beds (3 to 18 cm thick) of intraclastic-skeletal packstone-rudstone. These beds have sharp and possibly scoured bottom contacts and sharp to gradational top contacts, which are locally stylolitic; some beds are graded. Allochems consist of sub-rounded intraclasts (1-15 mm diameter), crinoid fragments (up to 3 mm diameter), and comminuted fossil debris. A fractured and laterally discontinuous hardground (1.2 cm thick) with smooth top and bottom surfaces was also observed near the base of the lithofacies. *Planolites* is the only distinguishable trace fossil in lithofacies B and occurs rarely concentrated within discrete intervals. Accessory pyrite is present as rare disseminated bands and as centimeter-scale nodules.

Porosity in Lithofacies B is generally poor but increases upwards and ranges from nearly tight to 15%; porosity is generally higher in dolostone. Vuggy porosity occurs in both nodules and matrix and is dominantly pinpoint but rarely up to 2 cm. Some of the pinpoint porosity may be moldic after peloids or fine skeletal material. Molds of gastropods, sub-centimeter size, and brachiopods, up to 3 cm in size, are present. Moldic

and vuggy porosity can be up to 15% in intraclastic-skeletal packstone-rudstone beds. In limestone, many vugs and molds are lined with medium to coarsely crystalline, dogtooth sparry calcite. Rare 1 to 2 cm size, angular vugs are probably the product of halite dissolution. Intercrystalline porosity (up to 30%) occurs in dolomitized nodules and the internodular matrix (Fig. 3.3D). Locally in dolomitic limestone, fractures cut across both nodules and internodular matrix and are partially filled with geopetal carbonate silt and a later coarse crystalline, sparry calcite cement; however, rare fractures remain open in dolostone.

Lithofacies B typically shows intermediate gamma-ray and resistivity log responses, and a fast sonic interval transit time which are consistent with a slightly argillaceous lithology with low porosity.

3.3.2 Interpretation

Lithofacies B is interpreted to have been deposited in an open subtidal environment with normal salinity as indicated by a faunal assemblage dominated by brachiopods, crinoids, bryozoans, and mollusks (cf. Heckel, 1972). The abundance of carbonate mud and variable argillaceous content in this lithofacies also suggest a tranquil setting. Much of the mottled texture in lithofacies B is likely due to bioturbation, which supports other evidence for a well-oxygenated sea-floor. The localized, upward increase in bituminous content observed in this lithofacies is interpreted to reflect localized stagnation and accumulation of organic matter.

Thin beds of intraclastic-skeletal packstone-rudstone are interpreted to have resulted from high-energy events of short duration, probably storms, and are therefore considered to be tempestites. Storm action would have remobilized sediment below fair-weather wave-base, winnowing mud and producing coarse grained beds interbedded with fair-weather lithologies (cf. Jones and Desrochers, 1992). Sediment gravity flows seem to be a less plausible origin for these beds because the Lower Winnipegosis Member and Elm Point Formation are generally accepted to be ramp deposits (e.g., Jones, 1965; Chow and Longstaffe, 1995). The presence of tempestites and absence of wave-formed bedforms support a depositional environment between fair-weather wave-base and storm wave-base.

Nodular fabrics are generally associated with low sedimentation rates and they are thought to have long durations of formation (e.g., Flügel, 2004). Although nodular limestones are commonly found in deep-marine settings, they can form at shallower depths where they are associated with burrows (e.g., Abed and Schneider, 1980), as they are in lithofacies B. Many workers have provided explanations for the origin of nodular limestone fabrics (e.g., Fisher and Garrison, 1967; Alexandersson, 1974; Jenkyns, 1974; Muller and Fabricius, 1974; Abed and Schneider, 1980). The various models for nodule formation can be grouped into three categories: solution processes, localized cementation within sediment, and mechanical processes (Flügel, 2004). Of the three, nodule formation via localized cementation seems most applicable for lithofacies B based on the following evidence indicating that nodules were lithified before the matrix: (1) some nodules are broken, likely due to compaction, and the fractures terminate at the nodule

margins, and (2) microstylolites show compactional drape around many of the nodules. In addition, the presence of hardgrounds shows that penecontemporaneous sea-floor lithification occurred. Hardgrounds were also observed by Yurkowski (1995) at the base of the Lower Winnipegosis Member in southeast Saskatchewan. Further petrographic study is required to better understand nodule formation in lithofacies B.

Much of the variation observed in lithofacies B is attributed to diagenesis. Primary depositional features show only subtle variations both up-section and laterally and therefore it is likely that the depositional environment remained fairly homogeneous during lithofacies B deposition.

Previous studies in Manitoba, Saskatchewan, and North Dakota that have described lithofacies that are stratigraphically equivalent to lithofacies B have typically interpreted them as having been deposited in open subtidal conditions (e.g., Wardlaw and Reinson, 1971; Perrin, 1982; 1987; Rosenthal, 1988; Martindale and MacDonald, 1989; Martindale et al., 1991).

3.4 Lithofacies C: Nodular-Patterned Mudstone

3.4.1 Description

Lithofacies C consists almost entirely of thick to very thick bedded dolomudstone (Fig. 3.4). It was observed in only two wells, 16-33-004-13W1 (677.57-682.14 m) and 14-13-009-28W1 (1311.90 -1312.80 m), and it is 0.9 m to at least 4.5 m thick. The most

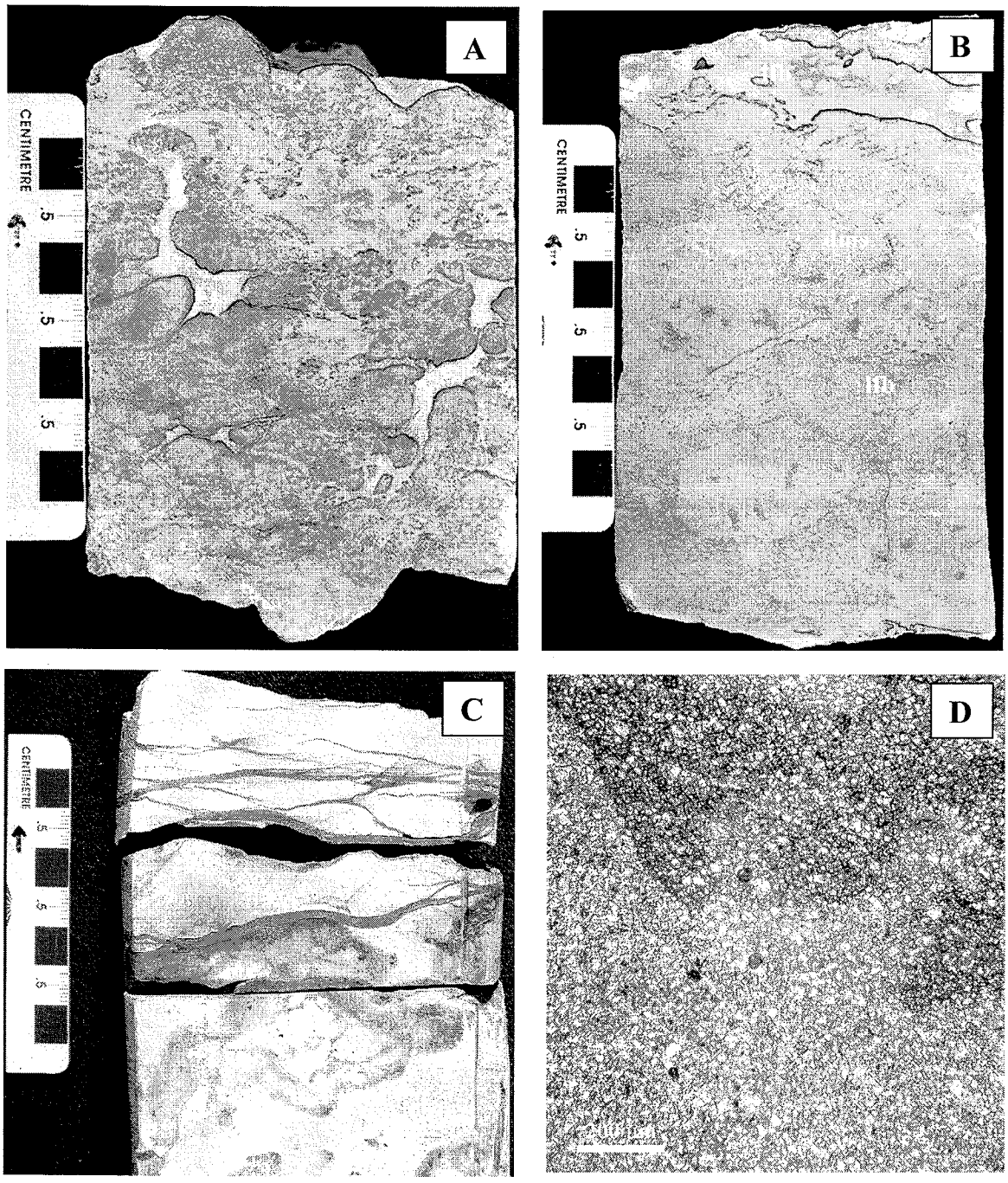


Figure 3.4 Lithofacies C: nodular-patterned mudstone. A) Core photograph showing nodular, patterned dolomudstone with unconsolidated, argillaceous, internodular sediment. 16-33-004-13W1, 682 m (2237.65'). B) Core photograph showing intraclast dolofloatstone beds (ifb) interbedded with dolomudstone (dms). 16-33-004-13W1, 678.2 m (2225'). C) Core photograph showing argillaceous to silty laminae in dolomudstone. 14-13-009-28W1, 1312 m (4304.5'). D) Photomicrograph showing fine crystalline, patterned dolomudstone with irregular distribution of dark opaque minerals. Plane polarized light. 16-33-004-13W1, 678.24 m (2225.2').

distinctive feature of this lithofacies is an irregular blotchy, locally leopard-like, maroon to purple colored patterning in an otherwise tan or light brown lithology (Fig. 3.4A). This feature is texturally similar to patterned carbonate rocks as described by Dixon (1976). A nodular texture is poorly developed and includes irregular internodular areas of friable, light grey clay (Fig. 3.4A). Locally, there are anhydrite nodules or laths within the clay.

Lithofacies C includes rare skeletal dolowackestone beds (8 cm to 1.2 m thick) and intraclastic dolofloatstone beds (0.3-7 cm thick) which have sharp and very irregular contacts (Fig. 3.4B). Bioclasts are mostly molds and appear to have been mainly brachiopod fragments. Intraclasts are composed of dolomudstone, 0.2-4 cm size, and sub-angular to rounded. Dark grey, undulatory and anastomosing, argillaceous to silty laminae, 2 to 3 mm thick, are present rarely (Fig. 3.4C). They contain scattered silt-sized quartz grains and anhydrite laths.

Lithofacies C is pervasively dolomitized and consists of very fine to fine crystalline, planar-s, non-planar, and planar-e dolomite (Fig. 3.4D). Aphanocrystalline to fine crystalline, opaque minerals, possibly magnetite or goethite (as determined by qualitative SEM-EDS analyses) occur finely disseminated, as patchy concentrations, lining pore space, and concentrated along stylolites. They are locally associated with aphanocrystalline hematite grains, which also occur disseminated and in patches and are the most likely cause of the macroscopic patterned texture observed in core.

Anhydrite occurs rarely as irregular bodies, 2 to 5 cm in size. Some are irregular in form and contain dolomite inclusions; others are rounded and inclusion-free. Rare, coarsely crystalline, angular bodies of anhydrite fills molds of halite hoppers. Accessories also include silt-size quartz grains. Porosity is generally low, between 1-5%, and includes intercrystalline, micro-vuggy, pinpoint, fracture, and rarely moldic.

There is no gamma-ray log available for well 16-33-004-13W1 but lithofacies C in well 14-13-009-28W1 does show a subtle gamma-ray "kick", which is likely due to the argillaceous content.

3.4.2 Interpretation

Lithofacies C is interpreted to be of lower intertidal to supratidal origin, based on the occurrence of patterned dolostone. Lithological and faunal associations in previously studied patterned carbonates suggest deposition in an intertidal to supratidal, but dominantly supratidal, depositional environment (Dixon, 1976). Modern analogues are found in tidal flats on Andros Island in the Bahamas and the Persian Gulf. The patterning is considered to be very early diagenetic in origin and is defined by concentrations of pyrite crystals. The origin of the pyrite is unknown but it is favored by reducing environments (e.g., Krumbein and Garrels, 1952) and facilitated by sulphate-reducing bacteria (e.g., Geldsetzer, 1973). Features common to previously known occurrences of patterning include laminae to thin bedding, partly to thoroughly dolomitized lithologies that are very fine to fine crystalline, and minor quartz silt to very fine sand that is either disseminated or concentrated in laminae (Dixon, 1976). In addition, patterned carbonates

are associated with stromatolitic beds, unpatterned laminated carbonates, and intraformational breccia. Patterned carbonates are usually devoid of fauna or where present they consist of taxa that were either tolerant of harsh environments (e.g., gastropods) or allochthonous. They are also commonly associated with evaporite minerals, especially anhydrite.

Lithofacies C is generally similar to the patterned carbonates described by Dixon (1976), except that patterning is associated with iron oxide minerals. The source of iron oxides is unknown but the patterned distribution suggests they formed diagenetically rather than detritally. Red hematitic deposits must be sufficiently subaerially exposed to maintain oxidizing and dehydrating conditions; if deposited subtidally, hematite hydrates to limonite or reduces to ferrous iron and loses its red coloration (e.g., Schmalz, 1968; Heckel, 1972). In addition, lithofacies C is nodular, which suggests that localized early cementation occurred. The abundance of siliciclastic silt and clay, which is of probable eolian origin, and the presence of anhydrite laths, anhydrite nodules, and halite hoppers all support an interpretation of a coastal sabkha environment (cf. Kendall, 1992). Skeletal dolowackestone and intraclast dolofloatstone beds were likely emplaced by periodic storm surges into the supratidal setting (cf. Shinn, 1983).

Perrin (1987) described a similar lithofacies referred to as the hematite dolomudstone lithofacies in the Winnipegosis Formation in North Dakota. This lithofacies contains rare to common, disseminated pyrite crystals and a common brecciated fabric. It was interpreted to have been deposited in a restricted, subtidal to lower-intertidal setting.

Likewise, Kostelnyk (1998) described a patterned dolostone lithofacies in the Winnipegosis Formation in North Dakota, which he interpreted to have been deposited in an arid supratidal setting, but the patterning was attributed to anhydrite.

3.5 Lithofacies D: Bituminous Laminite

3.5.1 Description

This lithofacies consists of light to dark reddish brown to black, finely laminated, bituminous mudstone to grainstone. It has sharp to rapidly gradational contacts which are horizontal to gently undulatory and ranges from 0.3 cm to greater than 77 cm thick. This lithofacies may be represented by a single bituminous lamina or by numerous bituminous laminae that are interlaminated or interbedded with non-bituminous mudstone, skeletal wackestone, or peloidal packstone, less than 1 mm to 1 m thick (Fig. 3.5; 3.6A, B). These carbonate beds and lenses are generally similar in lithology to the lithofacies that underlie or overlie lithofacies D (e.g., lithofacies B, F, and H). Where the carbonate interbeds are less than 30 cm thick, they are included in lithofacies D and the bottom and top lithofacies contacts are defined by the lowermost and uppermost bituminous laminae respectively. The top contact is rarely burrowed by *Planolites*(?) (Fig. 3.5D). Dolomite content ranges from 0 to 100% and includes aphanocrystalline and fine to medium crystalline, planar-e and planar-s dolomite. TOC content is highly variable and ranges from 0.8 to 52.2%.

Within the bituminous laminae, allochems range from 0 to 85%, the most common of which are peloids and cricoconarids. Cricoconarids are small (1 mm to few cm long)

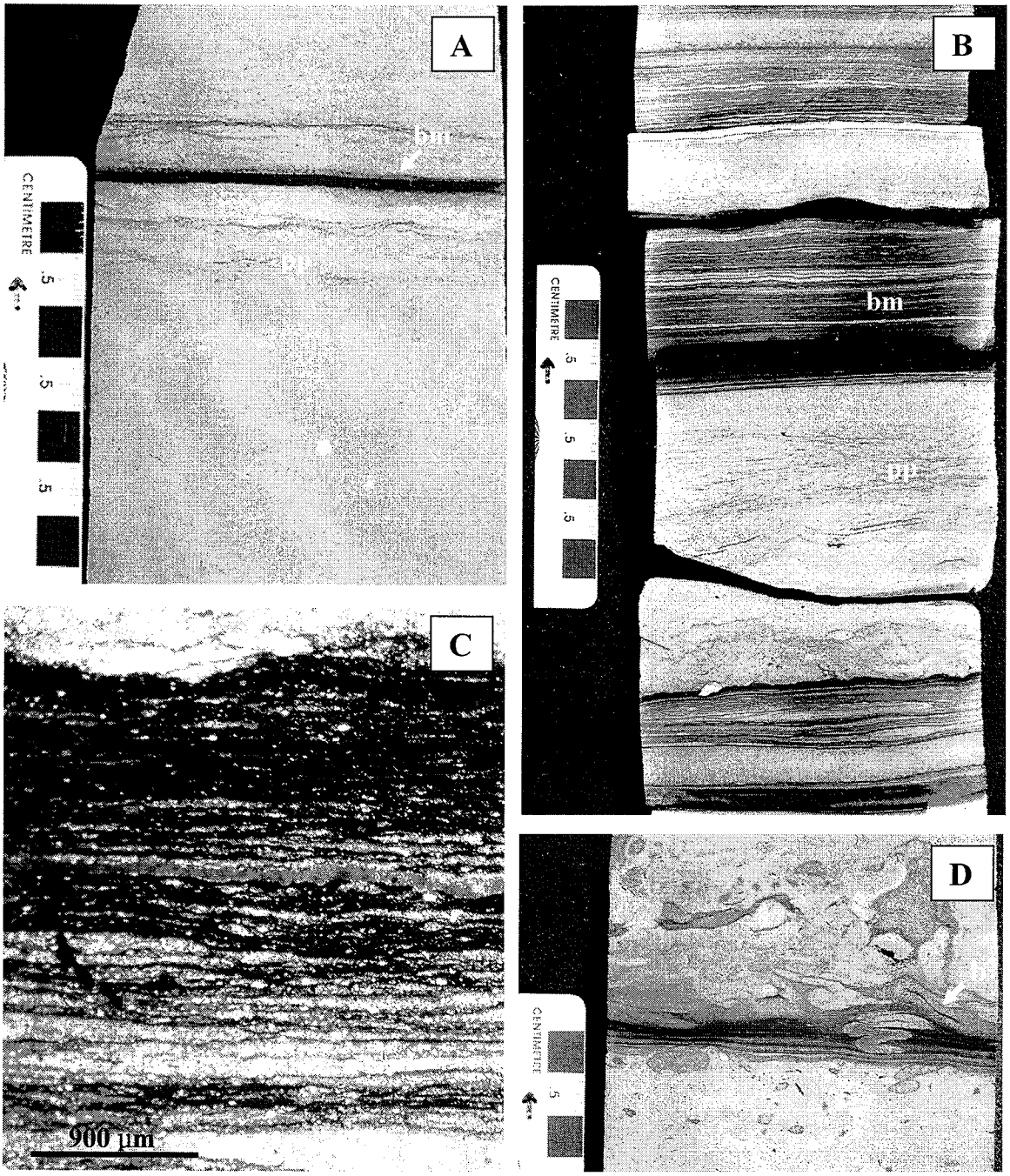


Figure 3.5 Lithofacies D: bituminous laminite. A) Core photograph showing bituminous laminite consisting of bituminous dolomudstone (bm) interbedded with non-bituminous peloidal dolopackstone (pp). 05-13-005-22W1, 1153.8 m (3785.4'). B) Core photograph showing interlaminated/interbedded bituminous dolomudstone and non-bituminous dolomudstone (bm) interbedded with non-bituminous peloidal dolopackstone (pp). 04-12-007-25W1, 1198.73 m (3932.8'). C) Photomicrograph of sample (B) showing finely interlaminated bituminous dolomudstone (dark brown to black) and non-bituminous dolomudstone (light grey). Plane polarized light. D) Core photograph showing bituminous laminite which has a burrowed upper portion (b), interbedded with nodular dolomudstone. 11-29-001-25W1, 1531.9 m (5026').

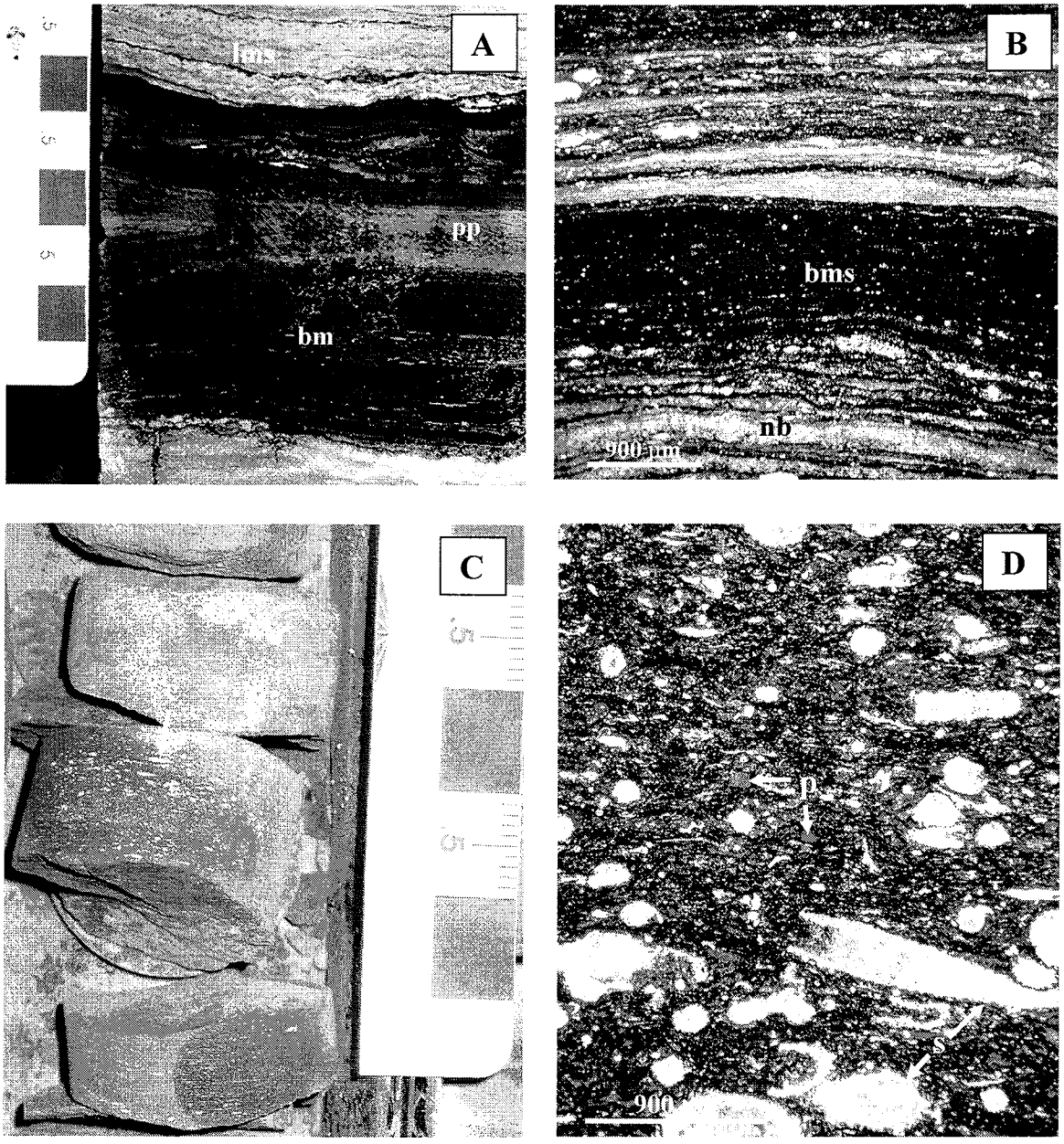


Figure 3.6 Lithofacies D: bituminous laminite. A) Core photograph showing bituminous mudstone (bm) interbedded with laminated dolomudstone (lms) and peloidal packstone (pp). 103/03-12-011-27W1, 1178.6 m (3866.8'). B) Photomicrograph of sample shown in (A) showing interlaminated bituminous dolomudstone (bms) and non-bituminous dolomudstone (nb). Plane polarized light. C) Core photograph showing bituminous peloidal-skeletal wackestone to packstone; cricoconarids (c) appear as white specks. 12-35-24-10W1, 17.45 m (57.25'). D) Photomicrograph of sample shown in (C) showing bituminous skeletal-peloidal wackestone with styliolinids (s) oriented parallel to bedding, peloids (p), and disseminated organic matter. Plane polarized light.

Paleozoic fossils that have long had uncertain taxonomic affinities but are now generally considered to be a class of the Mollusca (e.g., Flügel, 2004). They are typified by narrow conical shells of calcite and are found in open-marine and basinal carbonate rocks. Cricoconarids, up to 2.5 mm long, are mostly of the styliolinid (smooth-walled) variety in the study area but rare tentaculitids (ringed exterior) are present as well; both occur oriented parallel to bedding and are commonly broken and may be compacted (Fig. 3.6C, D). Skeletal wackestone intraclasts, crinoid fragments, calcareous algae tubules, ostracods, and coral fragments are trace constituents.

An unusual bituminous laminite in well 04-33-023-16W1 (205.44-206.1 m [673.8-676.2']) is a calcisphere grainstone consisting of nearly 100% calcispheres (Fig. 3.7A). The calcispheres are round to ovoid, 5-80 μm in diameter, and may have sutured grain contacts (Fig.3.7B). Some appear solid while others have a dark brown, oil-stained, round central chamber. The larger calcispheres generally occur in clusters and commonly have very thin, dark inner walls and thick radial fibrous calcite outer walls with very fine crystalline, blocky calcite cement occluding their chambers.

Organic matter in bituminous laminites occurs as disseminated particulates, short discontinuous microstylolites, swarms of anastomosing microstylolites, or solid laminae (Fig. 3.5C; 3.6B, D; 3.7B, D). Some laminites become progressively more bituminous upwards in the lithofacies. Accessories include opaque minerals, which are common and appear to be mostly framboidal and euhedral crystals of pyrite, rare to common quartz silt, and rare to abundant anhydrite laths which may be calcitized.

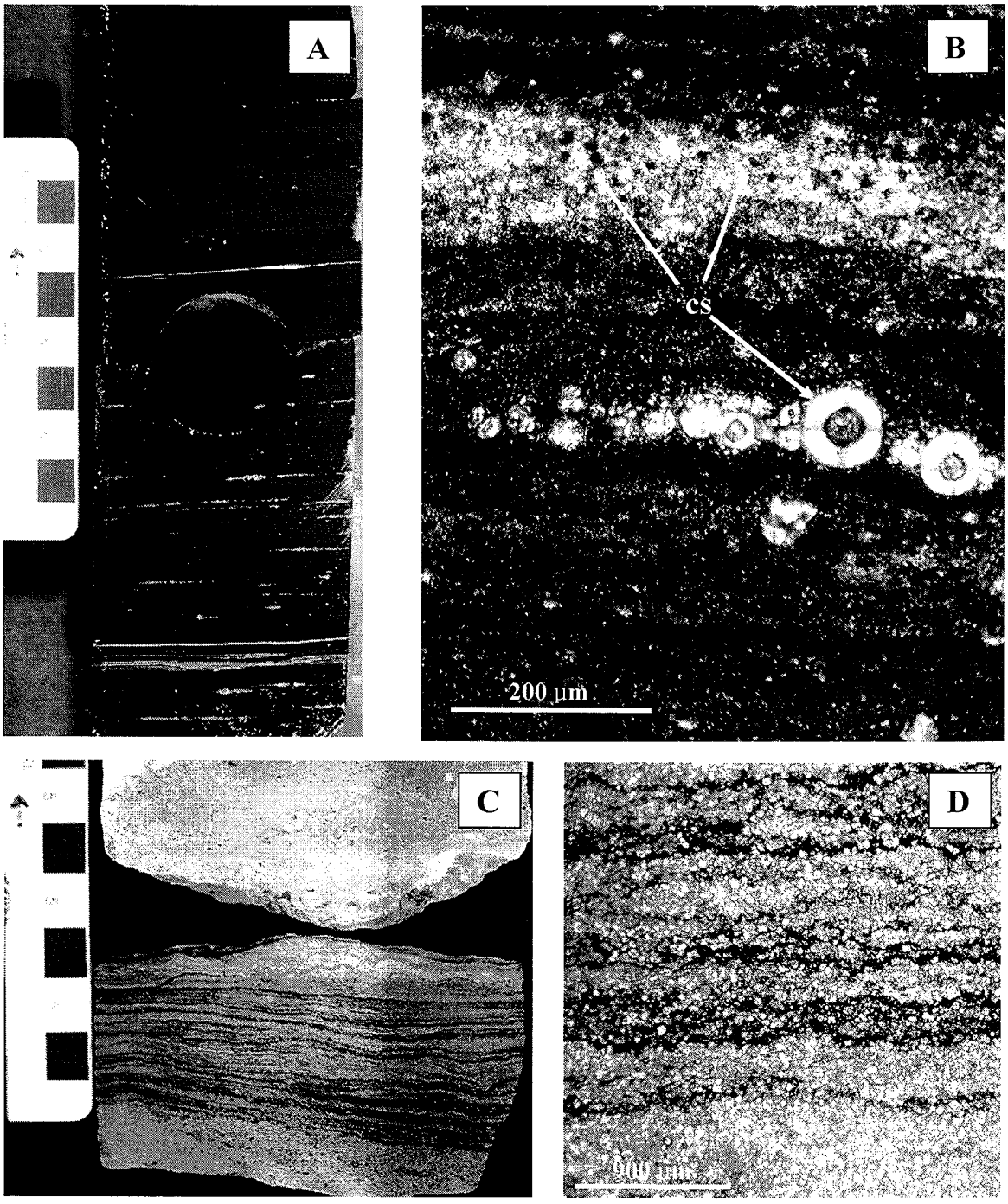


Figure 3.7 Variations of lithofacies D: bituminous laminite. A) Core photograph showing very finely laminated bituminous laminite. 04-33-023-16W1, 205.55 m (674.4'). B) Photomicrograph of sample shown in (A) showing bituminous laminite consisting of calcispheres (cs) in a kerogenous matrix. Crossed nicols. C) Core photograph showing bituminous laminae interlaminated with peloidal dolopackstone. 03-01-008-18W1, 783.9 m (2572'). D) Photomicrograph of sample shown in (C) showing widely spaced bituminous laminae and abundant intercrystalline porosity in non-bituminous interlaminations. Plane polarized light; porosity is shown by blue epoxy.

Porosity in carbonate laminae is up to 25% and includes intercrystalline, vuggy, microvuggy, moldic, and fracture porosity. Porosity in bituminous laminae is very low (0-3%) and includes fracture, moldic, intercrystalline, interparticle, and intraskeletal porosity. Uncompacted cricoconarid shells usually have radial-prismatic calcite cement lining the interior and exterior of the shells. Minor equant calcite and anhydrite cement, and rare silica cement (quartz and chalcedony) occur in fractures and vugs. Porosity estimation of some laminites is hampered by abundant bitumen and/or oil staining.

A full suite of petrophysical well logs is not available for all cores containing lithofacies D. However, generally where lithofacies D is well developed, it may be identified on well logs as a gamma-ray "shale kick", and by high interval transit times, increased resistivity, and a positive SP response. Only the thickest laminites are within the resolution of logging tools.

3.5.2 Interpretation

Bituminous laminae in lithofacies D are interpreted to have been deposited in low energy, anoxic, subtidal conditions below fair-weather wave base, as evidenced by the abundance of sedimentary organic matter. Where present, non-bituminous carbonate laminae and beds are compositionally similar to lithofacies B, F, and H, with which lithofacies D is interbedded, and represent normal background sedimentation in open conditions. Consequently, bituminous laminae are interpreted to represent, episodic short-term events, as evidenced by their sharp to rapidly gradational contacts and relatively thin nature. Burrows at the top of one bituminous lamina, which protrude downward, reflect a

return to normal oxic conditions following organic matter deposition. Bituminous laminites that contain anhydrite laths were deposited in waters that were both anoxic and had elevated salinity; elevated salinity associated with restricted circulation likely inhibited grazing and enhanced preservation (cf. Warren, 1986). Primary depositional controls on bituminous laminites will be considered further in Chapter 5: Organic Petrology.

Given the interpreted depositional conditions, the localized concentrations of cricoconarids warrant further discussion. Cricoconarids are currently considered to be pelagic or nektobenthic molluscans, which were tolerant of diverse environments (e.g., Fisher, 1962; Flügel, 2004). Although present in trace amounts in other lithofacies in this study, they are abundant in bituminous laminae in some occurrences of lithofacies D. The most plausible explanation for this association is that the inhospitable conditions that affected benthic infauna during deposition of bituminous laminites also extended up the water column at times exterminating pelagic organisms which settled out of suspension postmortally (cf. Chow et al., 1995).

Bituminous laminites in the Winnipegosis Formation have been described and interpreted as deep, restricted, euxinic deposits by previous studies in Saskatchewan (e.g., Wardlaw and Reinson, 1971; Kendall, 1975; Jin and Bergman, 2001) and in Manitoba, north of the study area (e.g., Rosenthal, 1988). However, these laminites are not necessarily stratigraphically equivalent or coeval with those in this study.

3.6 Lithofacies E: Interlaminated Mudstone-Anhydrite

3.6.1 Description

This lithofacies consists of laminated mudstone and interlaminated or interbedded mudstone and anhydrite. It is 0.2-6.5 m thick, has a sharp lower contact and a gradational upper contact. Only three occurrences of lithofacies E were encountered in core during this study and they vary widely with respect to thickness and extent of diagenesis over relatively short lateral distances of 30 to 40 km (02-21-007-28W1, 1441-1447.5 m [4727.7-4749']; 103/03-12-011-27W1, 1178.5-1180.5 m [3866.5-3873']; 04-12-007-25W1, 1198.35-1198.55 m [3931.6-3932.3']).

The mudstone is generally tan, brown, or grey and it is thinly laminated to thickly bedded (up to 45 cm thick), generally thickening upwards (Fig. 3.8). Mottling and possible burrows are present rarely. Contacts are sharp and may be nearly horizontal, undulatory, or crenulated. Where it is limestone, the mudstone consists of micrite, microspar, and pseudospar with rare, fine to medium crystalline, planar-e dolomite (Fig. 3.8B). More commonly, the mudstone is pervasively dolomitized and consists of fine to medium crystalline, planar-e, planar-s, and non-planar dolomite, and aphanocrystalline dolomite. The only evidence of allochems is rare molds of high-spired gastropods. Accessory constituents include silt size, angular feldspar and quartz clasts and scattered clusters of opaque minerals which appear to be mostly framboidal pyrite. Microstylolite swarms, 1 to 3 mm thick, are concentrated along laminae/bed contacts and contain organic matter, pyrite framboids and rare anhydrite laths (Fig. 3.8, 3.9).

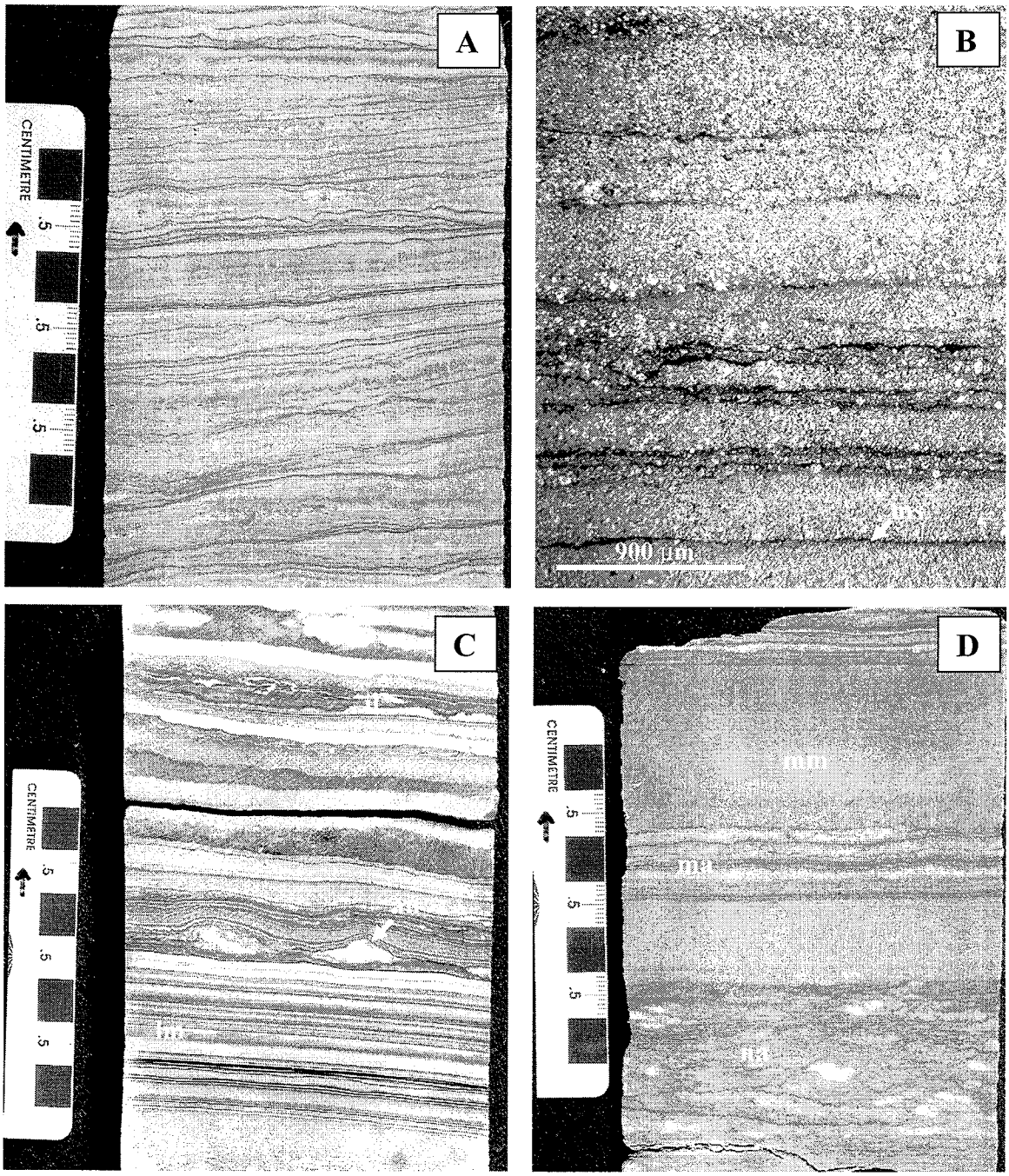


Figure 3.8 Lithofacies E: interlaminated mudstone-anhydrite. A) Core photograph showing laminated mudstone with microstylolitic contacts near the base of lithofacies E. 02-21-007-28W1, 1446.48 m (4745.7'). B) Photomicrograph of sample shown in (A) showing micrite and microspar. Sparse planar-e dolomite and organic matter are concentrated at microstylolites (ms), mostly along contacts. Plane polarized light. C) Core photograph showing thinly laminated to very thinly bedded dolomudstone (lm), irregular dolomitic laminae (il), which appear to have replaced anhydrite, and displacive anhydrite nodules (an). 04-12-007-25W1, 1198.52 m (3935.2'). D) Core photograph showing massive dolomudstone beds (mm), interlaminated dolomudstone and anhydrite (ma), and nodular anhydrite (na). 02-21-007-28W1, 1442.34 m (4732.1').

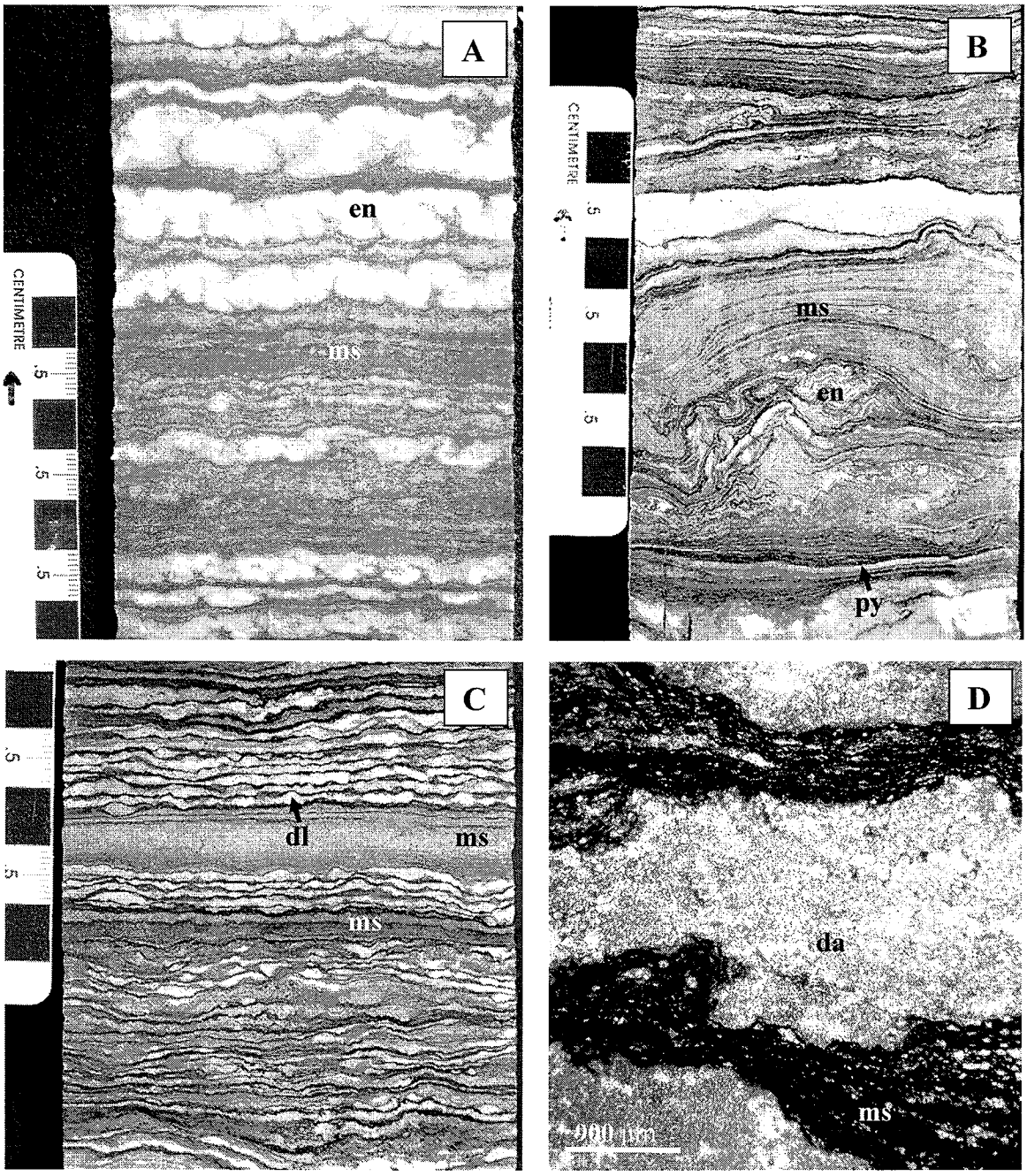


Figure 3.9 Lithofacies E: interlaminated mudstone-anhydrite. A) Core photograph showing interlaminated/interbedded dolomudstone (ms) and enterolithic anhydrite (en). 02-21-007-28W1, 1441.36 m (4728.9'). B) Core photograph showing the base of lithofacies E including pyrite lamina (py), dolomitized enterolithic anhydrite laminae (en), and finely laminated to very thinly bedded dolomudstone and microstylolites (ms). 103/03-12-011-27W1, 1180.40 m (3872.7'). C) Core photograph showing crenulated, dolomitic laminae (dl), which have replaced anhydrite, displacing dolomudstone laminae and microstylolites (ms). 103/03-12-011-27W1, 1178.75 m (3867.3'). D) Photomicrograph of sample shown in (C) showing dolomudstone laminae and bituminous microstylolite swarms (ms) and laminae of very fine to medium crystalline dolomite (da) that has replaced anhydrite. Plane polarized light; porosity is shown by blue epoxy.

Anhydrite occurs as (1) randomly distributed, displacive nodules showing round, ovoid, or lenticular shape (0.04 to 3.5 cm in diameter) (Fig. 3.8C, D); and (2) laminae and thin beds, 0.01 to 2.5 cm thick, with crenulated contacts. Anhydrite content generally increases upwards in the lithofacies; laminae and beds thicken and become increasingly enterolithic where lithofacies E is best developed (Fig. 3.9A). Where lithofacies E is poorly developed, very thin enterolithic laminae are the lowest occurrence of anhydrite (Fig. 3.9B). Anhydrite nodules and irregular and enterolithic laminae may be partly or completely replaced by very fine to medium crystalline, planar-e, non-planar, and planar-s dolomite and remnant anhydrite may occur locally (Fig. 3.9).

In lithofacies E, porosity is generally 0-5% and consists of intercrystalline, micro-vuggy, vuggy, fenestral, and fracture porosity. Most mudstone laminae contain some intercrystalline porosity that generally increases with the degree of dolomitization but the best porosity in lithofacies E occurs where dolomite appears to have replaced anhydrite nodules or laminae. Pores are partially or completely occluded by coarse crystalline anhydrite and fine crystalline quartz cement.

Due to the vintage of some of the petrophysical well logs, information regarding the physical properties of lithofacies E is limited; however where anhydrite is still preserved, lithofacies E may be identified from carbonate units below by a cleaner, or cleaning upward gamma-ray signature, higher resistivity, and faster interval transit times. Where anhydrite has been replaced by dolomite, lithofacies E is distinguished by rapidly fluctuating sonic and density logs associated with variable porosity between beds.

3.6.2 Interpretation

Lithofacies E is interpreted to have been deposited in a subtidal setting under progressively shallowing and increasingly saline conditions (cf. Kendall, 1992). Elevated salinity inhibited infauna, preserved laminae, and induced calcium sulphate precipitation (cf. Heckel, 1972; McCaffrey et al., 1987). Variability in the thickness of lithofacies E over relatively short lateral distances indicates that water depth and/or salinity was not uniform across the study area. The presence of a pyrite lamina at the base of lithofacies E in well 103/03-12-011-27W1, 1180.40 m (3872.7'), indicates that bottom waters were at least locally anoxic and H_2S-bearing (cf. Raiswell et al., 1988).

Basal carbonate laminae may have precipitated from the water column with increasing salinity (cf. McCaffrey et al., 1987) and/or been derived from the settling of winnowed mud (cf. Mullins, 1986). An absence of bedforms is suggestive of deposition below wave base; however, it may also be indicative of a water column too shallow to produce waves or storms (cf. Jin and Bergman, 1999). With increasing salinity, gypsum precipitation dominated (cf. Jin and Bergman, 1999; McCaffrey et al., 1987). Although enterolithic anhydrite is commonly associated with supratidal sabkha settings, it may also occur as a result of soft sediment slumping, dehydration during burial or re-hydration of anhydrite to gypsum and cannot be used accurately as a bathymetric indicator or to indicate if desiccation occurred (e.g., Shearman and Fuller, 1969; Warren, 1989; Kendall, 1992). Therefore, the enterolithic anhydrite observed in lithofacies E has little significance for inferring the depth of the water column at the time of deposition.

Hypersaline conditions were locally punctuated episodically by freshening as evidenced by the presence of gastropods and possible burrowing.

Laminated carbonates and anhydrites lithologically similar to lithofacies E have been described and interpreted in numerous previous studies of the Ratner Formation in North Dakota, Alberta, and Saskatchewan. Different interpretations of the Ratner Formation are due in part to the absence of modern analogues for large intracratonic basins such as the Elk Point Basin (Jin and Bergman, 1999). Shearman and Fuller (1969) concluded that the laminated and enterolithic anhydrite in the upper portion of the Ratner Formation in Saskatchewan are early diagenetic in origin having precipitated as a result of desiccation of the basin floor prior to precipitation of the Prairie Evaporite. Anhydrite nodules coalesced into sheets within a dominantly organic substrate resembling cyanobacterial mats that are analogous to those in Recent intertidal zones of the Arabian Gulf. Enterolithic anhydrite was interpreted to have been deposited in a sabkha.

In contrast, Wardlaw and Reinson (1971) were able to correlate individual laminations within the Ratner Formation in central Saskatchewan over distances up to 3 km and favored an extensive, deep-water depositional environment. Likewise, Davies and Ludlam (1973) were able to visually and statistically correlate individual laminae up to 25 km distance in northern Alberta. They attributed this lateral continuity to seasonal carbonate and evaporite precipitation in a uniform, density stratified basin or sub-basins with an estimated water depth of 50 m or less. Large carbonate banks and shoals

provided bathymetric restrictions to circulation. Due to the absence of algal filaments in thin-section, Davies and Ludlam (1973) also repudiated an algal mat influence.

Jin and Bergman (1998; 1999; 2001) studied the Ratner Formation from both the northern and southern parts of the Saskatchewan Sub-Basin and were able to discern basinal, reef-slope, and reef-top facies, which occur above drowned reefs. The northern laminites typically show three brining-upward depositional cycles of dolomudstone, interlaminated dolomudstone and anhydrite, and enterolithic to nodular anhydrite. In comparison, the southern laminites generally only show a single cycle and are also darker colored, characterized by wavy cryptalgal structures, have rare contorted and enterolithic bedding, and have anhydrite beds commonly diagenetically altered to coarse white dolomite. Depositional variations in the Ratner Formation within the sub-basin were attributed to differential water depth with deeper water occurring at the southern end, where isolated reefs are generally thicker, in contrast to the northern end where depositional cycles ended with near-desiccation. The Ratner Formation at both ends of the sub-basin was found to be best developed adjacent to isolated reefs, especially where they are closely clustered and the origin of the Ratner Formation was attributed to vadose dissolution of the isolated reefs during evaporative drawdown in a large intracratonic salina.

Perrin (1987) identified a sequence of four distinct lithofacies in the Winnipegosis Formation in North Dakota, that are similar to the Ratner Formation (from bottom to top): laminated mudstone, laminated dolomudstone, laminated and stromatolite, and

laminated anhydrite. This sequence was interpreted to represent environments progressing from normal deep-marine at the base of the sequence to an increasingly saline or possibly stratified water column to deep hypersaline conditions in which water depth exceeded the photic zone at times towards the top of the sequence. However, a shallow origin for the uppermost portion was not precluded.

3.7 Lithofacies F: Massive-Mottled Mudstone

3.7.1 Description

This lithofacies is predominantly tan to light brown or grey mudstone and 0.2 to 4 m thick with sharp to gradational contacts. The mudstone is generally massive, sparsely fossiliferous and locally faintly mottled and finely laminated (Fig. 3.10A, B). It consists of micrite, microspar and rare pseudospar and is variably dolomitized to aphanocrystalline to medium-crystalline, non-planar, planar-s, and planar-e dolomite (Fig. 3.10D). At some locations the dolomite has been variably dedolomitized.

Allochems range up to 8% and consist dominantly of brachiopod fragments, up to 2 cm size, and crinoid ossicles, up to 4 mm size. Subordinate constituents include thamnoporid coral fragments (up to 1 cm size), cricoconarids, udoteacean calcareous algae (including *Lancicula* or *Litanaia*?), ostracods, micritic intraclasts and peloids. In dolomudstones, some bioclasts remain undolomitized or occur as calcite cement-filled molds.

The mudstone is rarely interbedded with thin bioclastic floatstone beds (2-4 cm thick) consisting of brachiopod, crinoid, and gastropod fragments and molds in a mudstone or

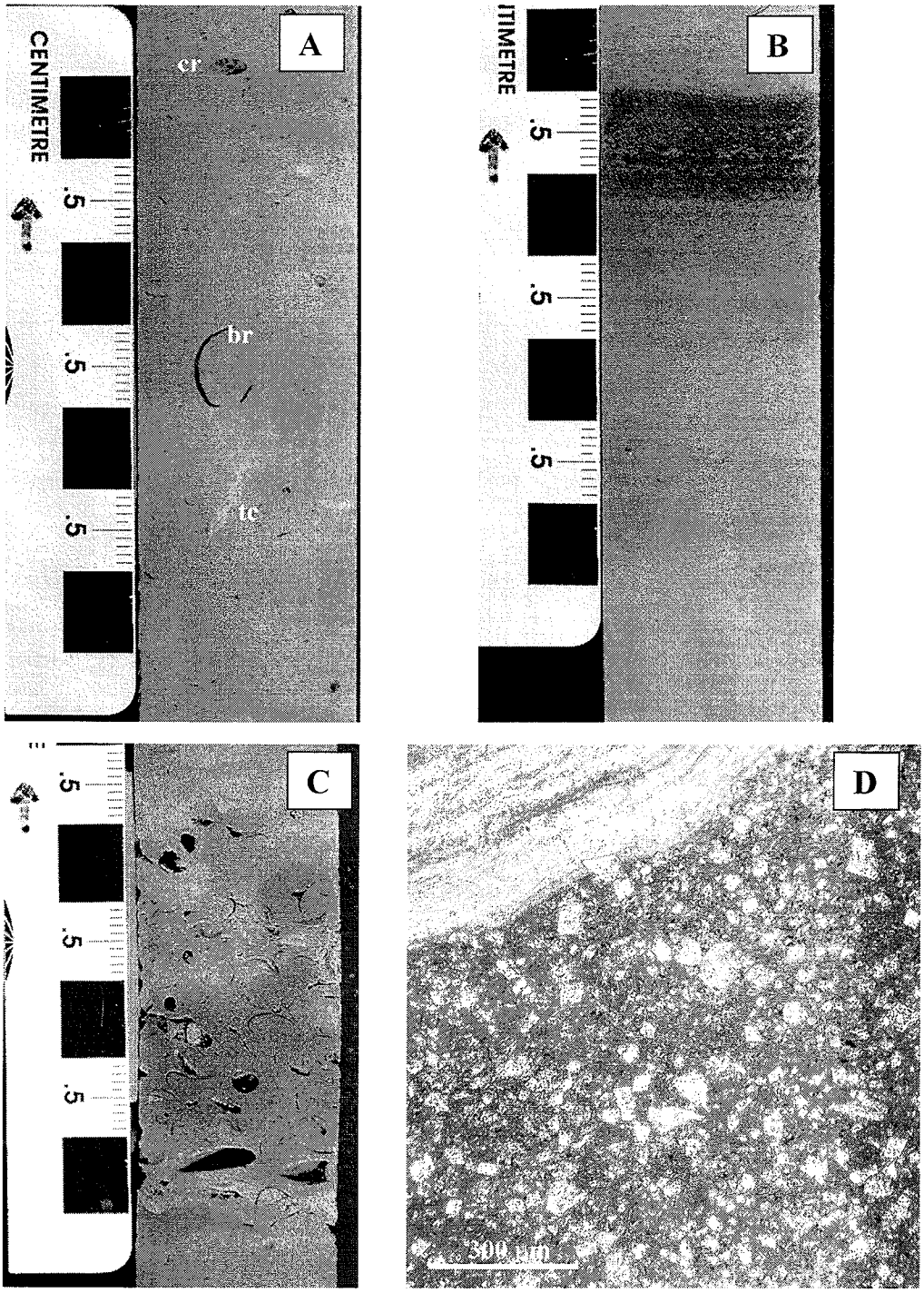


Figure 3.10: Lithofacies F: massive-mottled mudstone. A) Core photograph showing massive, sparsely fossiliferous mudstone. Bioclasts include brachiopod valves (br), crinoid ossicles (cr), and thamnoporid coral (tc) fragments. 5-35-24-10W1, 14.6 m (47.9'). B) Core photograph showing mudstone with faint thin laminae. 5-35-24-10W1, 16.5 m (54.1'). C) Core photograph showing bioclastic floatstone bed with peloidal packstone matrix. 5-35-24-10W1, 17.7 m (58'). D) Photomicrograph showing micrite and microspar partially dolomitized to planar-e dolomite. A brachiopod fragment is present at the upper left. Plane polarized light. 04-33-023-16W1, 218.38 m (716.5').

peloidal packstone matrix (Fig. 3.10C). The bottom and top contacts are sharp and irregular. Other features include very rare ovoid nodules (1.5-3 cm in diameter) and rare poorly preserved oncoids (at least 2 cm in diameter) which contain vuggy and concentric fenestral porosity.

Porosity in this lithofacies ranges between 0 and 7% and includes intercrystalline, vuggy, micro-vuggy, and moldic porosity; the best porosity generally occurs in the dolomitized lithologies. Porosity is partly or completely occluded by medium to coarse crystalline, dog-tooth and equant calcite.

3.7.2 Interpretation

Lithofacies F is interpreted to have been deposited in a low energy, subtidal setting between fair-weather wave-base and storm wave-base, as evidenced by the abundance of micrite and the local occurrence of bioclastic floatstone beds which are interpreted to be tempestites (cf. Jones and Desrochers, 1992). Conditions were generally open; however, the localized preservation of laminae suggests that slight restriction may have occurred resulting in either elevated salinity or dysoxia thereby inhibiting benthos (cf. Heckel, 1972; Thompson et al., 1985; Pickerill and Brenchley, 1991).

Kostelnyk (1998) recognized a mudstone lithofacies in the Winnipegosis Formation in North Dakota that is lithologically similar to lithofacies F. However, it contained anhydrite and was interpreted to have been deposited in a low energy, restricted, hypersaline environment. Detailed mapping of an Upper Winnipegosis patch reef at the

Narrows West Quarry in Manitoba by Davidson (1981) revealed that mudstones are commonly found in paleo-depressions, although no lithofacies was named.

3.8 Lithofacies G: Septarian-Type Nodular Skeletal Packstone

3.8.1 Description

This lithofacies consists of thin to very thickly bedded (4 cm to >2 m), nodular skeletal dolopackstone to locally dolowackstone and ranges from 0.45 to at least 5.8 m thick. The bottom and top contacts are sharp to gradational. The most distinctive feature of this lithofacies is the pervasive presence of nodules that possess septarian fractures. Nodules are invariably tan non-bituminous, and range from spheroidal and ovoid to amoeboid in shape (Fig. 3.11). Most nodules are 1-5 cm size, but locally they exceed 10 cm, and consist mostly of fine to medium crystalline, planar-e and minor planar-s dolomite. They may contain unidentifiable skeletal allochems. Individual nodules may have a single internal fracture or a network of fractures that join at triple junctions. In well-defined nodules, the internal fractures rarely extend to the edge of the nodule and never extend into the internodular matrix. The septarian fractures and triple junction voids usually have an unconsolidated, bituminous fill which may contain small anhydrite nodules, macerals, and opaque minerals. Some nodules are partly to completely replaced with anhydrite; organic matter is locally found within the anhydrite.

The internodular matrix has been completely dolomitized to aphanocrystalline to medium crystalline, non-planar, planar-s and planar-e dolomite. It varies from dark brown to tan depending on the bituminous content (Fig. 3.11). Bioclasts are up to 2 mm in size and

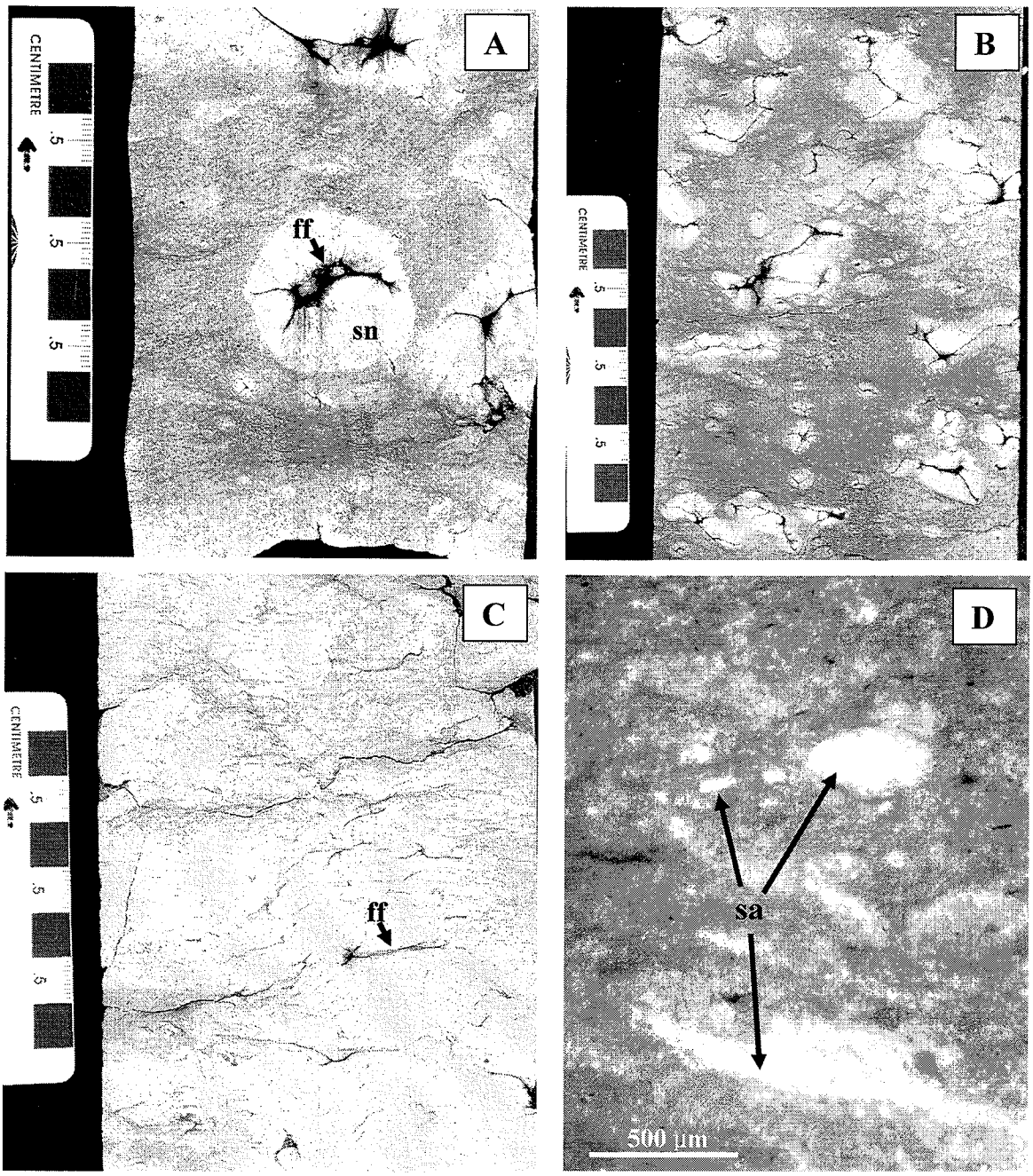


Figure 3.11: Lithofacies G: septarian-type nodular skeletal packstone. A) Core photograph showing skeletal dolopackstone with septarian nodules (sn) that contain a bituminous fracture fill (ff) and small anhydrite nodules. 04-12-007-25W1, 1209.4 m (3967.8'). B) Core photograph showing bituminous skeletal dolopackstone with small and large septarian nodules. 11-29-001-25W1, 1526.3 m (5007.6'). C) Core photograph showing skeletal dolopackstone with low bituminous content. Nodules are only identified by dark fracture fill (ff). 11-29-001-25W1, 1524.7 m (5002.4'). D) Photomicrograph showing skeletal allochems (sa) in internodular matrix of slightly bituminous dolopackstone. Diffused plane polarized light. 04-12-007-25W1, 1210.68 m (3972').

include crinoid ossicles, thamnoporid corals, brachiopods and ostracods (Fig. 3.11D). Rare cylindrical molds, 9 mm wide and 4.5 cm long, are likely after branching stromatoporoid fragments. Bituminous content is variable, occurring in scattered, patchy concentrations and in wispy microstylolites, which may be compacted between closely spaced nodules. Towards the upper lithofacies contact, the internodular matrix becomes less bituminous and the nodules become recognizable only by the internal fractures (Fig. 3.11C). Opaque minerals can be common, occurring disseminated in pore spaces and concentrated in microstylolites with organic matter.

Porosity ranges from 5 to 15% and includes vuggy, microvuggy, pinpoint, moldic, fracture, and intercrystalline porosity. However, intercrystalline porosity in nodules can be as high as 30 to 40%. Minor coarsely crystalline anhydrite cement occludes porosity in both the internodular matrix and nodules.

3.8.2 Interpretation

The bituminous content and absence of bioturbation, wave-formed bedforms, and tempestites suggest that lithofacies G was deposited in a dysoxic to anoxic, subtidal setting below storm wave base. Comminuted skeletal allochems, as well as some micrite in lithofacies G, are likely allochthonous, transported seaward from a shallow subtidal setting by tides or currents into deeper water (cf. Mullins, 1986). The decrease in bituminous content upsection in the dolopackstone matrix may represent a relative shoaling-upward trend.

Lithofacies G is similar to lithofacies B (mottled-nodular skeletal wackestone-mudstone). They both have variable bituminous content, faunal assemblages consistent with an open subtidal environment and muddy matrix, and are nodular and devoid of wave-formed bedforms. However, lithofacies G is distinguished by having an overall coarser texture, predominantly skeletal dolopackstone; an absence of mottling or burrows; and abundant septarian nodules.

As in lithofacies B, nodules in lithofacies G are interpreted to be early diagenetic, probably having formed via localized cementation of unconsolidated sediment and associated with low rates of sedimentation (see Section 3.3.2 for discussion). The origin of septarian structures in calcareous nodules or concretions has been a contentious issue for at least a century. Todd (1913) suggested that the cracking of concretion interiors was due to the expansive crystallization of the exterior rather than contraction of the interior, which was the long-held belief at the time. However, Pettijohn (1975) and several others favored an origin involving dehydration of a soft concretion core within a hard shell. Astin (1986) and Astin and Scotchman (1988) repudiated all previous theories and suggested that septa in septarian concretions are stress-induced fractures that occur as a result of overpressuring and low horizontal stress associated with rapid burial following concretion growth. In all of the known previous studies, the septarian concretions (nodules) were hosted in a clay or shale matrix and as such, their findings may not be directly applicable to the nodules in lithofacies G. Interpretation of the origin of the septarian nodules in lithofacies G is beyond the scope of this study. However, bituminous matter and macerals (mostly Prasinophytes) were displaced and are

concentrated in the fractures suggesting the fractures were an integral part of nodule growth.

3.9 Lithofacies H: Bedded-Mottled Peloidal Packstone

3.9.1 Description

Lithofacies H consists primarily of laminated to thickly bedded, peloidal (dolo)packstone and minor to rare, very thin to medium beds of dolograinstone and *Amphipora* dolofloatstone with dolopackstone matrix (Fig. 3.12). Beds may be massive or mottled and may contain *Planolites* burrows (Fig. 3.12C). Bituminous content is highly variable and occurs disseminated, in patchy concentrations, or concentrated along microstylolite swarms.

Peloids are the dominant allochems in lithofacies H and are spheroidal to elongate (Fig. 3.13). Subordinate allochems include cricoconarids, ostracods, crinoid fragments, thamnoporid corals, tabular and wafer stromatoporoids, *Amphipora*, and brachiopod valves including articulated stringocephalids. Allochems are most often represented as either dolomitized remnants or moldic porosity. The matrix includes micrite, microspar, and pseudospar, which in turn are variably dolomitized to fine to medium crystalline, planar-e and planar-s dolomite (Fig. 3.13A). Where completely dolomitized this lithofacies consists of fine to coarse crystalline, planar-e, planar-s, non-planar, and aphanocrystalline dolomite (Fig. 3.13B, C). Rarely, the dolomite is partly or completely altered to dedolomite. Disseminated opaque minerals are generally rare but locally concentrated in microstylolite seams.

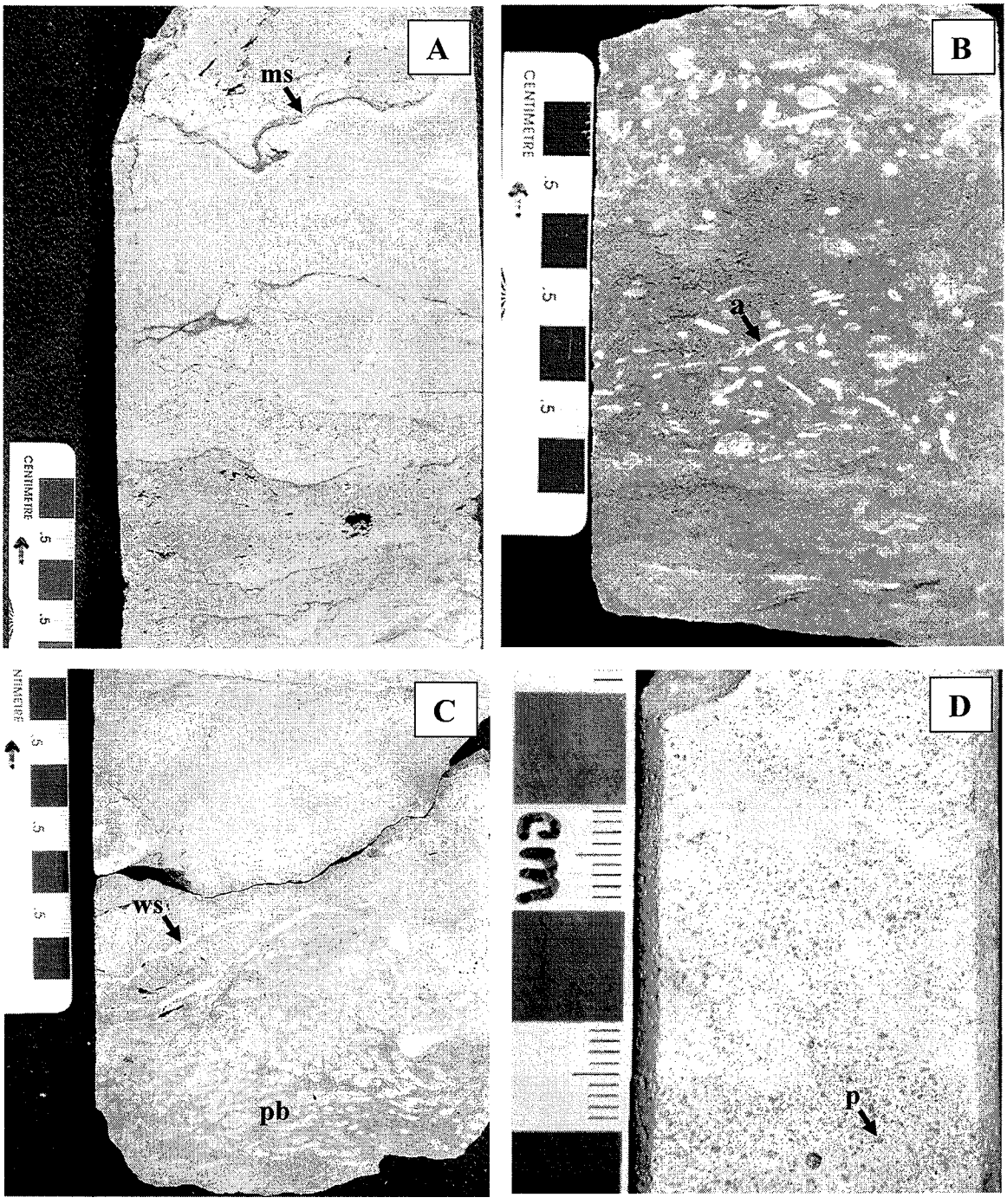


Figure 3.12: Core photographs of lithofacies H: bedded-mottled peloidal packstone. A) Peloidal dolopackstone with irregular microstylolitized bedding contacts (ms). 04-27-011-22W1, 857.46 m (2813.2'). B) *Amphipora* dolofloatstone bed with peloidal dolopackstone matrix. *Amphipora* molds (a) are occluded by anhydrite. 05-13-005-22W1, 1156.92 m (3795.7'). C) Peloidal dolopackstone with wafer stromatoporoids (ws) above *Planolites* burrows (pb). 04-27-011-22W1, 854.2 m (2802.5'). D) Peloidal dolopackstone-dolograinstone showing abundant moldic/pinpoint porosity (p). 16-26-24-10W1, 9.60 m (31.5').

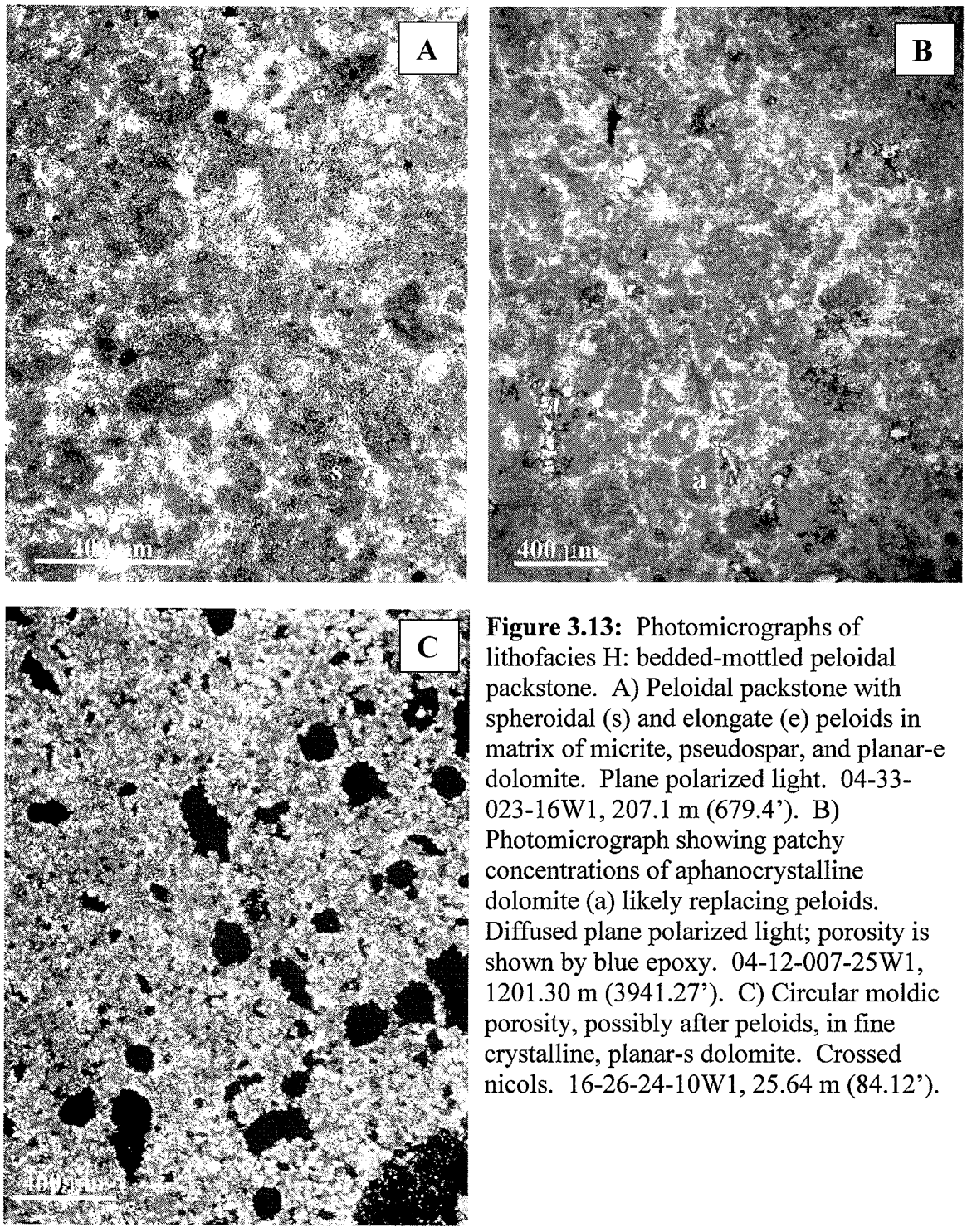


Figure 3.13: Photomicrographs of lithofacies H: bedded-mottled peloidal packstone. A) Peloidal packstone with spheroidal (s) and elongate (e) peloids in matrix of micrite, pseudospar, and planar-e dolomite. Plane polarized light. 04-33-023-16W1, 207.1 m (679.4'). B) Photomicrograph showing patchy concentrations of aphanocrystalline dolomite (a) likely replacing peloids. Diffused plane polarized light; porosity is shown by blue epoxy. 04-12-007-25W1, 1201.30 m (3941.27'). C) Circular moldic porosity, possibly after peloids, in fine crystalline, planar-s dolomite. Crossed nicols. 16-26-24-10W1, 25.64 m (84.12').

Porosity in this lithofacies is highly variable ranging between 1 and 35% including intercrystalline, moldic, fracture, micro-vuggy, pinpoint, and vuggy porosity which can exceed 4 cm size but is often occluded. Generally, porosity is proportional to the degree of dolomitization with very low porosity associated with dolomitic limestone intervals and high intercrystalline porosity associated with a predominance of planar-e dolomite (Fig. 3.13). Pores may be occluded by quartz, blue chalcedony, and medium to coarse crystalline anhydrite and equant calcite. Lithofacies H is not readily distinguishable from other Upper Winnipegosis Member lithofacies on petrophysical well logs.

3.9.2 Interpretation

Lithofacies H is interpreted to represent deposition in a subtidal setting between fair-weather and storm wave base in open to slightly restricted waters. The evidence for a lime mud matrix and the articulated nature of some fossils support a low energy environment. Non-bituminous lithologies in lithofacies H are interpreted to have been deposited in well-circulated waters. However, locally restricted conditions are supported by bituminous content and skeletal dolofloatstone beds containing *Amphipora* molds (cf. Flügel, 2004). The presence of burrowing/bioturbation suggests that oxygen deficiency (dysoxia) was more important than elevated salinity (cf. Enos, 1983). Rare dolograinstone beds may represent localized shoaling where current or wave agitation was sufficient enough to winnow or prevent carbonate mud from settling or alternatively they may be tempestite deposits (cf. Harris, 1985; Jones and Desrochers, 1992).

Lithofacies H is lithologically similar in part to the peritidal facies recognized by Ehrets and Kissling (1987) in the Winnipegosis Formation in North Dakota, which was interpreted as restricted, shallow subtidal through supratidal deposits, as well as the *Amphipora* wackestone and peloid packstone lithofacies recognized by Perrin (1987) which were interpreted to have been deposited in slightly restricted marine conditions and subtidal, moderate to high energy, normal marine conditions respectively. It is also similar in part to the *Amphipora* zone in the Upper Winnipegosis Member in Saskatchewan recognized by Jones (1965) for which no interpretation was provided.

3.10 Lithofacies I: Intraclast Floatstone

3.10.1 Description

Lithofacies I consists of medium to very thick beds of poorly sorted, intraclast floatstones which are pervasively dolomitized. The contacts are sharp and the beds are not laterally extensive. Intraclasts range from dolomudstone to dolograinstone in composition and are 0.01 cm to >5 cm in diameter (Fig. 3.14). They are equant to elongate and are subangular to rounded. Intraclasts consist of fine crystalline, planar-s and aphanocrystalline dolomite. Rare intraclasts are completely replaced by anhydrite or have been partially pyritized.

Matrix composition is variable, consisting of peloidal to skeletal dolopackstone or dolomudstone, and is similar lithologically to the lithofacies underlying and overlying lithofacies I. Peloids occur as molds or are replaced by aphanocrystalline dolomite. The matrix consists of very fine to medium crystalline, non-planar, planar-s, and planar-e

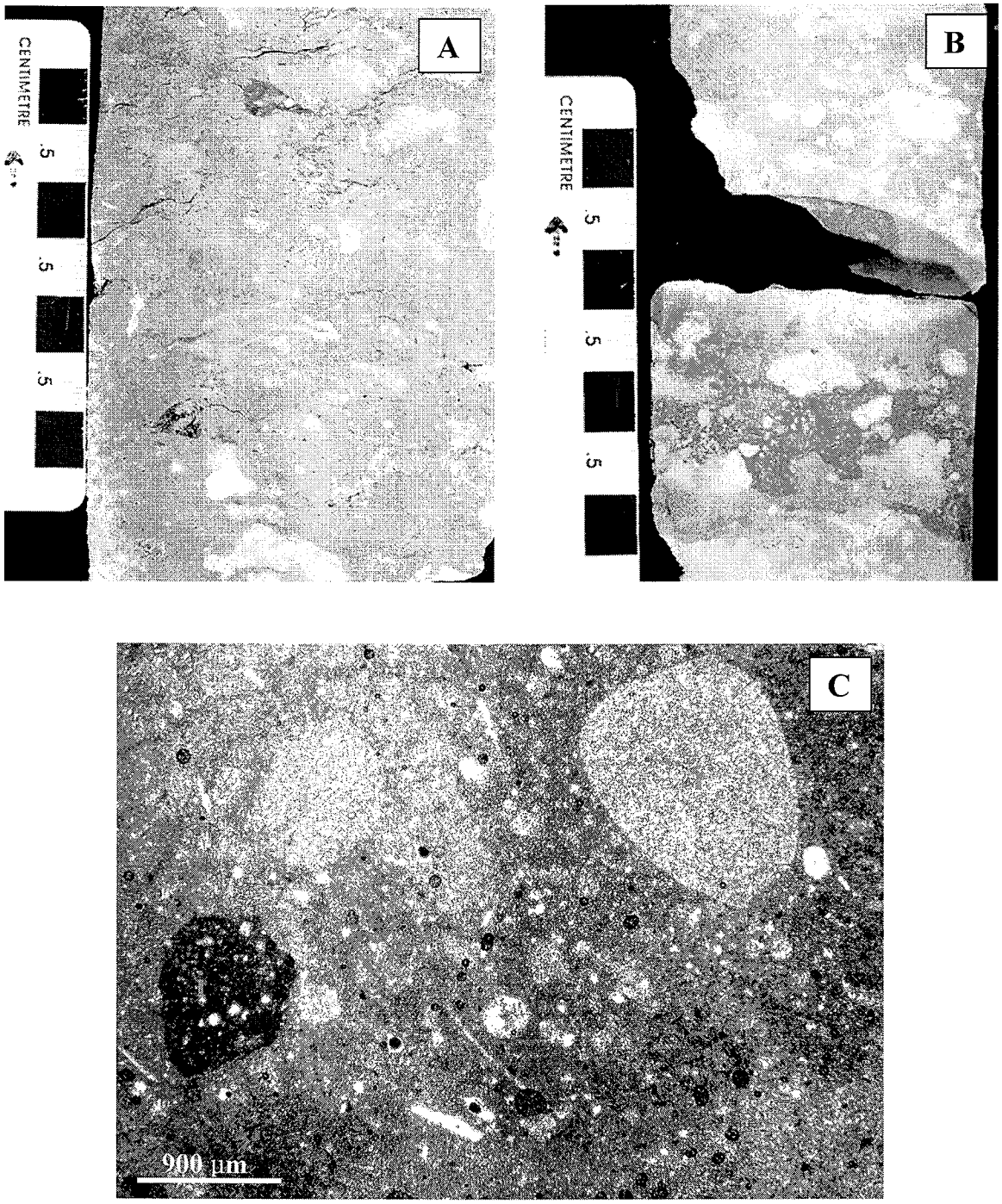


Figure 3.14: Lithofacies I: intraclast floatstone. A) Core photograph showing intraclast dolofloatstone with a peloidal-skeletal dolopackstone matrix. 07-08-011-29W1, 1378.15 m (4521.5'). B) Core photograph showing intraclast dolofloatstone with dolomudstone matrix. 04-33-023-16W1, 209.58 m (687.6'). C) Photomicrograph of sample shown in (B) showing dolomudstone intraclasts (i) in a dolomudstone matrix with unidentifiable skeletal remnants. Plane polarized light.

dolomite. Bituminous and argillaceous content in the floatstone matrix is variable but generally low. Identifiable skeletal allochems include crinoid ossicles, and remnants of probable brachiopods and udoteacean algae.

Porosity occurs predominantly in the intraclast matrix, ranges between 5 and 15%, and includes vuggy, micro-vuggy, intercrystalline, fracture, and moldic porosity. Lithofacies I does not occur in sufficient thickness and does not differ enough from adjacent lithofacies to be distinguished on petrophysical well logs.

3.10.2 Interpretation

Lithofacies I is interpreted to be either tempestites or subtidal debris flow deposits (debrites), which may also have a storm influence (cf. Cook and Mullins, 1983; Coniglio and Dix, 1992; Jones and Desrochers, 1992). The coarse-grained and poorly sorted nature of lithofacies I indicates deposition under high-energy conditions. The discrete beds with abrupt contacts and their laterally restricted occurrence suggest high energy events of short duration that reworked consolidated mudstone and grainstone beds.

3.11 Lithofacies J: Bituminous Skeletal Wackestone-Floatstone

3.11.1 Description

Lithofacies J consists of dark-brown to black, bituminous skeletal dolowackestone to dolofloatstone, which is medium to very thickly bedded (Fig. 3.15). It was observed in only one well in this study (04-17-019-29W1, 958.6-969.3 m [3145-3180']).

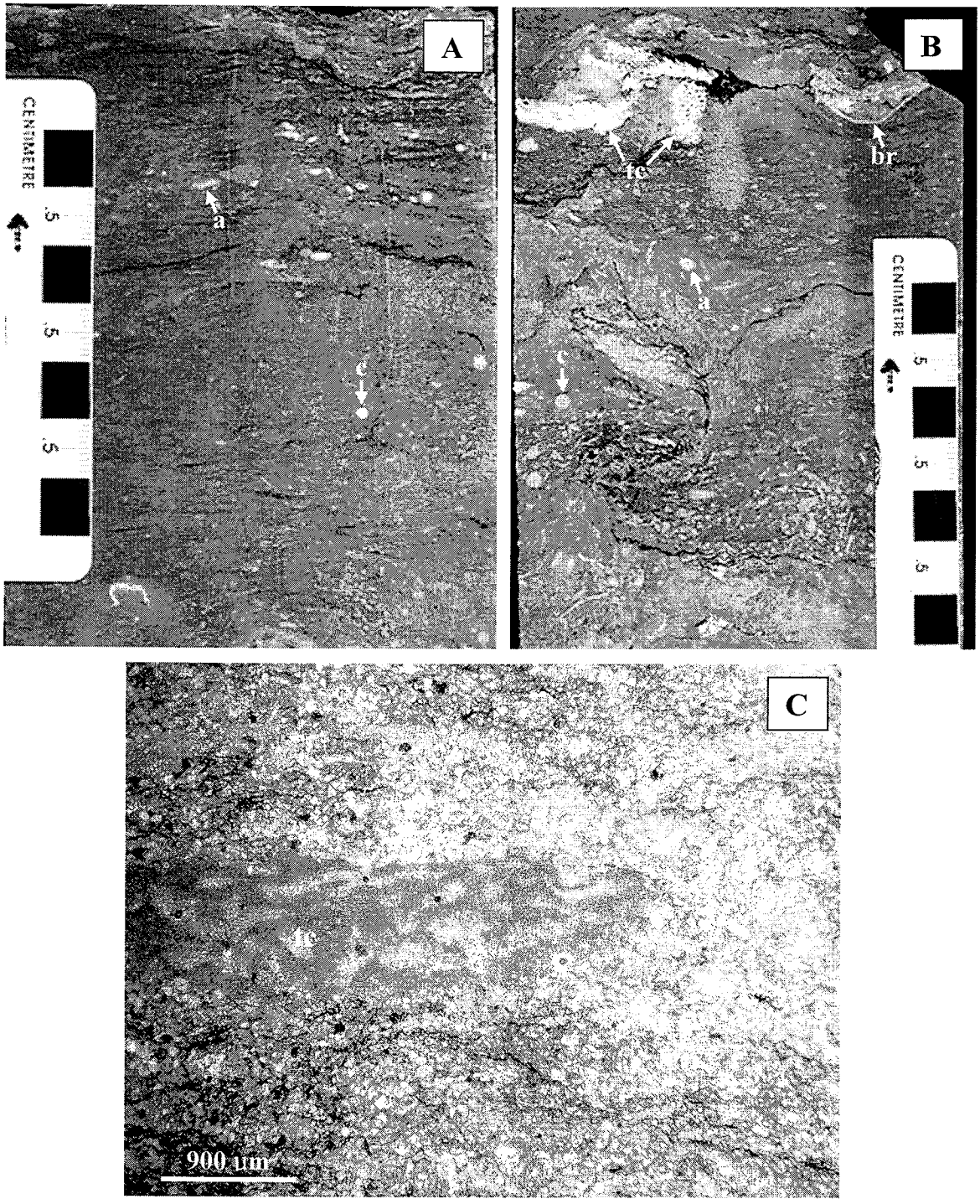


Figure 3.15: Lithofacies J: bituminous skeletal wackestone-floatstone. A) Core photograph showing bituminous skeletal dolowackestone; bioclasts include crinoids (c) and *Amphipora* (a). 04-17-019-29W1, 967.93 m (3175.65'). B) Core photograph showing bituminous skeletal dolowackestone grading upward to dolofloatstone; bioclasts include thamnoporid corals (tc), brachiopods (br), crinoids (c), and *Amphipora* (a). 04-17-019-29W1, 968.73 m (3178.25'). C) Photomicrograph showing thamnoporid coral (tc) in bituminous dolomudstone matrix. Plane polarized light. 04-17-019-29W1, 961.83 m (3155.63').

Allochems comprise 10-20% of this lithofacies. Bioclasts are often poorly preserved (Fig. 3.15A) and where identifiable consist of *Amphipora*, thamnoporid corals, crinoid ossicles, and brachiopods including rare molds of large, probable stringocephalids which are occluded by anhydrite cement. Sub-rounded dolomudstone intraclasts, 3 to 4 cm in diameter, also occur within the uppermost intervals. The mud matrix consists of fine to medium crystalline, non-planar dolomite in which the bituminous content occurs in microstylolite swarms (Fig. 3.15C) and gradually decreases upwards. Porosity is less than 1% and includes intercrystalline and scattered pinpoint porosity.

3.11.2 Interpretation

Lithofacies J is interpreted to have been deposited in a semi-restricted, quiet subtidal setting, possibly lagoonal, as evidenced by the abundance of thamnoporid corals and *Amphipora* in a bituminous muddy matrix (cf. Murray, 1966; James and Bourque, 1992; Wendte, 1992; Flügel, 2004). Restricted settings typically have elevated salinity, depleted nutrients and oxygen, and/or elevated temperatures (e.g., Enos, 1983). The gradual upwards decrease in organic matter is interpreted to reflect progressive shallowing and/or more open conditions.

3.12 Lithofacies K: Peloidal-Udoteacean Packstone

3.12.1 Description

Lithofacies K consists of tan to light brown, peloid-udoteacean packstone to grainstone, with packstone being the dominant lithology (Fig. 3.16, 3.17). The very thin to very

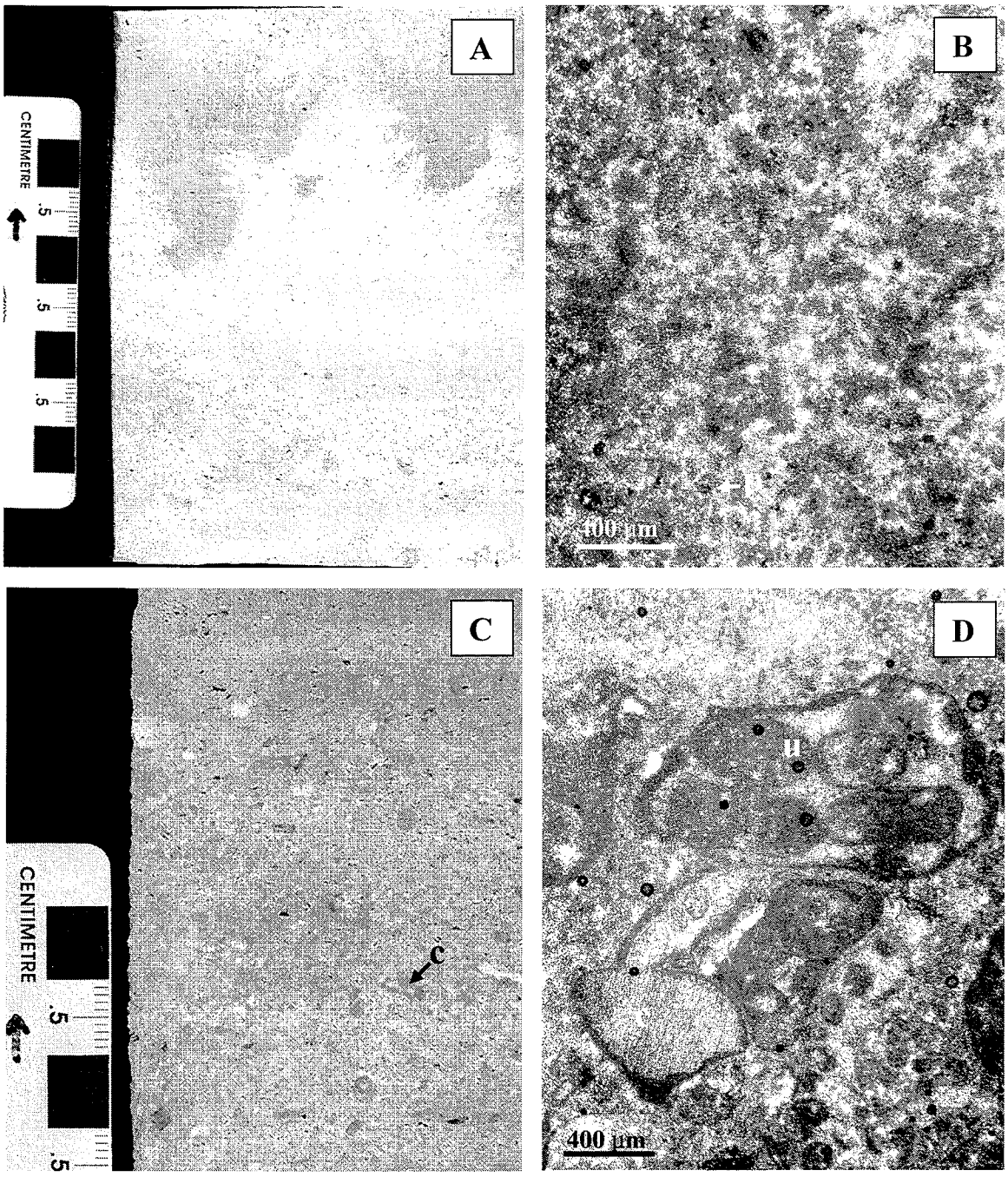


Figure 3.16: Lithofacies K: peloidal-udoteacean packstone. A) Core photograph showing peloidal-udoteacean dolopackstone. 14-13-009-28W1, 1303.90 m (4277.88'). B) Photomicrograph showing peloids (p) replaced by aphanocrystalline dolomite in peloidal dolopackstone. Plane polarized light; porosity is shown by blue epoxy. 14-13-009-28W1, 1303.80 m (4277.55'). C) Core photograph showing crinoid ossicles (c) in peloidal-udoteacean dolopackstone. 05-03-004-25W1, 1365.64 m (4480.45'). D) Photomicrograph showing dolomitized fragments of udoteacean algae (u) and crinoids (c) in a muddy (peloidal?) matrix. Plane polarized light; porosity is shown by blue epoxy. 04-17-019-29W1, 968.34 m (3177').

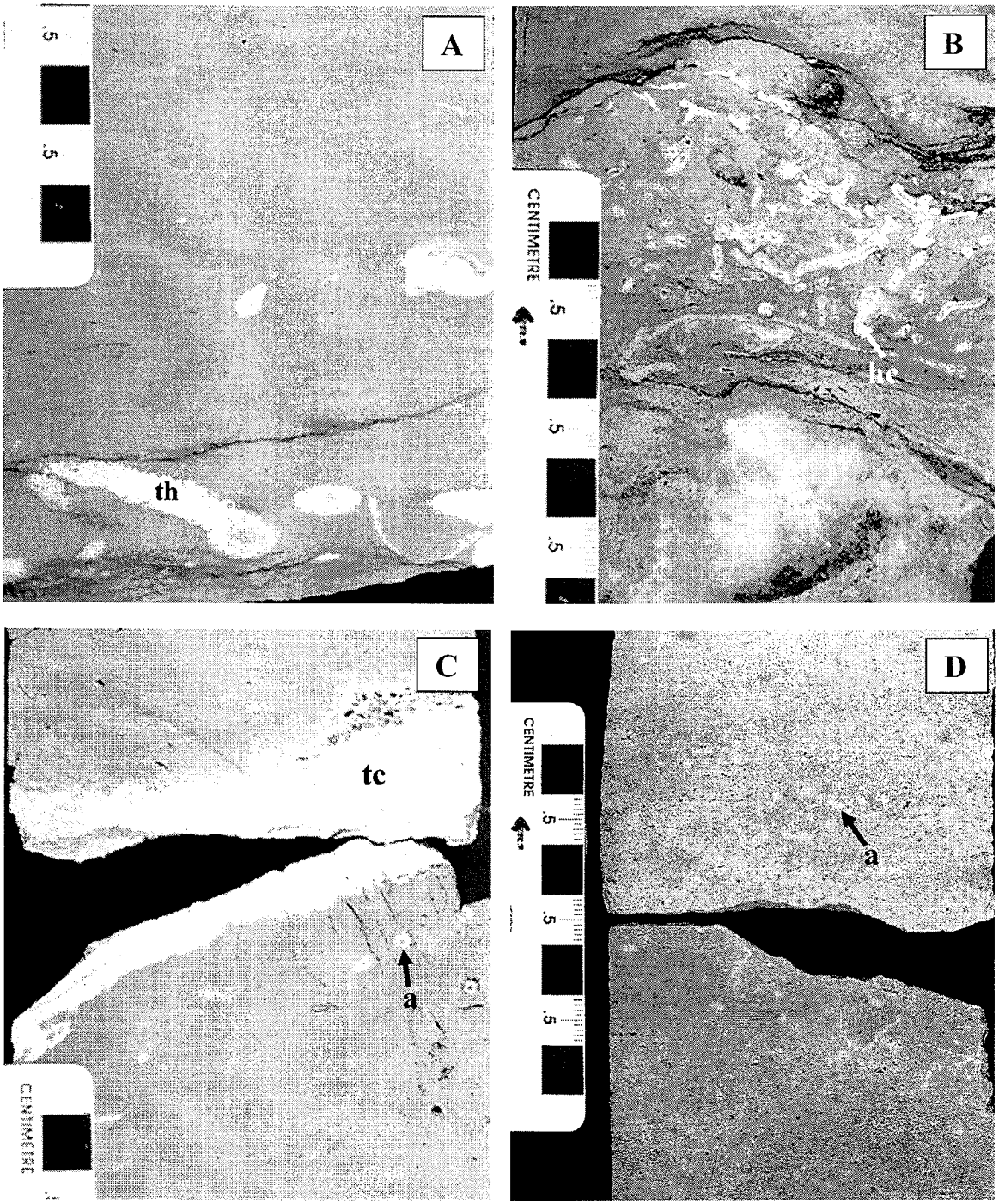


Figure 3.17: Core photographs of Lithofacies K: peloidal-udoteacean packstone. A) A very thin dolofloatstone bed of thamnoporid corals (th) in peloidal-udoteacean dolopackstone. 04-17-019-29W1, 956.4 m (3137.8'). B) A thin dolofloatstone bed of halysitoid (chain-like) tabulate corals (hc) in peloidal-udoteacean dolopackstone. An anhydrite nodule occurs below the bed. 04-17-019-29W1, 958.47 m (3144.6'). C) A tabular coral (tc) and *Amphipora* coenostea (a) in peloidal-udoteacean dolopackstone. 04-17-019-29W1, 955.72 m (3135.58'). D) Fragments of *Amphipora* coenostea (a) in peloidal-udoteacean dolopackstone-dolograinstone. 05-03-004-25W1, 1354.22 m (4443').

thick beds are massive to faintly mottled. Beds with low bituminous content are rare and show some burrowing.

Lithofacies K is pervasively dolomitized and composed of aphanocrystalline and very fine to coarse crystalline, non-planar, planar-s, and planar-e dolomite, which has largely destroyed the primary texture. In some samples, relicts of peloids and skeletal allochems remain (Fig. 3.16B). Identifiable skeletal allochems include udoteacean algae (*Lancicula* and/or *Litanaia*?) and crinoids (Figs. 3.16C, D). Corals are mostly thamnoporids (Fig. 3.17A); however, halysitoid (chain-like) and tabular tabulate corals (Fig. 3.17B, C), and solitary rugose corals are also present. Corals are rarely abundant enough to constitute skeletal floatstone beds. Fragments of *Amphipora* coenostea occur in some beds (Fig. 3.17C, D) and rare probable tabular stromatoporoids, which are poorly preserved, are also present. Other minor skeletal allochems include ostracods, brachiopods, and styliolinids; minor non-skeletal allochems are sub-rounded to rounded intraclasts.

Porosity in this lithofacies ranges between 3 and 20% and includes intercrystalline, micro-vuggy, pinpoint, vuggy, moldic, intraskeletal, and rare fracture porosity. The highest porosities are generally associated with planar-e dolomite. Moldic porosity appears to be mostly after crinoid ossicles and pinpoint pores appear to be moldic after peloids. Vugs are mostly <1 cm but rarely up to 3 cm and some are lined with dolomite rhombs or occluded by tan, chalky dolomite. Anhydrite is the most common cement and also occurs as nodules, 3 to 6 cm in size (Fig. 3.17B).

3.12.2 Interpretation

Lithofacies K is interpreted to have been deposited in an open, subtidal environment below fair-weather wave base but within the photic zone. This interpretation is based mainly on the abundance of udoteacean algae and an assumption that extant calcareous udoteaceans may be insightful for the interpretation of fossil forms. Recent udoteaceans are found in tropical marine waters of normal salinity where they colonize sand and mud substrates (Wray, 1977). They are most abundant and diverse in water depths of only a few meters but may be found down to at least 100 m. However, their fragile construction precludes habitation above wave base and also facilitates postmortem disintegration resulting in lime mud generation (e.g., Flügel, 2004). The presence of tabular and dendroid corals and stromatoporoids in lithofacies K is consistent with the interpretation of a muddy substrate in an open and quiet setting (cf. Wilson, 1975). Localized mottling is likely due to infaunal activity.

Lithofacies K is lithologically similar to the codiacean algae, calcisphere packstone lithofacies recognized by Perrin (1987) in the Upper Winnipegosis Member in North Dakota; and the peloid-codiacean algae mudstone-wackestone facies and the interior facies recognized by Minto (1996) and Teare (1990), respectively, in the Upper Winnipegosis Member in northern Devonian outcrop belt of Manitoba. It is also similar to the facies U1 and the buildup facies A: peloid/codiacean algal grainstone facies recognized by Stanford (1989) and Martindale and MacDonald (1989), respectively, in the Upper Winnipegosis Member in southeastern Saskatchewan. Where interpretations were provided, these reefal lithofacies were interpreted as having been deposited in an

open, shallow marine setting, below fair-weather wave base, with the exception of Martindale and MacDonald (1989) who interpreted the facies to represent a high energy shoal setting.

3.13 Lithofacies L: Stromatoporoid Floatstone

3.13.1 Description

Lithofacies L consists of mottled to crudely thin to medium bedded, skeletal dolofloatstone (Fig. 3.18). Bioclasts comprise 10 to 15% of this lithofacies and are predominantly angular to sub-rounded, stromatoporoid fragments which range from 2 mm to > 8 cm. Where the fragments are large enough to observe growth habit, the stromatoporoids appear to be bulbous and encrusting or tabular forms (Fig. 3.18A, B). Stromatoporoids are now composed of aphanocrystalline and fine to medium crystalline, planar-s and planar-e dolomite and some have been partially replaced with anhydrite. Accessory bioclasts include large articulated and disarticulated stringocephalid valves, solitary rugose corals, and *Amphipora* fragments. Many of the larger elongate bioclasts are oriented parallel to bedding. The matrix is brown, grey, or tan, peloidal-skeletal dolopackstone or dolograinstone which is locally mottled and lithologically similar to lithofacies K.

Porosity in lithofacies L is highly variable ranging between 0 and 8% and consists of intercrystalline, pinpoint (possibly moldic), intra-skeletal, and fracture porosity which are typically occluded by coarse crystalline anhydrite cement.

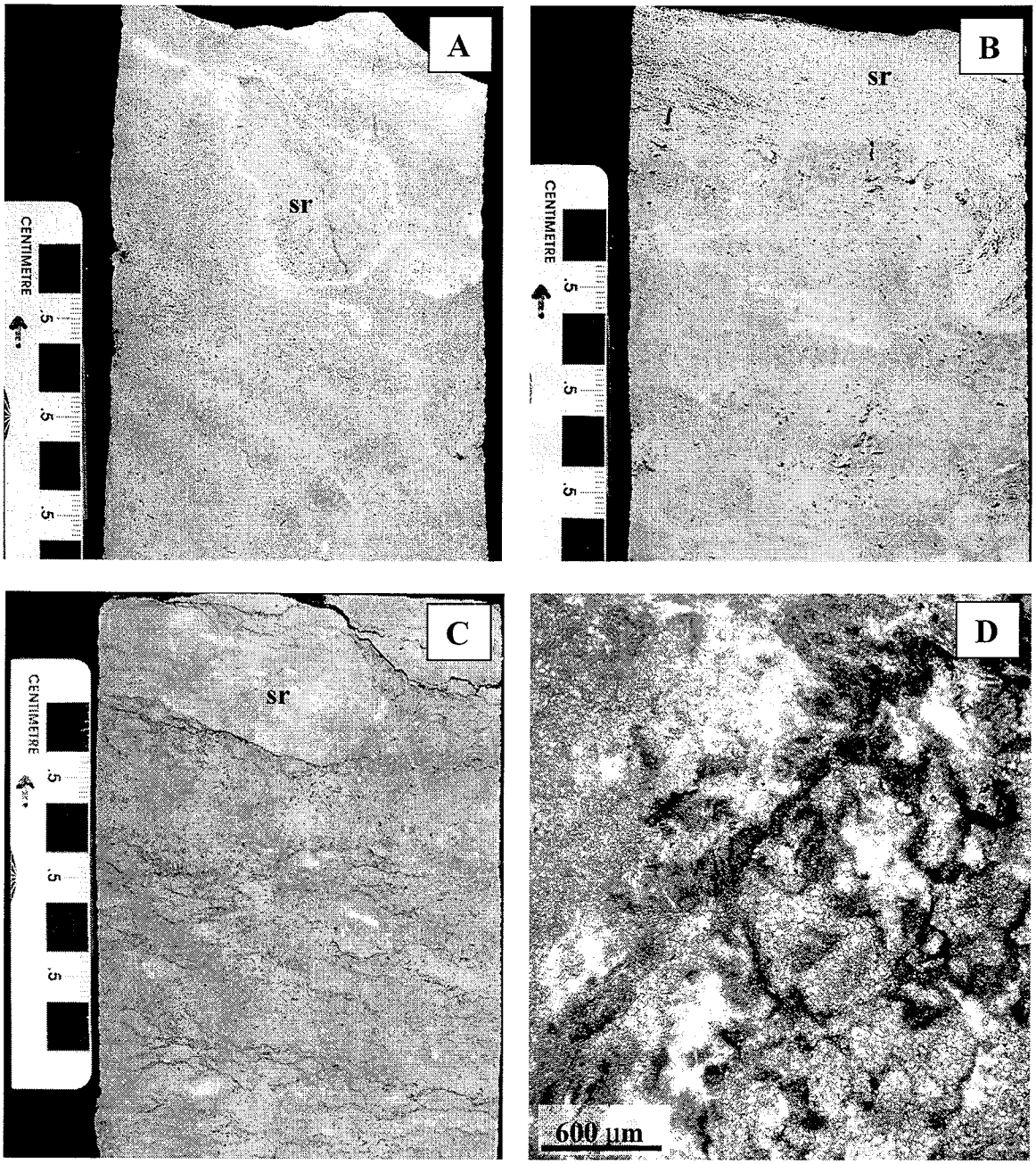


Figure 3.18: Lithofacies L: stromatoporoid floatstone. A) Core photograph showing stromatoporoid fragment (sr) with bulbous growth habit. 05-03-004-25W1, 1348.46 m (4424.11'). B) Core photograph showing stromatoporoid fragment (sr) with encrusting growth habit. 05-03-004-25W1, 1346.85 m (4418.8'). C) Core photograph showing poorly preserved stromatoporoid fragment (sr). 08-13-005-29W1, 1522.09 m (4993.73'). D) Photomicrograph showing very poorly preserved stromatoporoid with skeletal elements altered to aphanocrystalline dolomite. Plane polarized light. 08-13-005-29W1, 1521.57 m (4992').

3.13.2 Interpretation

Lithofacies L is interpreted to have been deposited in an open subtidal setting below fair-weather wave base based on the presence of stromatoporoids, and the absence of bedforms and bituminous content (cf. Wendte, 1992). The large size and roundness of bioclasts in lithofacies L suggest some reworking and short-distance transport, possibly shed from a shallower and higher energy environment. The dolopackstone matrix in lithofacies L may represent background sedimentation or may have been transported as well.

Lithofacies L is lithologically similar in part to reefal lithologies found in the stromatoporoid, tabulate coral boundstone lithofacies and the coral-stromatoporoid rim subfacies recognized by Perrin (1987) and Ehrets and Kissling (1987), respectively, in the Upper Winnipegosis Member in North Dakota, and to the stromatoporoid-coral floatstone facies recognized by Minto (1996) in the Upper Winnipegosis Member in the northern Devonian outcrop belt of Manitoba. Where interpretations were provided, these lithofacies were interpreted to have been deposited in open, agitated, shallow-marine conditions.

3.14 Lithofacies M: Coral-Stromatoporoid Rudstone-Framestone

3.14.1 Description

Lithofacies M occurs as thin to very thick beds of dolorudstone and possible doloframestone composed of stromatoporoids and tabulate corals. Skeletal fragments are angular to subrounded and range from 1 mm to greater than 8 cm in size (Fig. 3.19, 3.20).

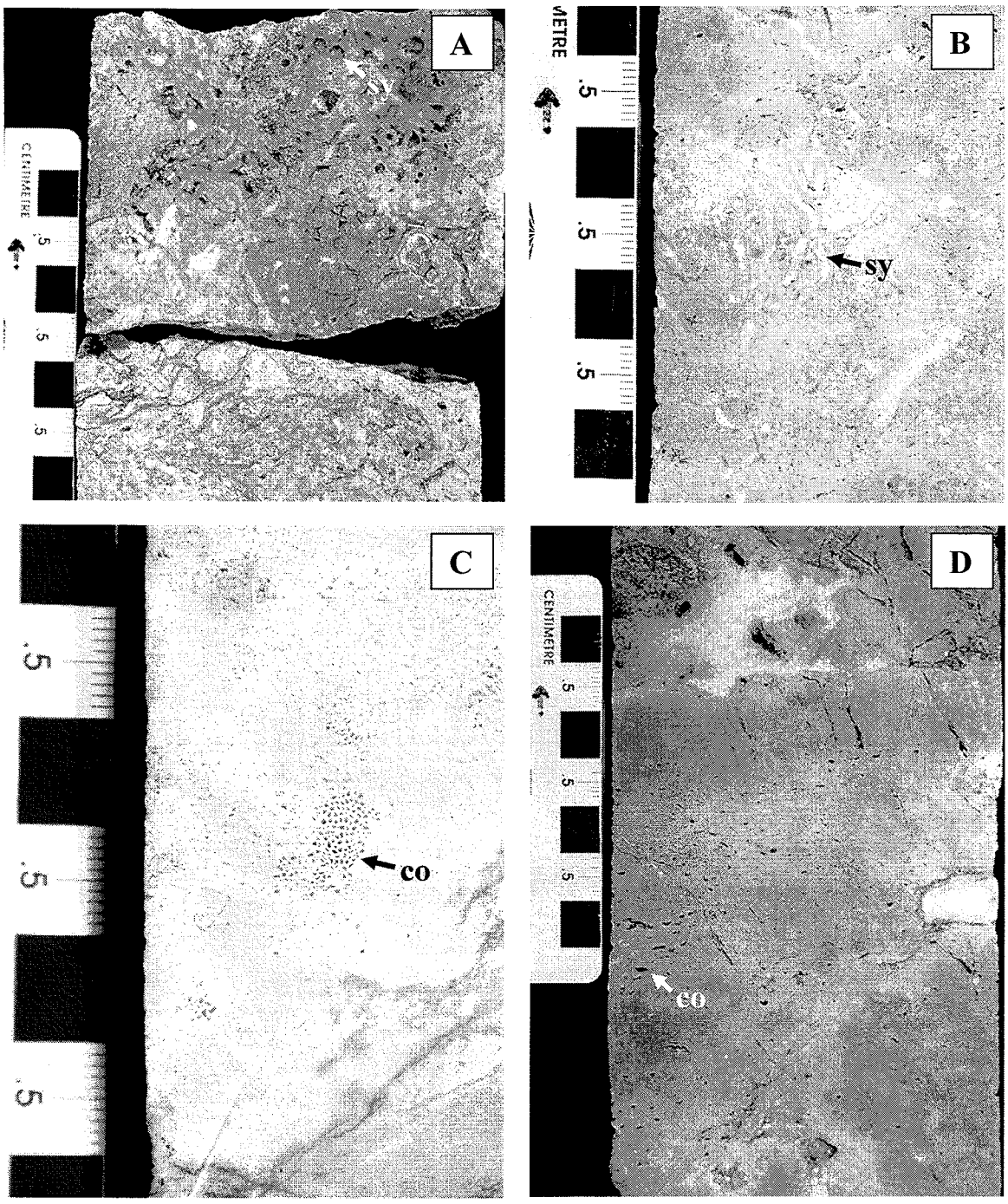


Figure 3.19: Core photographs of lithofacies M: coral-stromatoporoid rudstone-framestone. A) Syringoporid or "organ-pipe" type tabulate corals (sy) lying parallel to bedding. 16-33-005-24W1, 1120.59 m (3676.5'). B) Syringoporid corals (sy) in growth position. 05-03-004-25W1, 1353.92 m (4442'). C) Probable favositid tabulate coral showing open corallites (co) in transverse section. 11-29-001-25W1, 1521.56 m (4992'). D) Massive tabulate coral with partially occluded corallites (co) transected tangentially. 08-13-005-29W1, 1525.48 m (5004.9').

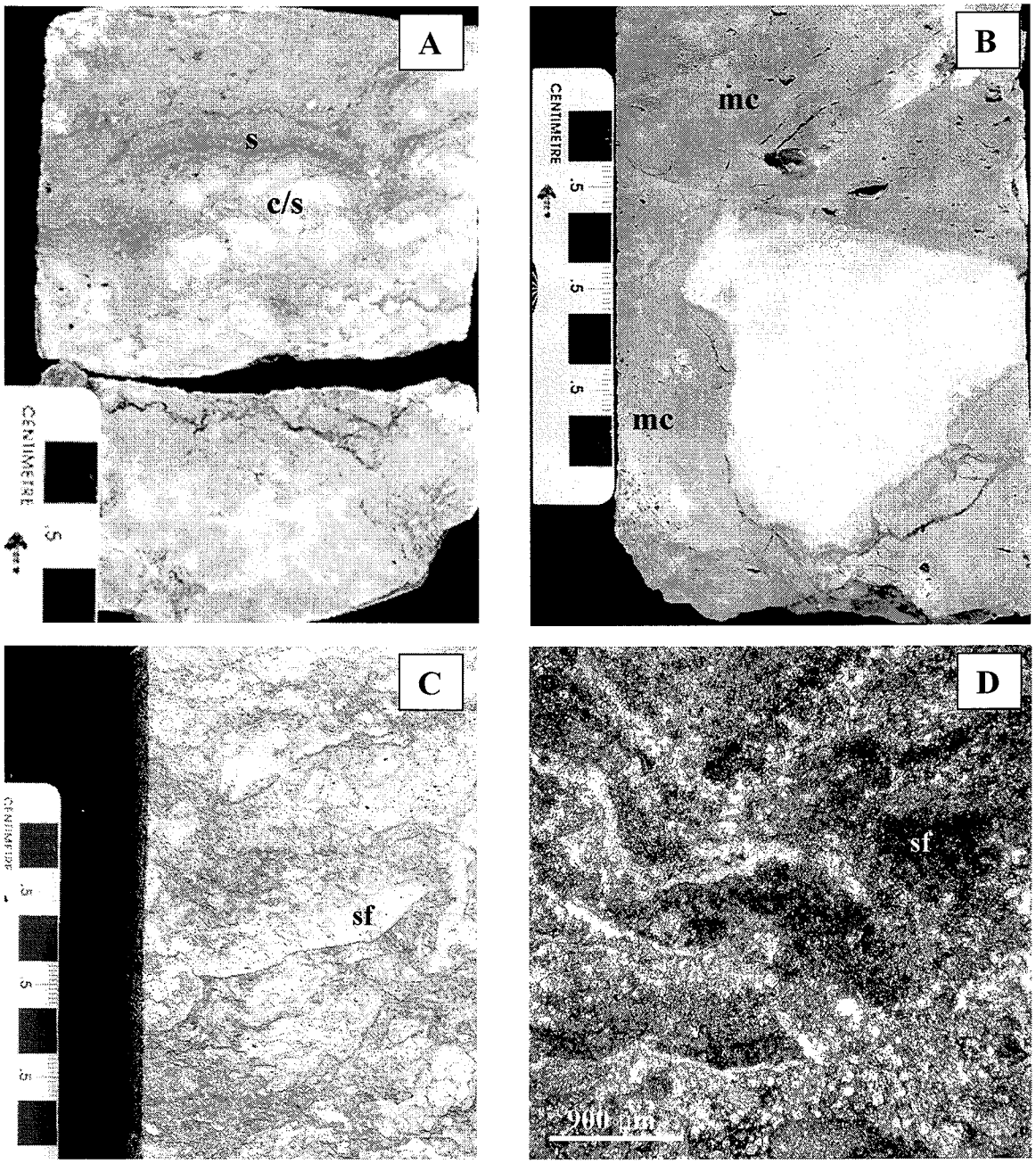


Figure 3.20: Lithofacies M: coral-stromatoporoid rudstone-framestone. A) Core photograph showing possible stromatoporoids (s) encrusting unidentifiable corals or stromatoporoids (c/s). 16-18-018-29W1, 961.2 m (3153.5'). B) Core photograph showing massive tabulate corals (mc) and interparticle porosity occluded by anhydrite cement. 08-13-005-29W1, 1524.32 m (5001'). C) Core photograph showing dolorudstone consisting of unidentifiable skeletal fragments (sf) in a slightly argillaceous/bituminous packstone? matrix. Some fragments show organized pinpoint porosity, possibly representing partially occluded corallites. 10-09-001-28W1, 1742.60 m (5717.2'). D) Photomicrograph of sample shown in (C) showing poorly preserved dolorudstone consisting of skeletal fragments (sf). Plane polarized light; porosity is shown by blue epoxy.

Some of the larger fragments suggest massive, bulbous, encrusting or tabular growth forms. Preserved internal structures in tabulate corals include round and oval corallites, 1 to 5 mm in diameter, suggesting fasciculate syringoporid or "organ-pipe" corals. They are commonly oriented parallel to bedding but rare occurrences of syringoporid corals are vertically oriented and appear to be in situ (Fig. 3.19A, B). Other identifiable coral fragments include favositid and rare thamnoporid corals (Fig. 3.19C). *Amphipora* fragments are locally encrusted by massive tabulate corals.

Corals and stromatoporoids have generally been dolomitized to aphanocrystalline to medium crystalline, non-planar dolomite (Fig. 3.20D). They cannot be readily differentiated where internal structure is not preserved. Skeletal fragments are commonly randomly oriented but in places they are arranged as interlocking fragments resembling shattered coral or stromatoporoid heads. Elongate, wavy forms, which locally span the width of the core, morphologically resemble encrusting or tabular stromatoporoids (Fig. 3.20A).

The matrix consists of dolopackstone, which may be slightly argillaceous or bituminous, and is generally more coarsely crystalline and porous than the rudstone bioclasts. Dolomite includes fine to medium crystalline, planar-s, planar-e, and non-planar types. Allochems include molds and relicts of possible peloids and brachiopod, crinoid, bryozoan, and ostracod fragments. The matrix is generally similar lithologically to lithofacies directly underlying and overlying lithofacies M. Where the matrix is absent, interparticle porosity is occluded by coarsely crystalline anhydrite cement (Fig. 3.20B).

Porosity is variable, ranging from 3 to 15%, and includes intercrystalline, moldic, fracture, micro-vuggy, vuggy, pinpoint, interparticle, and intraskeletal porosity. Coarsely crystalline anhydrite commonly occludes pore spaces and locally replaces dolomite.

3.14.2 Interpretation

Lithofacies M is interpreted to have been deposited in a high-energy, subtidal environment above fair-weather wave base. The relatively large size of the bioclasts in lithofacies M and the occurrence of corals and stromatoporoids in growth position suggest that postmortem transport of skeletal components was minimal. Corals and stromatoporoids, which dominate the faunal assemblage of lithofacies M, are consistent with normal marine conditions (cf. Heckel, 1972). Both are sessile benthos, and as such their morphology or growth habit reflects an adaptation to ecologic variables such as current activity and sediment accumulation (e.g., Wilson, 1975; Bourque and James, 1992). It is often not possible to determine growth habit because of fragmentation and poor preservation but it is evident that a variety of habits are represented in lithofacies M. The most common habits appear to be massive or encrusting, which is typical of a high energy setting above fair-weather wave base. However, the basket-shaped morphology of favositid corals is typical of moderate to low current energy conditions and fasciculates, such as *Syringopora*, are found in more protected areas.

Lithofacies M is lithologically similar to the stromatoporoid, tabulate coral boundstone lithofacies and the coral-stromatoporoid subfacies recognized by Perrin (1987) and Ehrets and Kissling (1987), respectively, in the Upper Winnipegosis Member in North Dakota.

It is also similar to the stromatoporoid coral-crinoid floatstone and rudstone facies, the organic rim facies, and the stromatoporoid-coral rudstone-framestone facies recognized by Rosenthal (1988), Teare (1990), and Minto (1996), respectively, in the Upper Winnipegosis Member in the northern Devonian outcrop belt of Manitoba and also to the coral/algal framestone facies recognized by Martindale et al. (1991) in southeastern Saskatchewan. Where interpretations were provided, these reefal lithofacies were interpreted to have been deposited in open, agitated, shallow-marine conditions.

3.15 Lithofacies N: Laminated Mudstone-Peloidal Packstone.

3.15.1 Description

Lithofacies N consists of thinly interlaminated to thinly interbedded mudstone and peloidal packstone, which is pervasively dolomitized (Fig. 3.21, 3.22). Bedding plane orientations vary from horizontal to a maximum apparent dip of 21° and no cross-bedding was observed. Laminae/beds are generally tan or light brown and contacts are flat to wavy and commonly stylolitized (Fig. 3.21A, 3.22B). Minor, slightly bituminous laminae/beds are present (Fig. 3.21B). Local small-scale, high-angle normal faults offset laminae by 2 mm to 1 cm.

Lithofacies N has been dolomitized to fine to medium crystalline, planar-s, planar-e, and non-planar dolomite (Fig. 3.22). Aphanocrystalline dolomite has a patchy distribution occurring mostly in discrete laminations and appears to have replaced peloids (Fig. 3.22C). Skeletal allochems are rare and include probable tabular stromatoporoids which are 1 to 3 cm thick and have irregular margins (Fig. 3.22A). Rare anhydrite laths are interspersed amongst dolomite crystals (Fig. 3.22D).

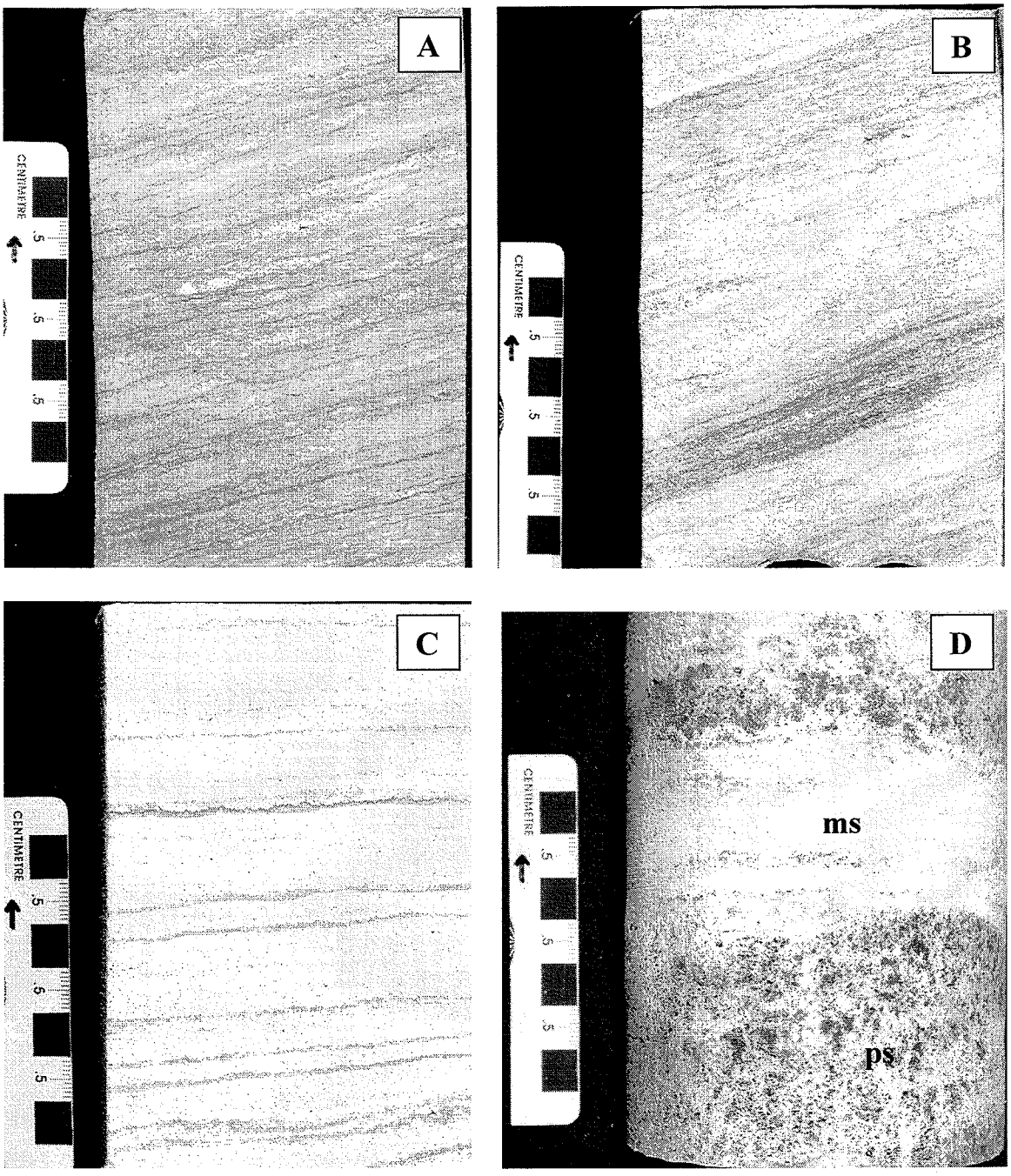


Figure 3.21: Core photographs of lithofacies N: laminated mudstone-peloidal packstone. A) Dolomudstone with dipping laminae. Contacts are accentuated by microstylolites. 11-29-001-25W1, 1520 m (4986.95'). B) Peloidal packstone with thin bituminous beds (dark brown in photo). 10-09-001-28W1, 1729.90 m (5675.52'). C) Faint laminae in non-bituminous dolomudstone. 14-13-009-28W1, 1291.80 m (4238.18'). D) Outer surface of core where mud infiltrate accentuates peloidal dolopackstone (ps) interbedded with dolomudstone (ms). 14-13-009-28W1, 1284.50 m (4214.23').

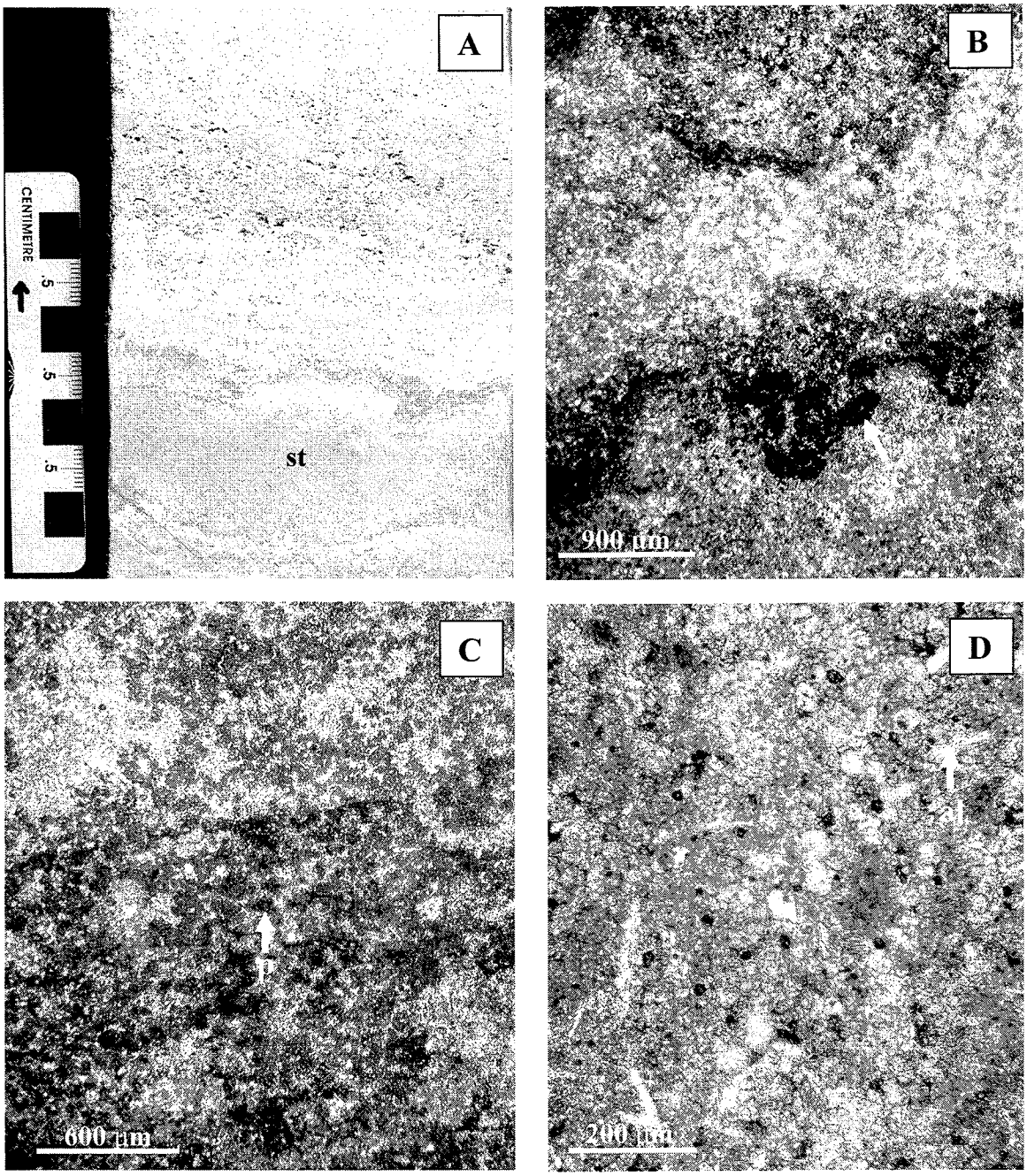


Figure 3.22: Lithofacies N: laminated mudstone-peloidal packstone. A) Core photograph showing dolopackstone and probable tabular stromatoporoid (st) with no internal structure preserved. 14-13-009-28W1, 1282.60 m (4208'). B) Photomicrograph showing wavy laminae with stylocumulate (sc) at contacts. Plane polarized light; porosity is shown by blue epoxy. 14-13-009-28W1, 1285.30 m (4216.86'). C) Photomicrograph showing patchy aphanocrystalline dolomite which probably replaced peloids (p). Plane polarized light; porosity is shown by blue epoxy. 14-13-009-28W1, 1292 m (4238.84'). D) Photomicrograph showing anhydrite laths (al) in a dolomitized muddy-peloidal matrix. Crossed nicols; porosity is shown by blue epoxy. 14-13-009-28W1, 1290.60 m (4234.25').

Porosity is highly variable, ranging between 5 and 30% and including intercrystalline, microvuggy, pinpoint (possible moldic), and fracture porosity. Minor coarse crystalline anhydrite cement, which locally contains scattered opaque minerals, occludes pore spaces; bitumen also occurs locally in pore spaces.

3.15.2 Interpretation

Lithofacies N is interpreted to have been deposited in a moderately deep-subtidal, slope setting with slightly restricted conditions. Muddy sediment indicates quiet conditions that would have permitted mud to settle from suspension. A slope setting is indicated by the generally inclined bedding plane. Low bituminous content, an absence of infaunal bioturbation as indicated by the good preservation of laminae, and rare benthos would suggest that the environment was dysoxic (cf. Tyson, 1987). Burrowers may also have been inhibited by rapidly shifting substrates and/or high sedimentation rates as supported by the fact that the bedding plane often changes orientation up-section and by the presence of small-scale normal faults, which may be growth faults (cf. Heckel, 1972).

Lithofacies N is lithologically similar to the laminated mudstone unit recognized by Gendzwill and Wilson (1987) in the Upper Winnipegosis Member in south central Saskatchewan, which was not interpreted, and to the laminated subfacies of the flank facies recognized by Teare (1990) in the Upper Winnipegosis Member from the northern end of the Devonian outcrop belt in Manitoba, which was interpreted as a combination of debris flows and pelagically-derived organic matter deposited in anoxic conditions.

3.16 Lithofacies O: Microbial Bindstone

3.16.1 Description

Lithofacies O consists of tan, light brown or yellow microbial bindstone which is pervasively dolomitized. This lithofacies is composed of thin, horizontal, crenulated or crinkly laminae which may coalesce in places (Fig. 3.23). Laminae alternate between dense micritic and fenestral fabrics and are rarely grouped in sets, 1 to 1.5 cm thick (Fig. 3.23A). The original microfabric of lithofacies O is locally obscured as it has been dolomitized to aphanocrystalline and fine to medium crystalline, planar-s and planar-e dolomite (Fig. 3.23D). The only allochems in this lithofacies are very rare, solitary rugose corals and possible remnants of an agglutinated peloidal texture are visible in places (Fig. 3.23A).

Porosity in Lithofacies O is quite high (10-15%) and includes intercrystalline, pinpoint, vuggy (up to 4 mm), and fenestral porosity. Fenestrae are typically of the irregular variety, which according to Shinn (1986) is typical of grainy sediment and may indicate that the original texture was more peloidal in places than can be recognized. Locally, pore spaces are partially occluded by coarsely crystalline anhydrite cement.

3.16.2 Interpretation

Lithofacies O is interpreted to be stromatolitic in origin having formed from the trapping, binding, and cementation of carbonate sediments, dominantly mud, by cyanobacterial mats (cf. Walter, 1976). In modern marine settings, these mats commonly form by filamentous and coccoid Cyanophyta in tropical intertidal and subaerial areas that have

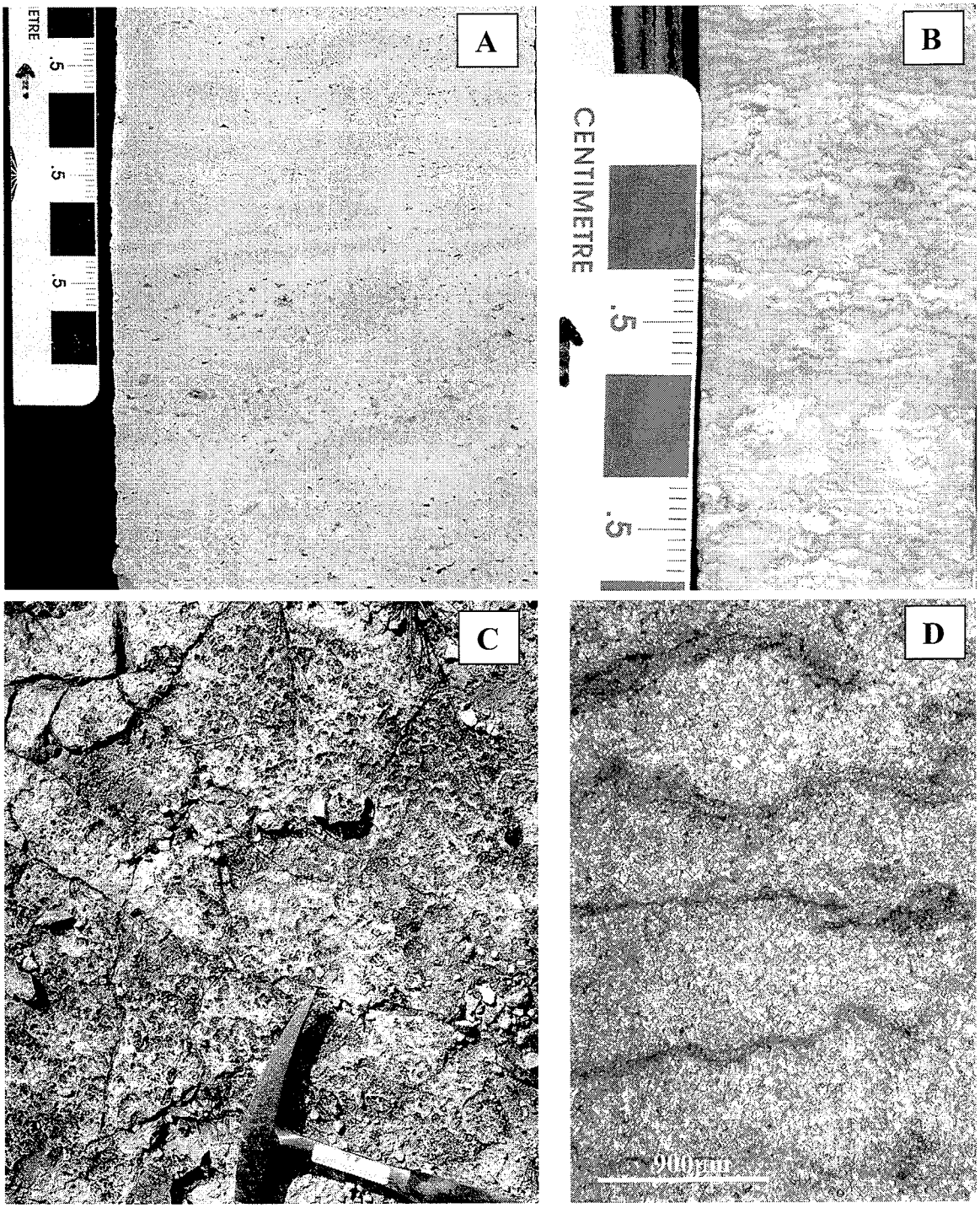


Figure 3.23: Lithofacies O: microbial bindstone. A) Core photograph showing fenestral porosity in laminae sets (above) and in agglutinated texture (below). 05-03-004-25W1, 1345.99 m (4416'). B) Core photograph showing crinkly laminated microbial dolobindstone. 12-35-24-10W1, 3.3 m (10.8'). C) Photograph showing present-day erosional surface of lithofacies O in outcrop at Rose Hill gravel pit (518030E, 5661405N); hammer for scale. D) Photomicrograph showing the stromatolitic laminations from the outcrop shown in (C). Plane polarized light; porosity shown by blue epoxy.

minimal wave disturbance (e.g., Round, 1981). According to Shinn (1986) stromatolites are generally restricted to the supratidal zone, although they may also persist in the upper intertidal zone in arid settings. This restriction was largely due to Phanerozoic browsers and burrowers (Garrett, 1970). A Recent analogue would likely be the protected intertidal areas of the Trucial coast and Qatar in the Arabian Gulf (e.g., Hughes Clarke and Keij, 1973).

Previous studies of lithofacies in the Upper Winnipegosis Member that are lithologically similar to lithofacies O have made similar interpretations. According to Ehrets and Kissling (1987) broad intertidal mud flats on the western platform in North Dakota were colonized by algal stromatolites. Perrin (1982) and Perrin and Precht (1985) interpreted crinkly stromatolites overlying isolated reefs and the eastern platform in North Dakota to have been deposited in a restricted, high intertidal to supratidal environment. Perrin (1987) attributed this facies to either algal stromatolites or algal/bacterial-induced tufa in association with peritidal crusts. Rosenthal (1988) attributed crudely laminated dolomudstone at the top of isolated reefs in central Manitoba to both algal laminations and caliche horizons.

CHAPTER 4: LITHOFACIES ASSOCIATIONS

4.1 Introduction

The previously described lithofacies can be genetically grouped into five lithofacies associations: 1) ramp - lithofacies A, B, and C; 2) platform interior – lithofacies H, I, and O; 3) platform slope – lithofacies F, G, H, I, M, N, and O; 4) isolated reef lithofacies I, J, K, L, M, N, and O; and 5) basinal salina - lithofacies E (Table 4.1; Fig. 4.1, 4.2). In addition, lithofacies D (bituminous laminite) is a constituent of the ramp, platform interior, platform slope, and basinal salina lithofacies associations; however, it will be discussed at length in Chapter 5 and is given minor consideration in this chapter. The ramp association comprises the Elm Point Formation and Lower Winnipegosis Member; the platform interior, platform slope, and isolated reef lithofacies associations comprise the Upper Winnipegosis Member; and the basinal salina association comprises the Ratner Formation. Limited core control in the study area precludes a detailed study of these facies associations and their distribution; however, a notable absence of cyclicity was observed. Lithofacies relationships observed in cores from the Hartney area (Township 5, Range 24W1) were not considered because of extreme thrust faulting in the area.

4.2 Ramp Lithofacies Association

Lithofacies A (non-fossiliferous mudstone), lithofacies B (mottled-nodular skeletal wackestone-mudstone), lithofacies C (nodular patterned mudstone), and lithofacies D (bituminous laminite) are interpreted to comprise the ramp lithofacies association (Fig. 4.1, 4.2, 4.3; Encl. 1-5). Lithofacies A is the lowermost lithofacies in the Elm Point

Table 4.1: Lithofacies associations and constituent lithofacies.

	LITHOFACIES NAME	LITHOFACIES ASSOCIATION	STRATIGRAPHIC UNIT
E	Interlaminated mudstone-anhydrite	Basinal Salina	Ratner Formation
D	Bituminous laminite		
O	Microbial bindstone	Isolated Reef	Upper Winnipegosis Member
N	Laminated mudstone-peloidal packstone		
M	Coral-stromatoporoid rudstone-framestone		
L	Stromatoporoid floatstone		
K	Peloidal- udoteacean packstone		
J	Bituminous skeletal wackestone-floatstone		
I	Intraclast floatstone		
O	Microbial bindstone	Platform Interior	
I	Intraclast floatstone		
H	Bedded-mottled peloidal packstone		
D	Bituminous laminite		
O	Microbial bindstone	Platform Slope	
N	Laminated mudstone-peloidal packstone		
M	Coral-stromatoporoid rudstone-framestone		
I	Intraclast floatstone		
H	Bedded-mottled peloidal packstone		
G	Septarian-type nodular skeletal packstone		
F	Massive-mottled mudstone		
D	Bituminous laminite		
D	Bituminous laminite	Ramp	Lower Winnipegosis Member/Elm Point Formation
C	Nodular patterned mudstone		
B	Mottled-nodular skeletal wackestone-mudstone		
A	Non-fossiliferous mudstone		

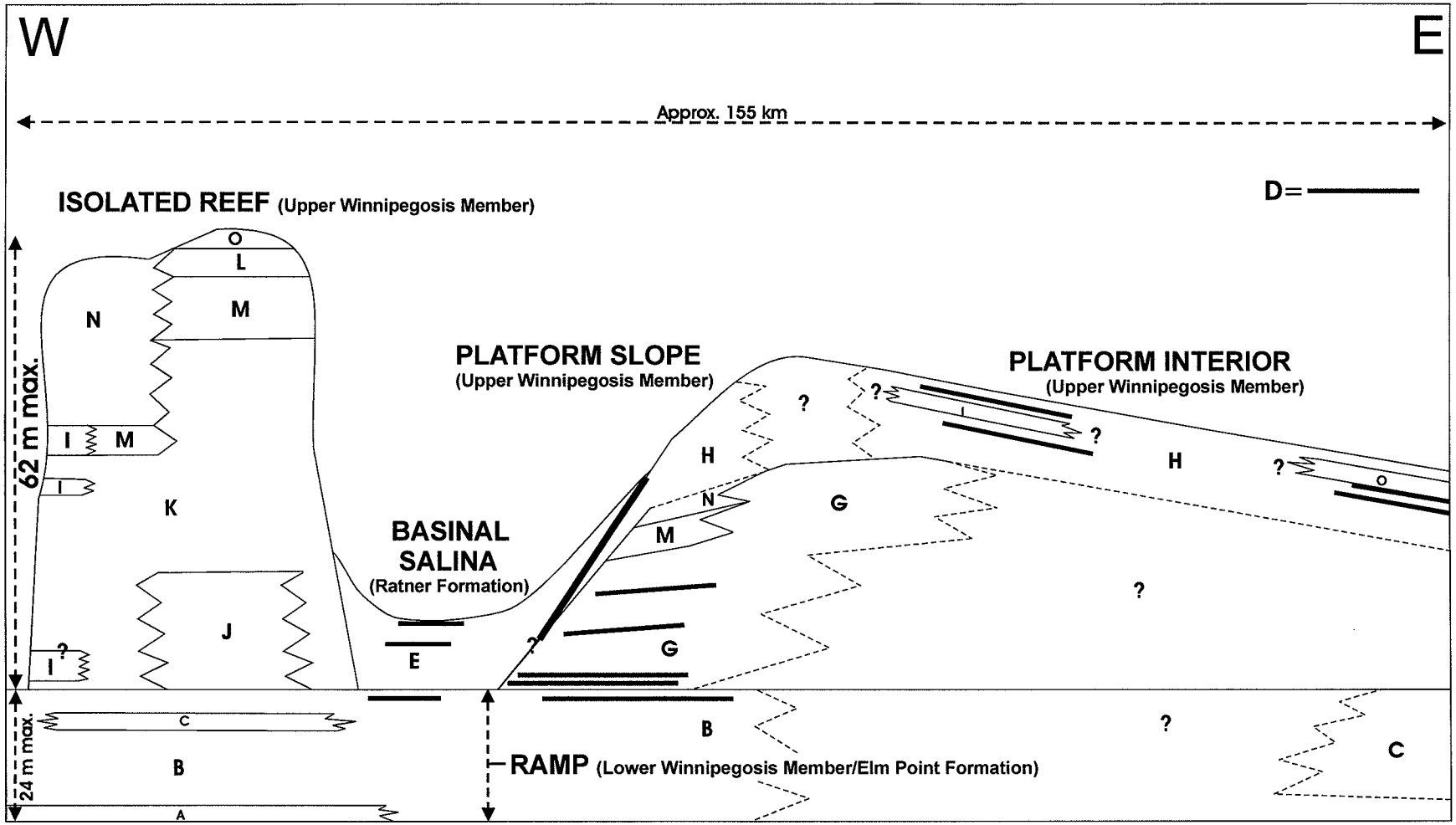


Figure 4.1: Schematic diagram for the platform to basin transition in the Elm Point and Winnipegosis formations on an W-E axis through the study area illustrating the lithofacies associations and their constituent lithofacies based on core examination. The lithofacies relationships illustrated in the isolated reef association are a compilation of those observed in all of the cored reefs. Scales are approximated and non-linear. Question marks indicate no core control and dashed lines are inferred contacts.

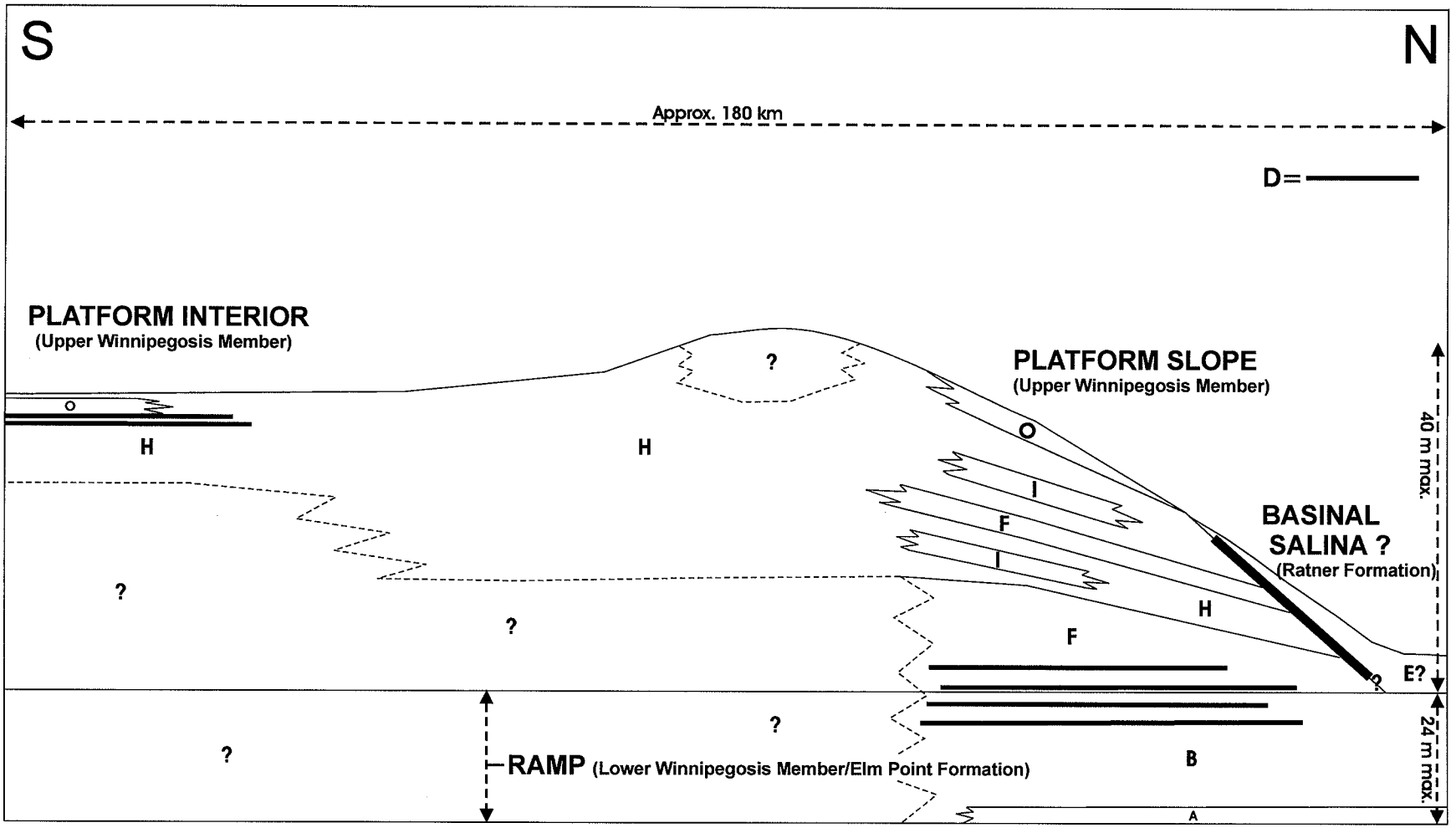


Figure 4.2: Schematic diagram for the platform to basin transition in the Elm Point and Winnipegosis formations on an S-N axis through the study area illustrating the lithofacies associations and their constituent lithofacies. Scales are approximated and non-linear. Question marks indicate no core control and dashed lines are inferred contacts.

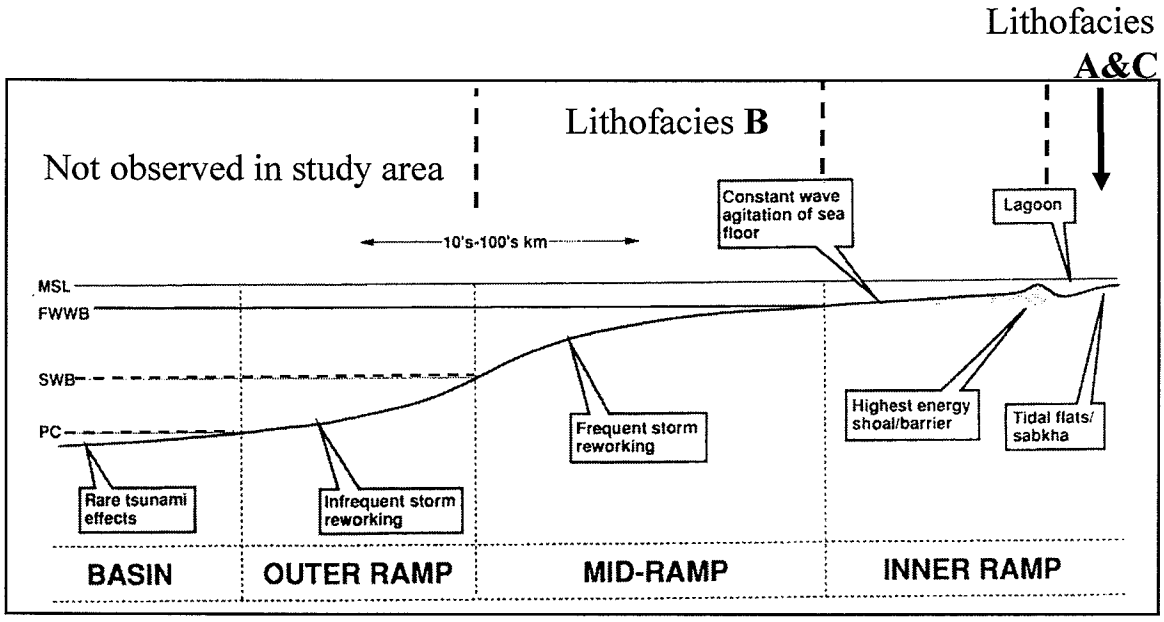


Figure 4.3: Schematic diagram of a carbonate ramp model illustrating the interpreted depositional settings of the lithofacies comprising the ramp lithofacies association in the Lower Winnipegosis Member and Elm Point Formation (modified from Burchette and Wright, 1992). MSL= mean sea level; FWWB=fair-weather wave base; SWB=storm wave base; PC=pycnocline.

Formation and Lower Winnipegosis Member and is laterally discontinuous. It is overlain gradationally by lithofacies B, which is by far the dominant lithofacies in the Elm Point Formation and Lower Winnipegosis Member. Locally, lithofacies C is interbedded with lithofacies B and locally comprises at least a third of the ramp succession in the southeastern part of the study area. The lateral relationships between lithofacies A and B and between B and C are unknown due to poor core control.

A carbonate ramp is defined as an unrimmed shelf that slopes basinward at less than 1° (e.g., James and Kendall, 1992). High energy, near-shore deposits grade laterally into low energy, deeper-water deposits and shallow sediments are readily transported offshore because there is no break in slope. The isopach map of the Elm Point Formation/Lower Winnipegosis Member shows widely spaced contour lines suggesting very broad, gentle slopes consistent with a ramp succession (Encl. 8). Lithofacies A (non-fossiliferous mudstone) is a transitional facies interpreted to represent low-energy peritidal deposition at the onset of transgression over the Ashern Formation and the initiation of ramp deposition. Lithofacies B (mottled-nodular skeletal wackestone-mudstone), which contains tempestites, is interpreted to represent mid-ramp deposition (Fig. 4.3), which occurs between fair-weather and storm wave base (Burchette and Wright, 1992). Lithofacies C (nodular patterned mudstone) is interpreted to represent low-energy peritidal deposition associated with both ephemeral, offshore tidal flat islands, where it occurs thickly interbedded with lithofacies B, and at inner-ramp positions (above fair-weather wave base) (cf. Burchette and Wright 1992; Pratt et al. 1992; Fig. 4.3). No lithofacies in the ramp lithofacies association are interpreted to represent high-energy

inner ramp, outer ramp, or basinal deposition. The thick and widespread occurrence of lithofacies B suggests that carbonate sedimentation kept up with relative sea-level rise.

4.3 Platform Interior Lithofacies Association

Lithofacies D (bituminous laminite), lithofacies H (bedded-mottled peloidal packstone), lithofacies I (intraclast floatstone), and lithofacies O (microbial bindstone) are interpreted to comprise the platform interior lithofacies association (Fig. 4.1, 4.2, 4.4; Encl. 1, 2, 3, 5). The lowermost lithofacies in this association are unknown due to a lack of core control; however, lithofacies H is typically the lowest known lithofacies, occurring at least 23 m above the base of the Upper Winnipegosis Member. Lithofacies H is laterally persistent and is volumetrically the dominant lithofacies. Lithofacies D and lithofacies I are laterally discontinuous and occur interbedded with lithofacies H. Lithofacies G (septarian-type nodular skeletal packstone) was also found to underlie lithofacies H at one location (04-27-011-22W1, 859.2-865 m [2819-2838']) (Encl. 2, 3); refer to Section 4.4 for discussion. Lithofacies O (microbial bindstone) occurs locally interbedded with lithofacies H near the top of the Upper Winnipegosis Member.

Carbonate platforms are steep-sided, flat-topped structures that can extend over hundreds of square kilometers (e.g., James and Kendall, 1992). In this study, the platform interior is interpreted as an open to slightly restricted lagoonal setting. Low energy, subtidal deposition is represented by lithofacies H; the bituminous and *Amphipora* content reflects the minor degree of restriction during deposition. An upsection decrease in bituminous content in the platform interior may represent a shoaling trend or ameliorated circulation.

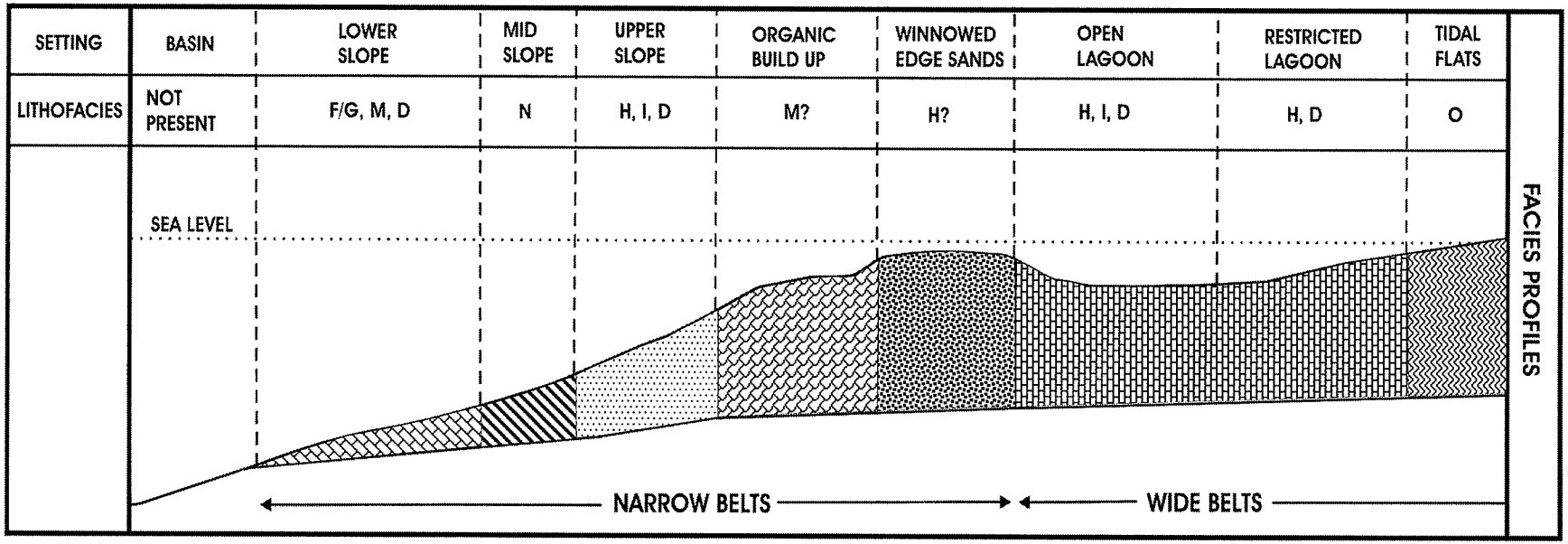


Figure 4.4: Schematic diagram of a carbonate platform illustrating the interpreted depositional settings of the lithofacies comprising the platform interior and slope lithofacies associations in the Upper Winnipegosis Member (modified from Wilson, 1975).

Restricted circulation on platforms may result from either the dampening effect of an aerially extensive shallow body of water or from the baffling effects on wave energy from a continuous or discontinuous platform-fringing rampart consisting of reefs and/or shoals (e.g., Enos, 1983; James and Kendall, 1992). Evidence for a rampart was not observed in core within the study area; however, patch reefs are known to occur on the northern platform slope near the Lake Manitoba Narrows (e.g., Rose Hill locality, Bezys and McCabe, 1996; the Narrows West Quarry, Davidson, 1981). Patch reefs also occur along the platform margin in North Dakota (Perrin and Precht, 1985) and platform margin reefs are known to occur on the western side of the basin in North Dakota (Ehrets and Kissling, 1987).

Lithofacies I (intraclast floatstone) is interpreted to represent tempestites in the platform interior, which punctuated the low energy deposits of lithofacies H. Lithofacies O (microbial bindstone) is interpreted to represent intertidal to supratidal deposition on tidal flats that formed at locations where the platform-interior grew up to sea-level.

4.4 Platform Slope Lithofacies Association

Lithofacies D (bituminous laminite), lithofacies F (massive-mottled mudstone), lithofacies G (septarian-type nodular skeletal packstone), lithofacies H (bedded-mottled peloidal packstone), lithofacies I (intraclast floatstone), lithofacies M (coral-stromatoporoid rudstone-framestone), lithofacies N (laminated mudstone-peloidal packstone), and lithofacies O (microbial bindstone) are interpreted to comprise the platform slope lithofacies association (Encl. 1-3). This association overlies the ramp

lithofacies association and grades laterally shorewards into the platform interior lithofacies association (Fig. 4.1, 4.2, 4.4). The lowermost lithofacies in this association is either lithofacies G or F, both of which gradationally overlie lithofacies B (mottled-nodular skeletal wackestone-mudstone) of the ramp lithofacies association. Lithofacies M occurs sharply interbedded with the upper half of lithofacies G. Lithofacies N is laterally discontinuous and sharply overlies lithofacies M. It is not known if lithofacies N is succeeded by another lithofacies because of a lack of core control. Lithofacies H (bedded-mottled peloidal packstone) appears to be laterally persistent and is gradationally interbedded with, but mostly overlies lithofacies F and also overlies lithofacies G with a gradational contact. Lithofacies I is laterally discontinuous and occurs sharply interbedded with lithofacies H. Lithofacies D is laterally discontinuous and occurs sharply interbedded with lithofacies F and G and is locally the uppermost lithofacies in this association where it sharply overlies lithofacies H. Lithofacies O locally sharply overlies lithofacies H and is the uppermost lithofacies where present.

Platform slopes represent the seaward termination of carbonate platforms and are composed of a suite of environments from euphotic, shallow water to deep basin floor (e.g., Coniglio and Dix, 1992). In the study area, the western and northern margins of the platform succession in the Upper Winnipegosis Member, where well control is sufficient to show tightening of contour lines on the isopach map (Encl. 9), are interpreted to represent areas of slope deposition.

Lithofacies G (septarian-type nodular skeletal packstone) and lithofacies F (massive-mottled mudstone) are interpreted to represent lower slope deposits on the western and northern slopes respectively (Fig. 4.4, refer to Section 2.7). The bituminous skeletal packstone of lithofacies G was likely deposited as allochthonous periplatform deposits transported off the platform margin by tides and/or currents into poorly oxygenated waters (cf. Mullins, 1986). Off-bank transport of coarse-grained carbonate allochems occurs preferentially on leeward-facing bank margins (e.g., Hine and Neumann, 1977; Hine, 1983). Conversely, windward-facing platform margins typically have little coarse sediment because storm and wave energy is directed onto the platform (e.g., Hine et al., 1981). The northern platform slope in the vicinity of the Lake Manitoba Narrows, where lithofacies F is the lowermost lithofacies in closely spaced cores is consistent with this latter scenario (Encl. 5). At one location (04-27-011-22W1, 859.2-865 m [2819-2838']) in the outer platform interior, lithofacies G was observed underlying lithofacies H (bedded-mottled peloidal packstone) (Fig. 4.1; Encl. 2, 3) suggesting either slope deposits underlie the platform or lithofacies G is actually a deep blanket-like platform deposit that was succeeded by shallower platform lithofacies in this area. Lithofacies M (coral-stromatoporoid rudstone-framestone) is interpreted to represent thin biostromes that developed locally along uppermost-lower to mid-slope positions.

Lithofacies H (bedded-mottled peloidal packstone) is interpreted to represent upper slope deposition on both the western and northern slopes. Because the upper slopes would have been in the euphotic zone, lithofacies H is probably composed of sediment derived in-situ and also from the platform interior, as typically a significant part of the carbonate

sediment generated on platforms is deposited in periplatform settings (e.g., Neumann and Land, 1975). Occurrences of grainstone in lithofacies H may represent localized, well washed shoals on the slope or tempestites. Lithofacies I (intraclast floatstone) is interpreted to represent debris flow deposits (debrites) on the platform slopes that punctuated the background deposition of lithofacies H.

Lithofacies N (laminated mudstone-peloidal packstone) was observed to overlie lithofacies M at one location on the western platform slope (11-29-001-25W1, 1519.85 m [4986.4']; Encl. 3) and is interpreted to represent moderately deep deposition on the platform slope, intermediate between lithofacies G and lithofacies H. Lithofacies O (microbial bindstone) is interpreted to represent intertidal deposition above the upper platform slope deposits, including the Rose Hill patch reef observed in outcrop, that developed during the regressive phase (see Chapter 8).

4.5 Isolated Reef Lithofacies Association

Lithofacies I (intraclast floatstone), lithofacies J (bituminous skeletal wackestone-floatstone), lithofacies K (peloidal-udoteacean packstone), lithofacies L (stromatoporoid floatstone), lithofacies M (coral-stromatoporoid rudstone-framestone), lithofacies N (laminated mudstone-peloidal packstone), and lithofacies O (microbial bindstone) are interpreted to comprise the isolated reef lithofacies association (Fig. 4.1; Encl. 4). The lowermost and dominant lithofacies is typically lithofacies K, which sharply overlies lithofacies B (mottled-nodular skeletal wackestone-mudstone) of the ramp lithofacies association. Lithofacies K appears to volumetrically comprise at least 50% of most cored

reefs. Lithofacies J is rarely the lowermost lithofacies and it is sharply interbedded with thin to medium beds of lithofacies K. Lithofacies I occurs either sharply interbedded with or sharply overlies lithofacies K. Lithofacies N occurs in the upper half to one third of some cored reef intervals and sharply overlies either lithofacies K or I. It is not known if another lithofacies overlies lithofacies N because of poor core control. Lithofacies M is found in the upper half of some reefs and preferentially occurs towards the top. This lithofacies occurs sharply interbedded with lithofacies K but is best developed where it overlies lithofacies K. Lithofacies L sharply overlies lithofacies M near the top of the reefs and is in turn sharply overlain by lithofacies O (microbial bindstone), which is stratigraphically the highest lithofacies.

Reefs in the study area are sparsely drilled, cored intervals are very limited, and there are no seismic data available. Although insufficient data are available to determine reef morphology, the basinal reefs in the study area are referred to as isolated reefs based on their bulls-eye configuration as outlined by the Upper Winnipegosis Member isopach map (Encl. 9). Furthermore, reef thicknesses intersected by wells are considered to be minimum thicknesses as it is unlikely that the reefs were penetrated at their apices.

Lithofacies K (peloidal-udoteacean packstone) is interpreted to represent reef initiation and early deposition that occurred by baffling and trapping of sediment to form mounds or shoals on the basin floor (Fig. 4.5A, B). Based on the faunal assemblage, udoteacean algae likely played a key role. Deposition may have begun with smaller mound features, which coalesced to form the base of the reefs (i.e. "proto-reefs") (cf. Martindale and

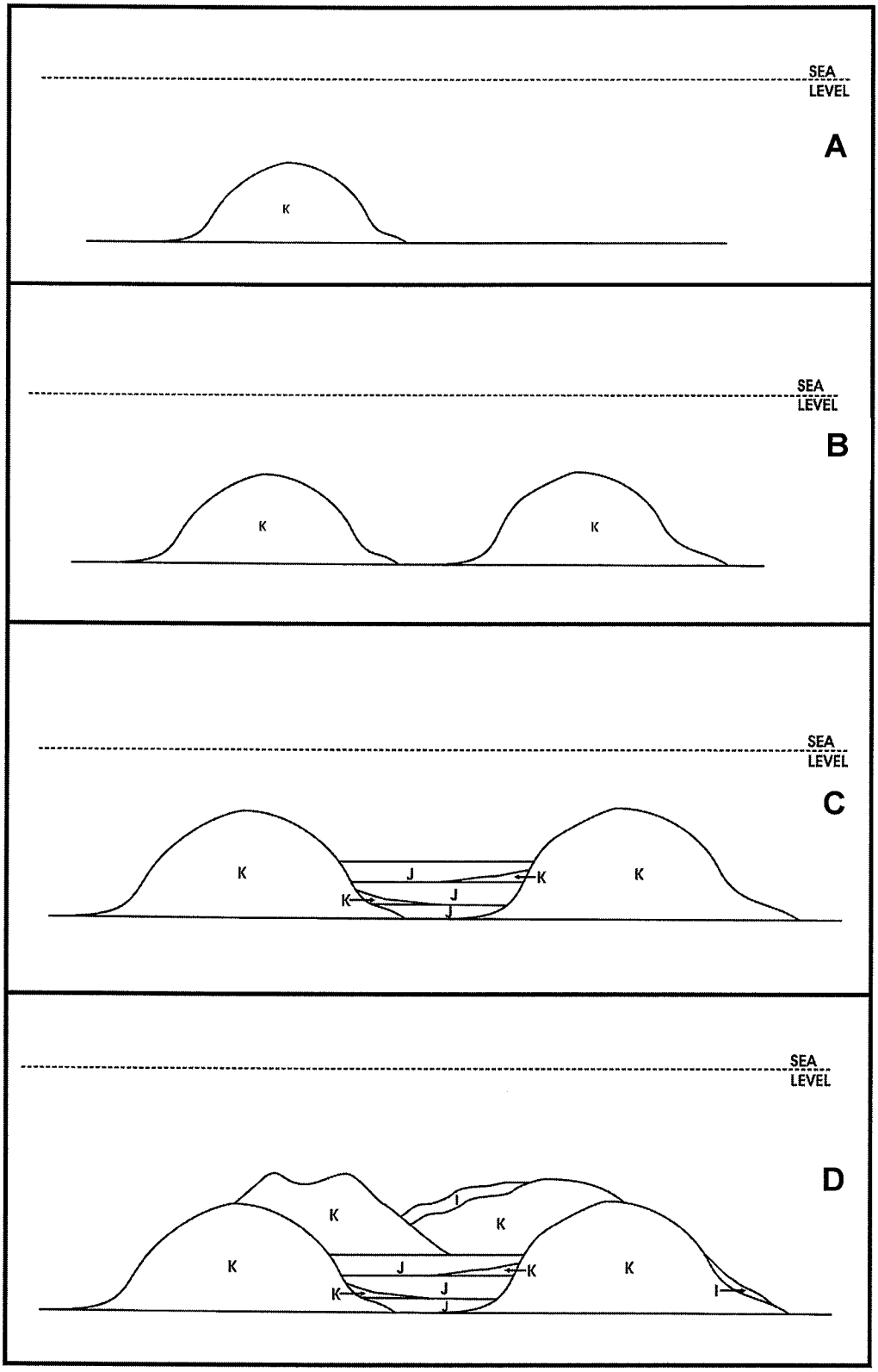


Figure 4.5: Schematic time-lapsed diagrams illustrating the interpreted progression of depositional settings of all of the lithofacies comprising the isolated reef lithofacies association. Note that all lithofacies are not likely present in all isolated reefs. Description of the different stages are provided in the text. No scale implied.

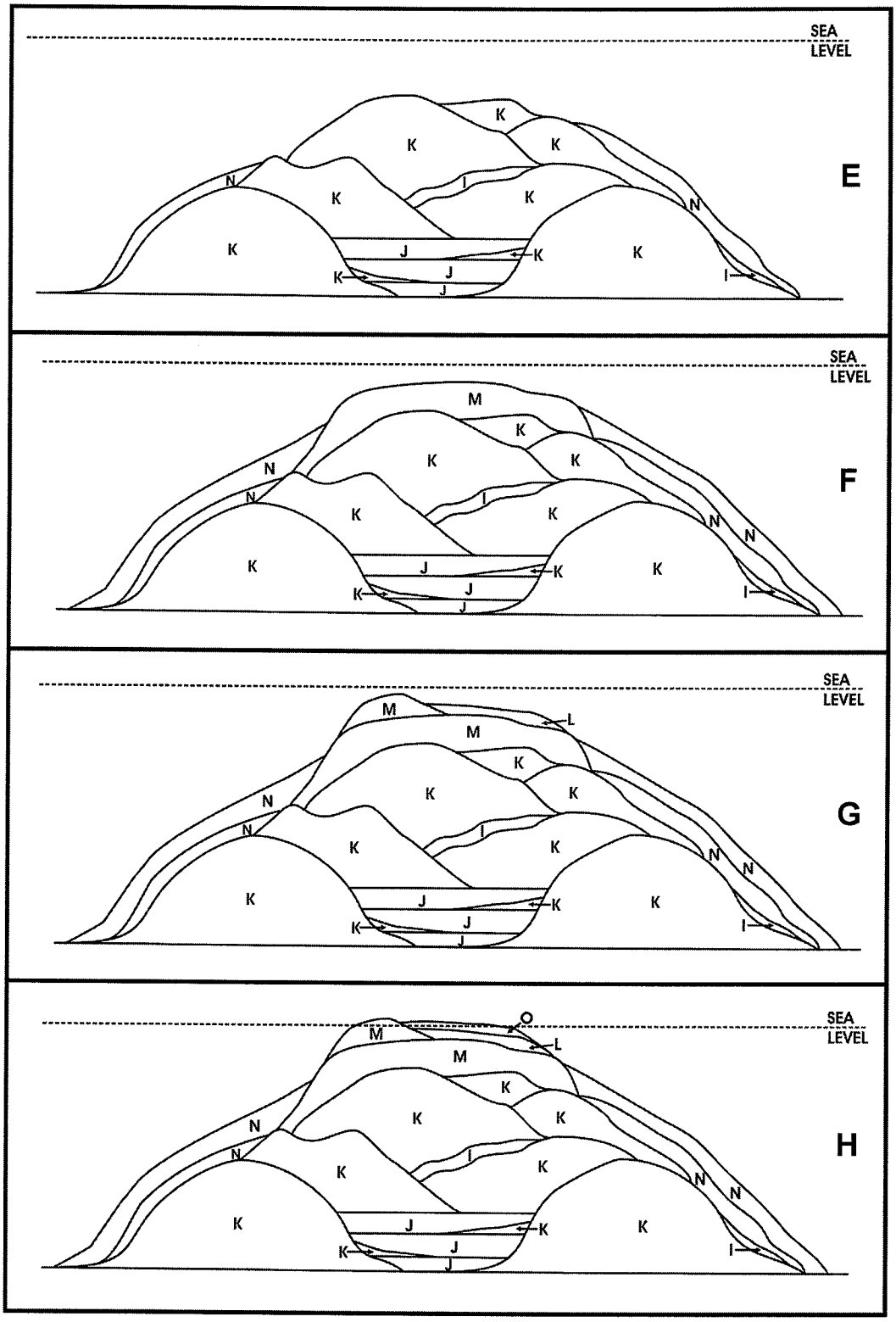


Figure 4.5: Continued.

MacDonald, 1989). However, deposition of lithofacies K apparently continued for some time in the reef core as other lithofacies developed at the periphery of the reefs.

Lithofacies J (bituminous skeletal wackestone-floatstone) is interpreted to represent a quiet, deep lagoonal setting, where much of the reefal mud settled from suspension (Fig. 4.5C) (cf. James and Bourque, 1992). This lithofacies is interpreted to be a feature of the "proto-reef" rather than an atoll-like lagoon of a mature reef because lithofacies J directly overlies lithofacies B (mottled-nodular skeletal wackestone-mudstone) of the ramp lithofacies association. Interbedded lithofacies J and K (peloidal-udoteacean packstone) indicates that lithofacies K was deposited adjacent to the lagoon and possibly formed topographically higher portions of the "proto-reef". Restricted circulation resulted in deposition of lithofacies J which was eventually overlain by lithofacies K as shoals and/or mounds (Fig. 4.5D).

Lithofacies I (intraclast floatstone) are interpreted to be either tempestites that punctuated lithofacies K (peloidal-udoteacean packstone) deposition on early mounds or "proto-reefs" or debris flow deposits (debrites) along fore-reefs, which may have also been storm-triggered (Fig. 4.5D) (cf. Coniglio and Dix, 1992). Lithofacies N (laminated mudstone-peloidal packstone) is interpreted to represent a quiet fore-reef setting, where mostly fines derived from topographically higher lithofacies on the reefs, as well as organic matter, settled out of suspension (Fig. 4.5E). Lithofacies M (coral-stromatoporoid rudstone-framestone) is interpreted represent a high-energy, reef-crest setting (Fig. 4.5G) (cf. James and Bourque, 1992; Wendte, 1992). The fact that

lithofacies M occurs at various stratigraphic positions within the upper half of the reef successions suggests that some reefs approached sea-level earlier in their depositional histories than others.

Lithofacies L (stromatoporoid floatstone) is interpreted to represent a reef flat setting, which evidently migrated over portions of the reef crest (lithofacies M) in at least some reefs (Fig. 4.5G). The bioclasts in lithofacies L were likely washed onto the reef flat from the reef crest, possibly during storms (cf. James and Bourque, 1992). Lithofacies O (microbial bindstone) is interpreted to represent either the final stage of reef deposition during which parts of the reef reached and exceeded sea-level, permitting peritidal deposition over the reef flat, or the regressive phase which followed reef aggradation, during which the reefs were gradually exposed (Fig. 4.5H) (see Chapter 8).

A general paucity of core control has been recognized as an impediment to determination of the size and shape of Upper Winnipegosis Member reefs as well as lithofacies relationships in the subsurface (e.g., McCabe, 1988; Kent and Minto, 1991). Consequently, these reefs have been variably described as buildups (e.g., Rosenthal, 1988; Martindale and MacDonald, 1989; Martindale et al., 1991), mounds (e.g., Gendzwill, 1978), pinnacle reefs (e.g., Ehrets and Kissling, 1987; Fisher and Burke, 1987), and "pseudo-atoll" pinnacle reefs (e.g., Perrin and Precht, 1985).

McCabe (1988) used a combination of outcrop observation from the Manitoba Devonian outcrop belt and statistical analyses of isopach data from the Swan River area, which is

just north of the study area, and central Saskatchewan to hypothesize that Winnipegosis reefs are of relatively uniform thickness in any given area, but range between 80 and 110 m thick, reflecting differential subsidence. They have both pinnacle and flat-topped configurations. He concluded that flat-topped reefs have maximum dimensions of ~5 by 12 km and that pinnacle reefs have diameters of ~0.5 km with a similar shape to their Keg River Formation counterparts in Alberta, which have aspect ratios of ~1:10, but are less than 40% of the size of the Winnipegosis reefs. The Winnipegosis reefs are also simpler structures and generally represent a single depositional cycle, which is consistent with observations made in this study, whereas the Keg River reefs underwent several episodes of reef development punctuated by evaporite deposition. However, Fu et al. (2004, 2006) documented calcrete and paleokarst related to several periods of subaerial exposure in some Winnipegosis reefs in Saskatchewan. Using closely spaced coreholes, Kent and Minto (1991) determined that the Bluff reef in the Dawson Bay area of the Manitoba Devonian outcrop belt measures 916 m long, 460 m wide, and is 43-70 m thick.

Using seismic, drill-hole, and mining data, Gendzwill (1978) concluded that Winnipegosis reefs in central Saskatchewan are typically elongate, steep-sloped and flat topped structures, 1 km wide, 8 km long, and 70-100 m thick. They are distributed in an irregular patchwork pattern. According to Martindale et al. (1991), reefs in the Hitchcock area of Saskatchewan are conical in shape with flat tops and steep sides and occur distributed as chain-like complexes. The reefs have an aerial extent of 0.23-0.31 km^2 and are 57-63 m thick. Employing a detailed gravity survey, Braun (1991) found that the

Shell Golden Reef in North Dakota, previously referred to as a pinnacle reef, is in fact an elongate structure, which is 8 km long, 850-1500 m wide and 90-105 m thick. According to Perrin (1987), an un-named reef in North Dakota is oval in plan view measuring ~1.2 km by ~0.8 km based on seismic lines, and is 76 m thick based on core study.

4.6 Basinal Salina Lithofacies Association

Lithofacies E (interlaminated mudstone-anhydrite) and lithofacies D (bituminous laminite) comprise the basinal salina lithofacies association (Encl. 4); however, lithofacies D is a subordinate lithofacies and has only been observed interbedded with lithofacies E in well 103/03-12-011-27W1 (1178.5-1180.5 m [3866.5-3873']). Within the study area the basinal salina lithofacies association occurs in the basinal area to the west of the western platform margin (Fig. 4.1). It sharply overlies lithofacies B (mottled-nodular skeletal wackestone-mudstone) of the ramp lithofacies association and it is adjacent to occurrences of the isolated reef lithofacies association on the basin floor. Lateral relationships with the reefs within the study area are unknown due to poor core control. A thin (0.2 m) occurrence of the basinal salina lithofacies association also sharply overlies (onlaps) lithofacies D (bituminous laminite) of the platform slope lithofacies association on the western slope (Fig. 4.1). The upper contact of lithofacies E is gradational with mosaic anhydrite of the Whitkow Member of the Prairie Evaporite Formation. Although no core is available above the platform slope lithofacies association at the northern platform margin or in the basinal area immediately to the north within the study area, laminites equivalent to lithofacies E are known to be present at several locations north of the study area (e.g., 10-22-30-16W1; 09-15-46-22W1; Teare, 1990).

Therefore it is reasonable to expect that the basinal salina lithofacies association is likely present at the northern end of the study area.

The basinal salina lithofacies association is interpreted to have been deposited in large, perennial salina(s) associated with evaporitic drawdown in the basinal area (cf. Maiklem, 1971). A thin occurrence of lithofacies E onlapping the western platform slope at a mid to upper slope position establishes the basinal salina lithofacies association as postdating the previously described lithofacies associations and indicates that the basin was at least half submerged at the onset of salina deposition. Variation in thickness and lack of correlation between salina deposits on opposite sides of an isolated reef cored in well 100/14-13-009-28W1/00 (1280.87-1310 m [4202.3-4297.9']) (Encl. 9) suggest that the degree of restriction in salina(s) proximal to the platform slope may have been controlled in part by the extent to which they were bounded by isolated reefs in addition to seafloor paleotopography.

CHAPTER 5: ORGANIC PETROLOGY

5.1 Introduction

Organic petrology, as defined by Taylor et al. (1998), is concerned with all aspects of the origin, occurrence, and history of sedimentary organic matter. In this study, the maceral components of bituminous laminites (lithofacies D) from various stratigraphic positions in the Winnipegosis, Elm Point, and Ratner formations were identified using incident-light microscopy including reflected white light and fluorescence. The presence and relative abundance of various macerals in each laminite provide a snapshot of the pelagic flora and sometimes fauna in the water column at the time of deposition, thereby permitting paleoenvironmental and paleoecological interpretations.

Organic petrology can be employed to investigate whether enhanced preservation in depth-related anoxic conditions or elevated primary productivity was the first-order control on the accumulation of sedimentary organic matter in organic-rich facies. This issue has generated a long-running debate amongst the geological fraternity (e.g., Wignall, 1994; Tyson, 1995; Scheiber, 2001). The long held "classical model" assumes that anomalous accumulations of organic matter in lithologies other than coals are supplied by normal primary bio-productivity and accumulate in restricted, sub-oxic to anoxic environments (e.g., Demaison and Moore, 1980; Tyson, 1987; Tyson and Pearson, 1991). Preservation is enhanced by inhibiting benthic scavengers and aerobic heterotrophic bacteria; all other factors are considered secondary. The more contemporary model contends that elevated primary bio-productivity and carbon flux is

the single most important control on accumulation and preservation of sedimentary organic matter and occurs where mineral nutrient supply is highest (e.g., Parrish, 1982; Calvert, 1987; Pedersen and Calvert, 1990; Calvert and Pederson, 1992). High productivity in the oceanic realm presently occurs in zones of upwelling and in shelf seas where there is high runoff from the adjacent land. This chapter describes the maceral composition and organic facies of representative laminites in the study area to provide insight as to whether organic matter accumulated primarily as a function of anoxia or elevated primary productivity during Winnipegosis time.

5.2 Types of Macerals

As originally defined by coal petrologists, macerals are the microscopically identifiable, individual components of coal which are analogous to minerals but are not crystalline (e.g., Stopes, 1935). Macerals are variable in chemical composition and identified based on their morphology, reflectance, and autofluorescent properties (e.g., Bustin et al., 1985; Tyson, 1995; Hunt, 1996). Disseminated macerals are also recognized as constituents of kerogen in bituminous rocks and their visual identification provides an independent method of determining the source of organic matter which can be used in conjunction with bulk, organic geochemical analyses (e.g., Wignall, 1994; Hunt, 1996). Conventionally, macerals fall into one of three different groups based on petrographic and chemical properties: huminite/vitrinite, liptinite, and inertinite (e.g., Crelling and Dutcher, 1980; Brooks et al., 1987; Mukhopadhyay, 1992). The huminite/vitrinite group consists of organic matter derived from the lingo-cellulose components of higher plants (e.g., Mukhopadyhay, 1992). The liptinite group is organic matter derived from either

microalgae constituents or the waxy, lipid, and resinous parts of higher plants including spores, cuticles, and resins (e.g., Crelling and Dutcher, 1980; Brooks et al., 1987; Stasiuk, 1999). The inertinite group consists of oxidized, carbon-rich, organic matter derived from plant material that was strongly altered and degraded prior to burial by water circulation, bacteria, or forest fire (e.g., Crelling and Dutcher, 1980; Brooks et al., 1987; Mukhopadyhay, 1992).

5.3 Macerals from Bituminous Laminites (Lithofacies D) within the Study Area

Although many types of macerals have been identified in the Western Canada Sedimentary Basin, only those types identified in bituminous laminites (lithofacies D) in this study are described in this section and listed in Table 5.1. (cf. Potter et al., 1998). The liptinite group consists of alginite, acritarch, sporinite, resinite, cutinite, and amorphinite macerals. The huminite/vitrinite group consists of vitrinite and corpohuminite-like macerals and the zooclast group consist of conchostracans and chitinozoans. In addition, calcareous/phosphatic microfossils are included because they enhance the understanding of depositional conditions.

5.3.1 Alginite Macerals

Alginite macerals were originally defined as macerals derived from a limited number of algae precursors found in coal; however, many more alginite macerals are now recognized and show significant morphological variability that is dependent on the precursor algae (Hutton, 1987). Prasinophyte, filamentous, and coccoidal alginites are relevant to this study.

Table 5.1: Classification of the types of macerals and microfossils found within bituminous laminites in the Elm Point, Winnipegosis, and Ratner formations (modified from Stasiuk, 1999). ICCP = International Committee for Coal Petrology (1971). N/A=not applicable. N/D=not determined.

MACERAL GROUP (after ICCP)	MACERAL	MACERAL VARIETY
Liptinite	Alginite	Prasinophyte (*Tasmanites* & *Leiosphaeridia*)
		Filamentous
		Coccoidal
	Acritarchs	Acanthomorphic
	Sporinite	Microspore
		Megaspore
	Resinite	N/A
	Cutinite	N/A
	Amorphinite	Hebamorphinite (non-fluorescing)
		Fluoramorphinite
Huminite/Vitrinite	Vitrinite	N/A
	Corpohuminite-like	Akinete cells
Zooclast (informal group)	Conchostracans	N/A
	Chitinozoans	N/A

CALCAREOUS/PHOSPHATIC MICROFOSSILS	
TYPE	**VARIETY**
Calcispheres	N/A
Cricoconarids	Styliolinids & Tentaculitids
Fish bones	N/D

Prasinophyte Alginites

Prasinophyte macerals are derived from the phycoma, or non-motile stage vesicle, in the life cycle of phylogenetically primitive, dominantly marine, green algae which form when the motile flagellate stage encysts (e.g., Mendelson, 1993). Phycomata consist of condensed fatty acid derivatives. Extant Prasinophytes inhabit marine through fresh waters and their phycomata float passively in the water column with the assistance of lipid globules and are sedimented after their contents have been expelled or their lipid reserves metabolized (e.g., Parke et al., 1978; Tappan, 1980). Originally spheroidal, the vesicles are typically preserved as compressed discoids with the degree of folding and cracking determined to some extent by wall thickness (e.g., Mendelson, 1993). Thicker-walled fossil taxa, such as *Tasmanites*, are 30-600 μm long and have pore-bearing vesicle walls, typically 4-5 μm thick (e.g., Bignot, 1985; Mendelson, 1993). Thinner-walled forms, such as *Leiosphaeridia*, are characterized by vesicle walls typically less than 0.5 μm thick (e.g., Mendelson, 1993). Although conspicuous and often the dominant structured maceral, Prasinophytes rarely exceed 10 vol % of kerogen (e.g., Tyson, 1995).

Prasinophytes are the most persistent alginite maceral found in the bituminous laminites examined in this study and occur as both small and large forms ranging from 5-341 μm long, and are mostly yellow-fluorescing but rarely yellow-orange or pale blue-fluorescing (Fig. 5.1).

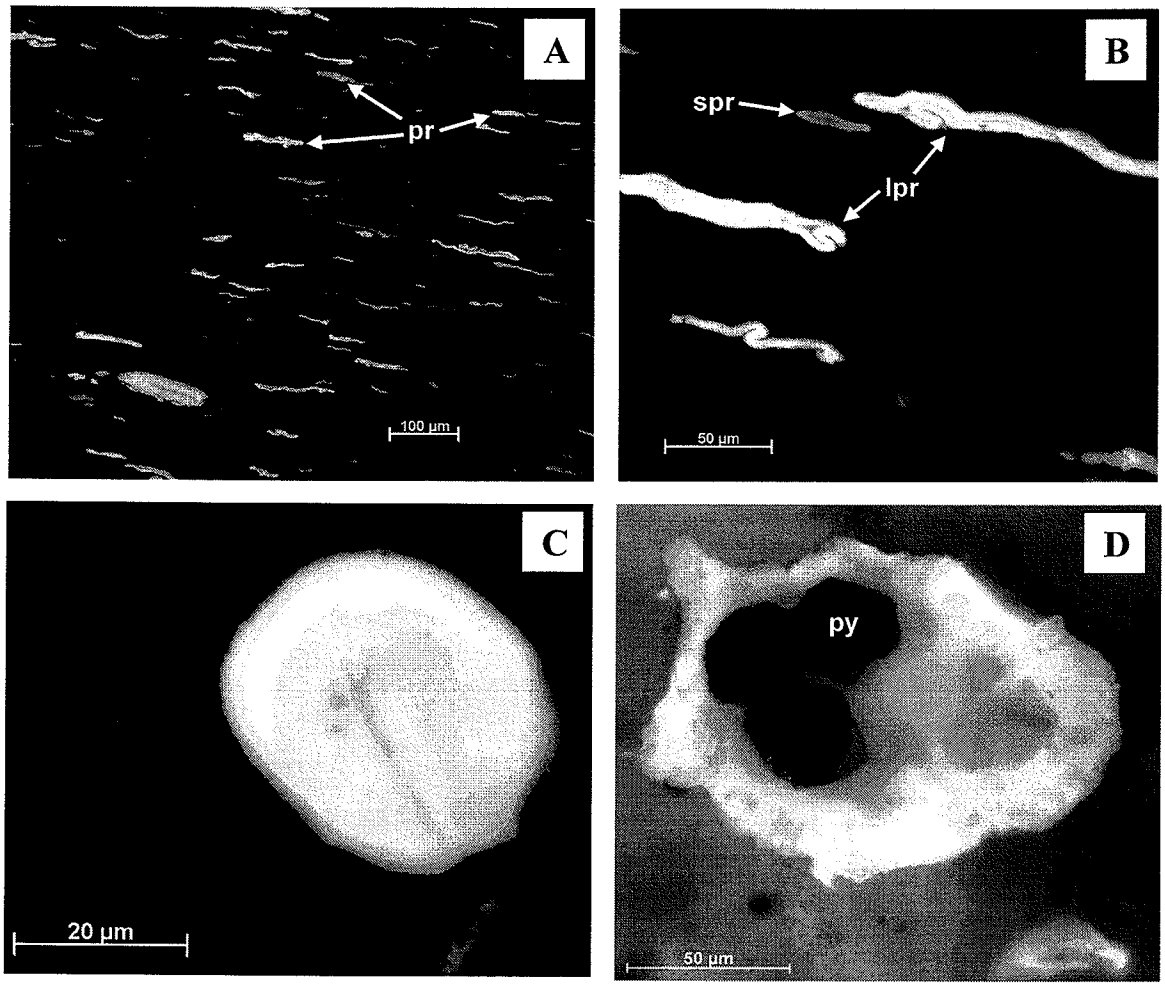


Figure 5.1: Photomicrographs of Prasinophyte alginite macerals in lithofacies D. A) Prasinophyte alginites (pr) in an amorphinite and carbonate matrix, sectioned perpendicular to bedding; UV fluorescence. 05-13-005-22W1, 1157.94 m (3799'). B) Higher magnification photomicrograph of (A) showing large (lpr) and small (spr) Prasinophyte alginites. C) A small Prasinophyte alginite in an amorphinite matrix sectioned parallel to bedding; UV fluorescence. 09-26-007-25W1, 1175.46 m (3856.5'). D) A large sectioned Prasinophyte alginite containing intra-vesicle euhedral pyrite crystals (py), which is dislodged from the matrix and floating in epoxy; UV fluorescence. 11-29-001-25W1, 1531.85 m (5025.75').

Filamentous Alginites

Filamentous alginites are derived from multicellular filaments of cyanobacteria, consisting of cells, typically 2-4 μm in diameter, which are arranged in chains called trichomes and enveloped in a gelatinous sheath (e.g., Tappan, 1980; Lee, 1999). Filaments may be free-floating or bound to a substrate as in a stromatolite; the free-floating varieties may have intracellular gas vacuoles to aid with buoyancy and form surface mats during elevated productivity (e.g., Tappan, 1980). Filamentous alginites are generally rare due to the poor preservation potential of their fragile cellular structure (e.g., Golubic and Knoll, 1993). Only trace amounts of possible filamentous alginites were observed in the Winnipegosis Formation in this study; however, their presence has been confirmed by proxy from the presence of akinete cells (see Section 5.3.5).

Coccoidal Alginites

Coccoidal alginites are derived from unicellular algae that consist of non-motile, envelope-bounded, colonial aggregates which form following cell division (e.g., Golubic and Knoll, 1993; Lee, 1999). Within the Elk Point Group, two varieties of coccoidal alginites have previously been identified including lacustrine to brackish water, chlorophyte-derived *Botryococcus* alginites and shallow marine, cyanophyte-derived *Gloeocapsomorpha prisca* alginites (Stasiuk, 1999).

Coccoidal alginites are relatively rare in this study and were not differentiated. They occur as irregular, orange-fluorescing discoids (35-105 μm long), in which individual cells can typically be discerned (Fig. 5.2).

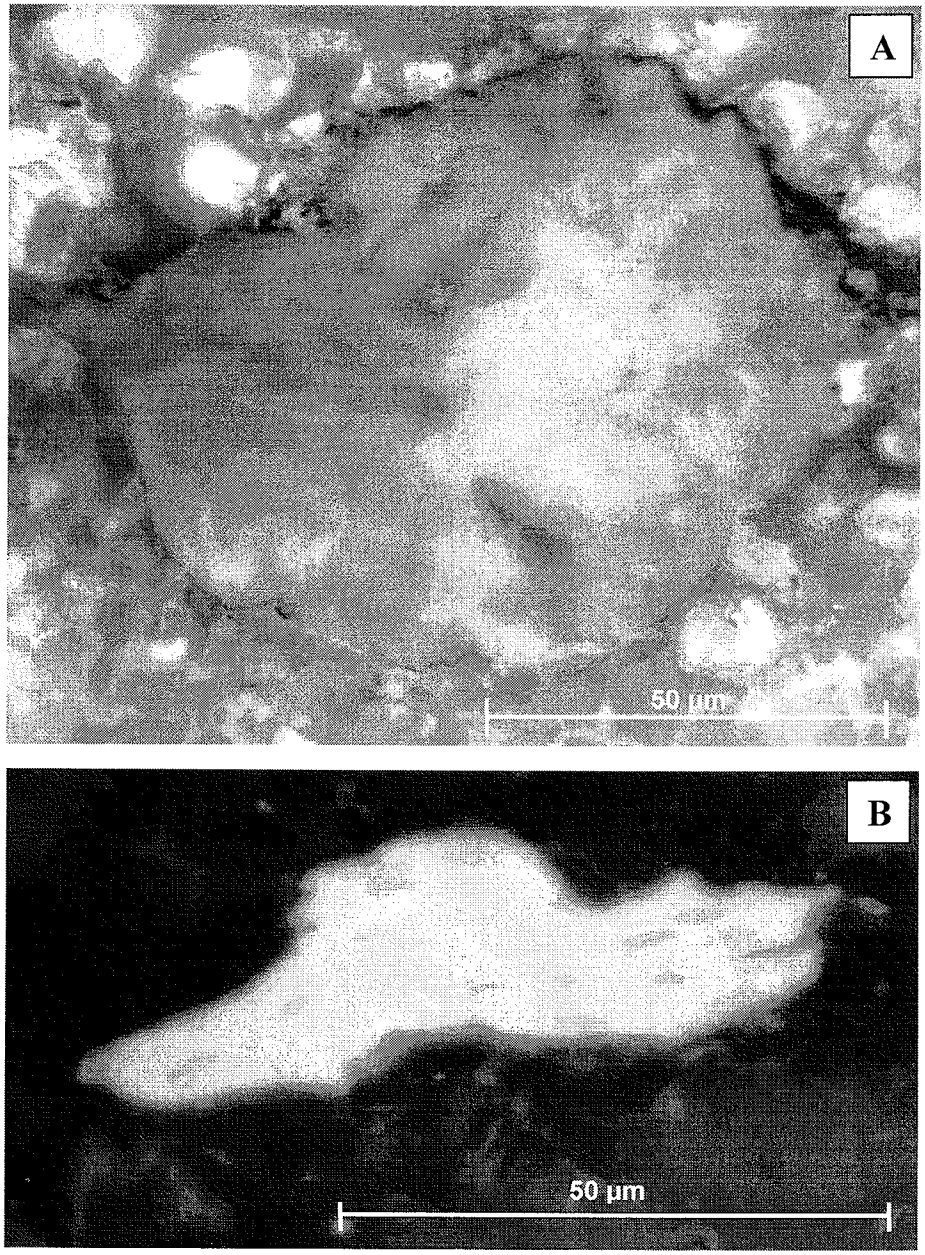


Figure 5.2: Photomicrographs of coccoidal alginite macerals in lithofacies D. A) A coccoidal alginite in a carbonate and amorphinite matrix, sectioned parallel to the bedding plane; UV fluorescence. 04-33-023-16W1, 205.95 m (675.7'). B) A coccoidal alginite with cells compressed into ellipsoids in a carbonate and amorphinite matrix, sectioned perpendicular to the bedding plane; UV fluorescence. 11-29-001-25W1, 1531.85 m (5025.75').

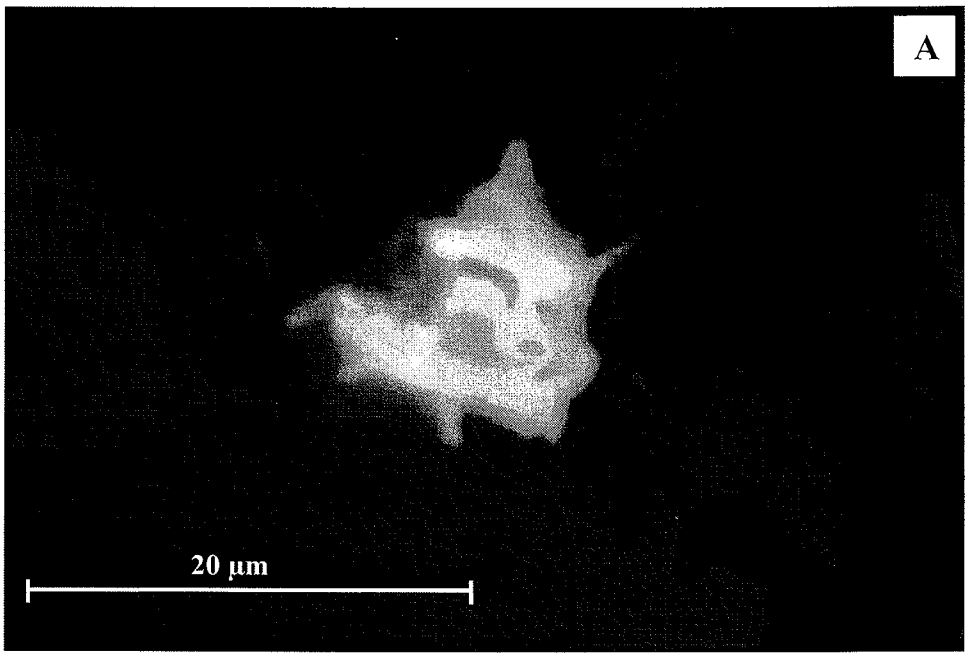
5.3.2 Acritarchs

Acritarch microflora is a polyphyletic group of organic-walled microscopic organisms, most of which are likely remnants of a thick-walled resting stage or cysts in the life cycle of planktonic eukaryotic algae (e.g., Downie, 1973; Mendelson, 1993). Some are thought to be dinoflagellate cysts, while others have more in common with chlorophytes or green algae. The acritarchs are an artificial group that will likely be dissolved should their biological relationships ever be confirmed. In the meantime, they are divided into artificial groupings on the basis of overall morphology, ornament, and excystment opening (e.g., Downie, 1973). Occurring as vesicles, acritarchs range in size mostly from 50 to 100 μm and rarely between 1 to 500 μm (e.g., Bignot, 1985). Their morphology ranges from spherical to cubic with surfaces that can be smooth, granular, or ornamented with extensions or processes having variable aspect and arrangement.

In this study, all acritarchs were found to be of the acanthomorphic (spiny) variety (4.8-22 μm in diameter) with processes of variable length, and are invariably blue-fluorescing (Fig. 5.3).

5.3.3 Sporinite Macerals

Sporinite macerals are structured microfossils derived from the spores and pollens of terrestrial higher plants (e.g., Bignot, 1985; Stasiuk, 1999). Sporinite macerals from the Devonian are derived from: (1) trilete spores that have a germinal aperture with three branches and were produced by the Psilophytales, (2) "prepollens" that were produced by pterydophytes (Lycopodiales) or (3) primitive gymnosperms (e.g., Bignot, 1985). Only the central sporopollenin-containing membrane (the exine) is fossilized and it may be



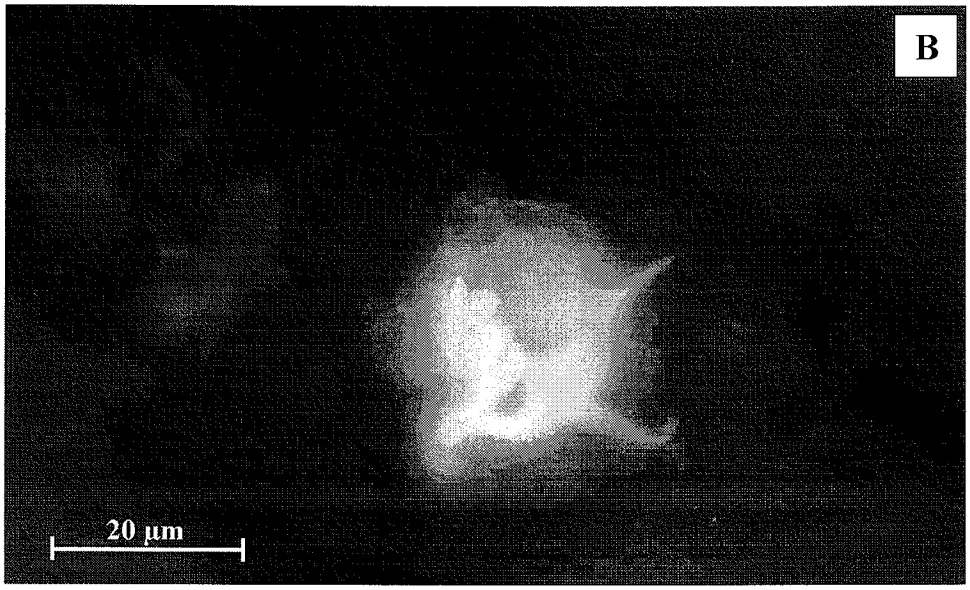


Figure 5.3: Photomicrographs of acanthomorphic (spiny) acritarchs in lithofacies D. A) An acanthomorphic acritarch with short processes in an amorphinite and carbonate matrix; UV fluorescence. 09-26-007-25W1, 1175.46 m (3856.5'). B) An acanthomorphic acritarch with longer processes in an amorphinite and carbonate matrix; UV fluorescence. 11-29-001-25W1, 1531.85 m (5025.75').

smooth or ornamented with protuberances. Sporinites range from a few micrometers to 4 mm but because biological information is absent, sporinite macerals are simply divided by size into microspores (<200 μm) and megaspores (>200 μm). Although generated on land, sporinites were widely dispersed and are found in a wide variety of marine deposits, having been transported primarily by water (e.g., Muller, 1959). However, wind dispersal may have been significant where persistent offshore winds prevailed and no fluvial sources were available (e.g., Groot and Groot, 1971; Witzke and Heckel, 1988) as would be expected for the study area during the Middle Devonian. Once in water, sporinites were transported and deposited as suspended clay to fine-silt sized particles (e.g., Heusser, 1988).

In this study, sporinites are 45-220 μm long, however, microspores are much more common than megaspores but both types are generally minor components of the kerogen in which they were found (Fig. 5.4). The sporinites are typically pale-blue fluorescing, but rarely dull orange, orange-yellow, or pale-brown fluorescing, and occur both ornamented and unornamented. Additionally, unornamented, orange megaspores (0.32 - 4.6 mm long) are observed with transmitted light (Fig. 5.4d).

5.3.4 Resinite and Cutinite

Resinite is a structureless maceral that is derived from the resins of terrestrial higher plants and is easily rounded during transport due to its softness but is highly resistant to decay (e.g., Tyson, 1995). It forms both as intracellular secretions and extracellular exudations on the surfaces of plants. On a macroscopic scale, resinite is also known as

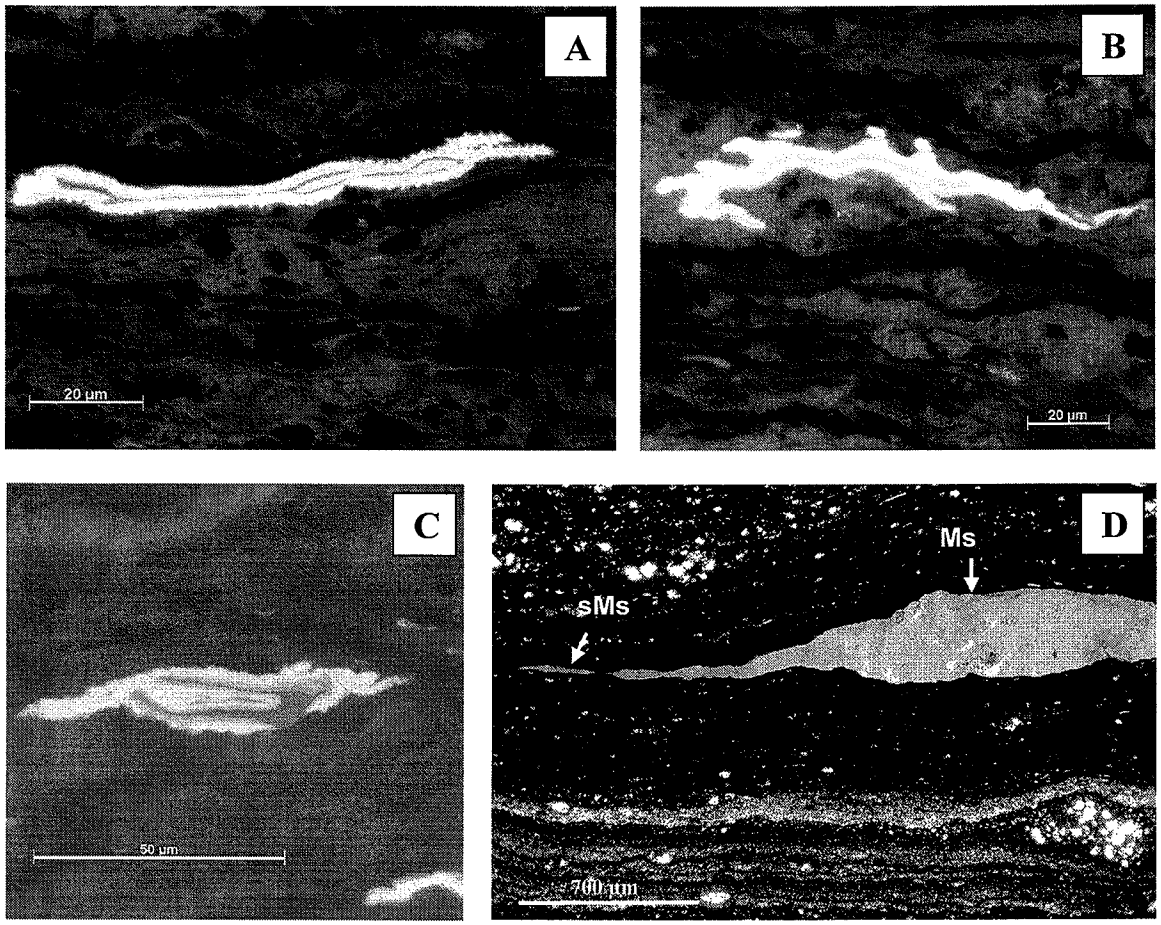


Figure 5.4: Photomicrographs of sporinite macerals in lithofacies D. A) A highly ornamented sporinite in an amorphinite and carbonate matrix, sectioned perpendicular to bedding; UV fluorescence. 04-12-007-25W1, 1198.68 m (3932.68'). B) A sporinite maceral with long protuberances in an amorphinite and carbonate matrix, sectioned perpendicular to bedding; UV fluorescence. 04-12-007-25W1, 1198.68 m (3932.68'). C) An unornamented sporinite maceral in an amorphinite and carbonate matrix, sectioned perpendicular to bedding; UV fluorescence. 09-26-007-25W1, 1175.76 m (3856.5'). D) A large megaspore (Ms) and expelled smaller megaspore (sMs) still attached via a fine filament, indicating minimal transport, in an amorphinite and carbonate matrix, sectioned perpendicular to bedding; transmitted plane-polarized light. 103/03-12-011-27W1, 1178.57 m (3866.70').

amber (e.g., Teichmuller, 1982). Cutinite is a structured maceral that consists of the resistant biomacromolecule "cutin" and is derived from the waxy cuticular layer of the epidermis of leaves and needles from terrestrial higher plants (e.g., Tyson, 1995; Stasiuk, 1999). In this study, both macerals are very rare and only occur in a bituminous laminite best described as a marine-influenced coal (see Section 5.5.2).

5.3.5 Amorphinite

Amorphinite is a shapeless and structureless maceral that was defined by van Gijzel (1982) as organic detritus that is commonly present in the matrix and has an unknown origin or affinity but likely consists of plant and bacterial remains. Carbon isotopic evidence has since shown that amorphinite in fine-grained marine sediments is ultimately derived from phytoplankton or bacteria (e.g., Lewan, 1986). Amorphinite is the most volumetrically abundant maceral in marine sedimentary organic matter (e.g., Tyson, 1995). Amorphinite may be simply divided into that which fluoresces (fluoramorphinite) and that which does not (hebamorphinite) (Senftle, 1987). Amorphinite is a persistent maceral in the laminites examined in this study (Fig. 5.1, 5.2, 5.3, 5.4).

5.3.6 Huminite/Vitrinite

The vitrinite group macerals are generally derived from woody terrestrial and marginal marine plants and formed in the diagenetic to early metagenetic zones of thermal maturation (e.g., Tyson, 1995; Stasiuk, 1999). They have an intermediate or "grey level" reflectance under white light. Huminite is the low-rank precursor to vitrinite and is generally more morphologically distinct (e.g., Tyson, 1995). Vitrinite is very rare in this

study and only occurs in a bituminous laminite best described as marine-influenced coal (see Section 5.5.2) (Fig. 5.5A).

More rarely, rounded to sub-rounded, huminite/vitrinite macerals are derived from algal precursors (e.g., Stasiuk, 1993). Akinete cells are enlarged, thick-walled, resting cells that are produced by filamentous cyanophytes in response to adverse environmental conditions and sink to the sea floor where they germinate once conditions improve (e.g., Lee, 1999). Although of algal origin, akinete cells in reflected light appear to be similar to corpohuminite macerals, which are homogeneous ovoid particles, derived from tannin-rich, intracellular precipitates of humic colloidal gels in terrestrial plants that are structureless and resistant. Akinete cells are described as corpohuminite-like bodies and included in the vitrinite group (Stasiuk, 1991; 1993; Tyson, 1995).

In this study, akinete cells, ranging between 1 and 24 μm in diameter, were found both as individuals and aggregated (Fig. 5.5). The aggregates may represent a self-sedimentation mechanism similar to that described by Grimm et al. (1997) in which phytoplankton generate a gel to promote flocculation of cells and detritus to expedite sedimentation and evade grazing during blooms. Pyrite spheres, similar in size and shape to the corpohuminite-like bodies, were also found in some laminites and are postulated to represent pyritized akinete cells (cf. Wiebe, 2003) (Fig. 5.5C).

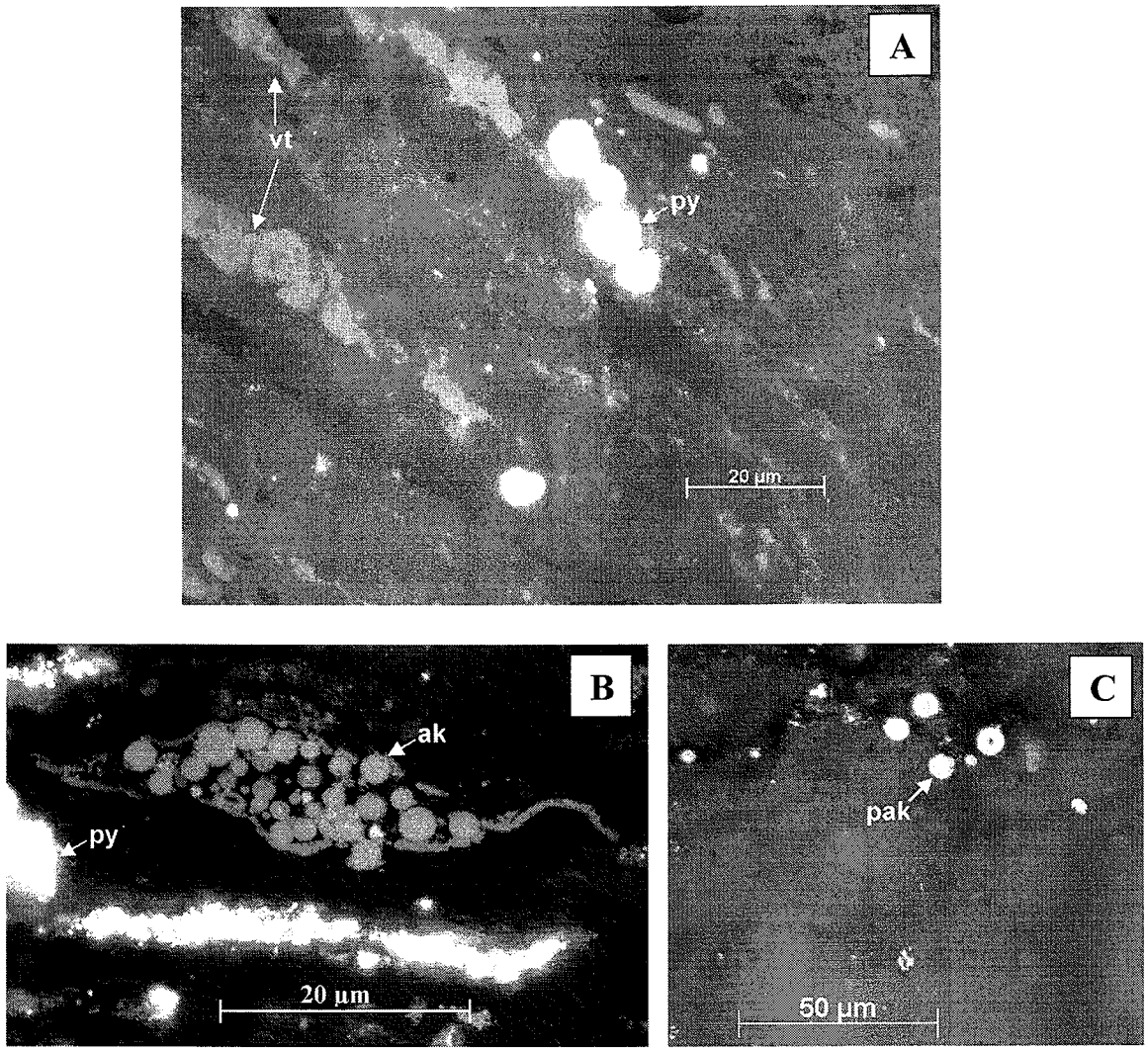


Figure 5.5: Photomicrographs of huminite/vitrinite group macerals in lithofacies D. A) Vitrinite macerals (vt) and high-reflecting, pyrite framboids (py) in an amorphinite matrix, sectioned perpendicular to bedding; reflected white light. 03-01-008-18W1, 784.55 m (2574'). B) A cluster of akinete cells (ak) in an amorphinite matrix with high-reflecting pyrite (py), sectioned perpendicular to bedding; reflected white light. 103/03-12-011-27W1, 1178.57 m (3866.70'). C) Pyrite spheres (pak) postulated to be pyritized akinete cells in an amorphinite and carbonate matrix, sectioned perpendicular to bedding; reflected white light. 04-12-007-25W1, 1198.68 m (3932.68').

5.3.7 Zooclasts

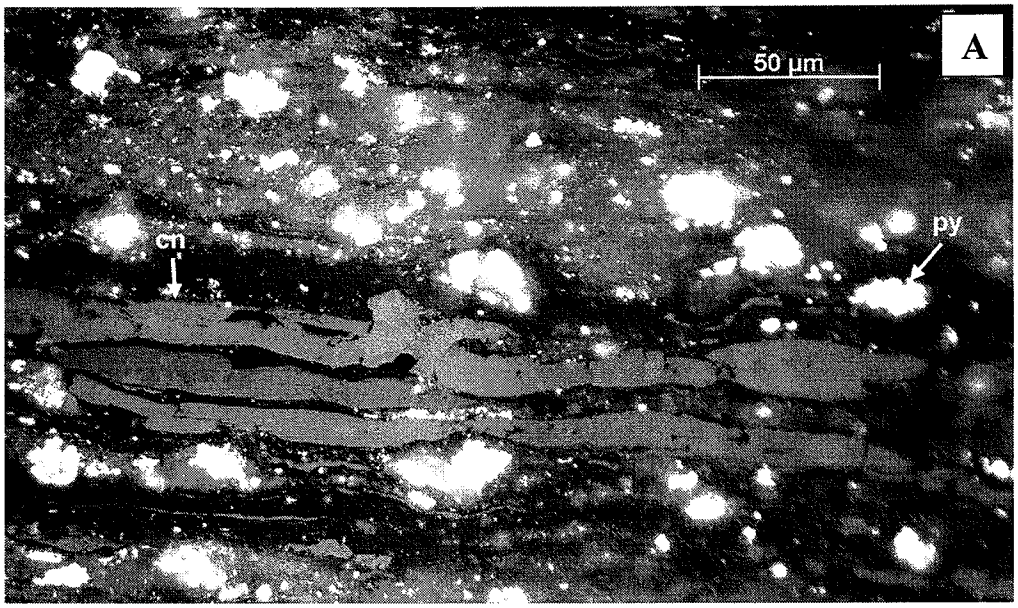
Zooclasts are an informal group of microfossils that are derived from both benthic and planktonic animals and are a very subordinate but distinctive component in maceral assemblages (e.g., Tyson, 1995; Stasiuk, 1999). Zooclasts may be considered to include microfossils with a chitinous, phosphatic (bony), calcareous, or siliceous composition (e.g., Stasiuk, 1999) or strictly those with an organic composition (e.g., Tyson, 1995). In this study, only those with an organic composition are included for the sake of consistency.

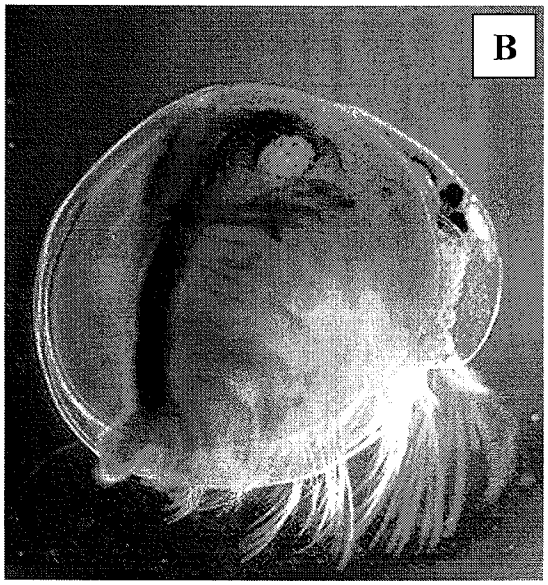
Conchostracans

Conchostracans, or clam shrimp, are crustaceans that have a body enclosed in a bivalved chitinous carapace which is generally 2 to 16 mm long (Fig. 5.6B); only the valves are usually preserved (e.g., Tasch, 1969). Extant conchostracans are able to float, swim, and burrow, and dominantly inhabit ephemeral, fresh water, alkaline inland ponds but also occur in springs and coastal salt flats. However, the occurrence of fossil conchostracans in marine assemblages has led some workers to suggest they also had marine origins (e.g., Kobayashi, 1954). Conchostracan carapace fragments are relatively rare in this study, occurring up to 229 µm long, and have hooked terminations where intact (Fig. 5.6A).

Chitinozoans

Chitinozoans are small spherical, ovoid, cylindrical, or conical vesicles of chitin-like composition which are exclusive to the Paleozoic (e.g., Bignot, 1985). The vesicles





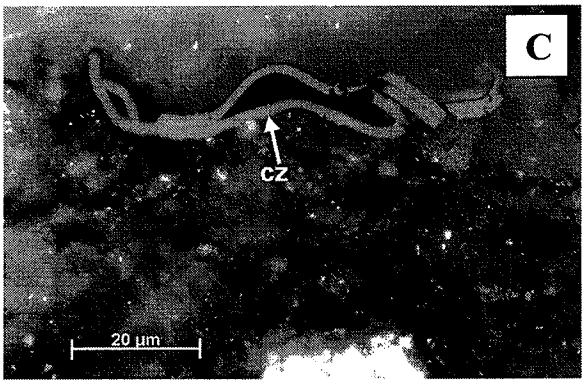


Figure 5.6: Photomicrographs of conchostracans and chitinozoans. A) Conchostracan zooclasts (cn), some with hooked terminations, in an amorphinite and carbonate matrix with high-reflecting pyrite framboids (py) in lithofacies D, sectioned perpendicular to bedding; reflected white light. 04-12-007-25W1, 1198.68 m (3932.68'). B) An extant conchostracan (clam shrimp), scale unknown (from BioMEDIA Associates, ebiomedia.com, accessed May 2005). C) A compacted and fragmented chitinozoan zooclast (cz) in a carbonate and amorphinite matrix in lithofacies D, sectioned perpendicular to bedding; reflected white light. 12-35-024-10W1, 17.58 m (57.68').

generally range from 50 μm to 2 mm in length and have highly variable surface texture and ornamentation. Although usually found as individuals, they originally had a colonial habit and are thought to be reproductive structures most likely produced by pelagic, soft-bodied, vermiform metazoans. Chitinozoans are very rare in this study and typically occur compressed and fragmented (Fig. 5.6C).

5.3.8 Calcareous/Phosphatic Microfossils

Microfossils of inorganic composition, including calcispheres, cricoconarids, and fish bones, occur as trace to major constituents within the lithofacies D bituminous laminites. Although they do not qualify as macerals based on their composition, their presence is significant for paleoenvironmental interpretation.

Calcispheres

Calcispheres are small (<500 μm diameter), calcitic microfossils that are hollow, spherical or ovoid in shape (e.g., Flügel, 2004). They have long been included in microproblematica but are now largely considered to be algal cysts, some of which may be planktonic. Marszalek (1975) documented extant *Acetabularia* dasycladacean algae in the Florida Keys that produce calcified reproductive aplanospores (calcispheres). Therefore it is possible that many fossil calcispheres may have originated from dasycladaceans (e.g., Wray, 1977). In Devonian carbonate rocks, calcispheres with simple or differentiated walls commonly occur in restricted lagoonal or back-reef settings and may be considered an indicator of paleosalinity (e.g., Flügel, 2004).

Calcispheres are not a persistent component of the bituminous laminites examined in this study but are extremely numerous where present (Fig. 5.7). The calcispheres are spherical to ovoid and are 5-80 μm in diameter but most are <10 μm. Some appear solid while others have a round central chamber. The larger calcispheres typically have very thin, dark inner walls and thick radial fibrous calcite outer walls with very fine crystalline, blocky calcite cement occluding their chambers.

Cricoconarids (Styliolinids & Tentaculitids)

The class Cricoconarida consists of two orders, the Tentaculitida and the Dacryconarida which includes styliolinids (e.g., Flügel, 2004). Tentaculitid shells are characterized by a smooth inner wall, an exterior surface that has concentric ringed thickenings, a terminal point, and partial chambering. Styliolinid shells are distinguished by walls that are smooth on both the interior and exterior. They are unchambered and typically terminate with a small bulbous extremity. The styliolinids are thought to have had a pelagic existence, although it is not clear whether they were nektonic or planktonic; the more robust tentaculitids are thought to have been nektobenthonic (e.g., Fisher, 1962).

Cricoconarids are not a persistent component of the bituminous laminites examined in this study but they are relatively common where present and are predominantly the styliolinid variety, occurring up to 2.5 mm long (Fig. 5.8A). The shells may remain intact but are commonly broken and/or compressed and are typically rimmed by radial-prismatic calcite cement. See Section 3.5.1 for more information on cricoconarids.

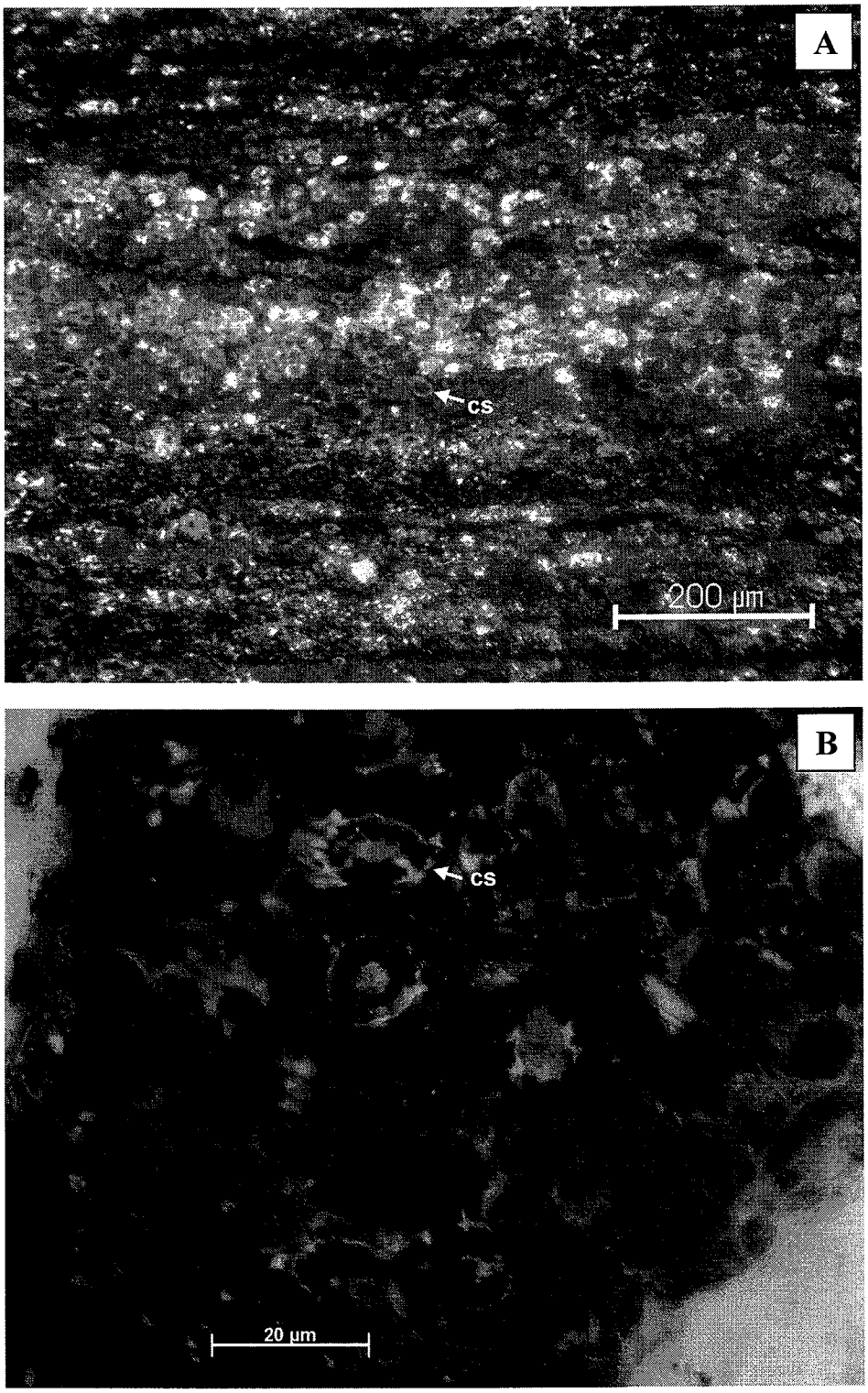


Figure 5.7: Photomicrographs of calcisphere microfossils in lithofacies D. A) Calcispheres (cs) in an amorphinite matrix, sectioned perpendicular to bedding; UV fluorescence. 04-33-023-16W1, 205.53 m (674.3'). B) Higher magnification photomicrograph of (A) showing spherical and ovoid calcispheres; blue light excitation, which yields higher intensity fluorescence from calcareous calcispheres (cs).

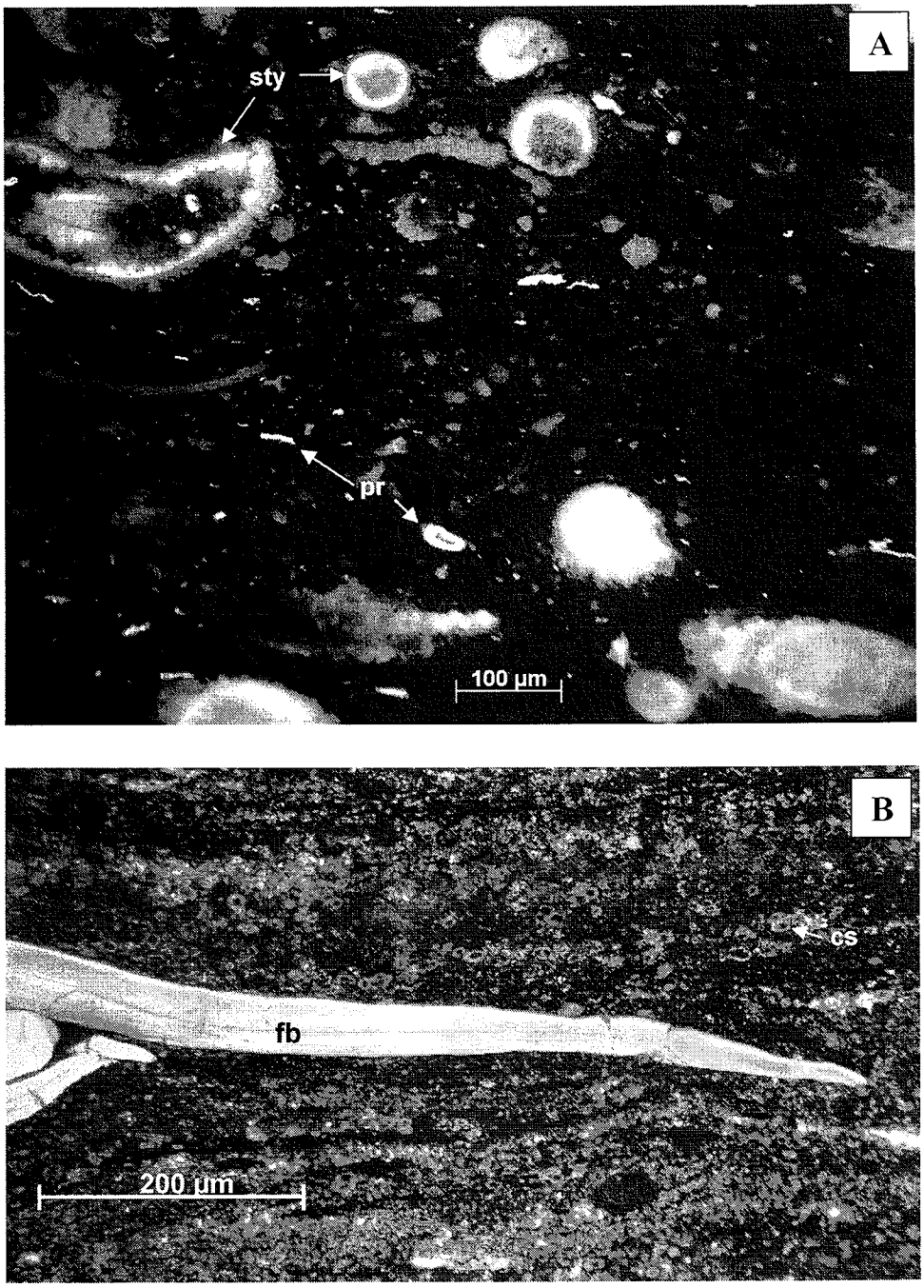


Figure 5.8: Photomicrographs of cricoconarids and fish bone microfossils in lithofacies D. A) Styliolinids (sty) sectioned transversely and longitudinally and small Prasinophyte alginites (pr) in carbonate and amorphinite matrix, sectioned perpendicular to bedding; UV fluorescence. 12-35-024-10W1, 17.58 m (57.68'). B) Fish bone zooclasts (fb) in a calcisphere (cs) and amorphinite matrix, sectioned perpendicular to bedding; UV fluorescence. 04-33-023-16W1, 205.53 m (674.3').

Fish Bones

Fish bone fragments were only found in one bituminous laminite in this study but their presence may be significant for the interpretation of paleodepositional conditions (Fig. 5.8B). Their taxonomic affinity is unknown; however, arthrodire placoderm skeletal fragments have been reported from quarries in both the Elm Point Formation and the Upper Winnipegosis Member within the study area (Hanke et al., 1996).

5.4 Organic Facies Model

The concept of organic facies, which originated in the 1970's with the increased integration of microscopy and bulk organic geochemical techniques, has evolved over the years (e.g., Tyson, 1995). One of the more current definitions is that it is "a body of sediment containing a distinctive assemblage of organic constituents which can either be recognized by microscopy, or is associated with a characteristic bulk organic geochemical composition" (Tyson, 1995, p. 5). Organic facies may be applied to petroleum exploration and basin analysis to predict the hydrocarbon potential of source rocks as a function of paleoenvironment or they may be employed in paleoecological and paleoclimatic studies to assist in the identification of cycles associated with relative sea-level changes or biological productivity (e.g., Stasiuk and Fowler, 2004).

The organic facies model used in this study is modified from that of Stasiuk and Fowler (2004), which was devised for Devonian and Mississippian strata in the WCSB. The model is based on petrographic organic facies and their relative proximity to the shoreline in a marine paleodepositional environment under conditions of normal phytoplankton

productivity (Fig. 5.9). The model of Stasiuk and Fowler (2004) is an updated version of a previous model (see Chow et al., 1995; Stasiuk, 1999). In the current model, organic facies A is the most distal and is representative of deep water depth. It consists of a maceral assemblage dominated by small thin-walled Prasinophyte alginites with rare large thick-walled Prasinophytes and acanthomorphic (spiny) acritarchs. Organic facies B is more proximal and is representative of intermediate water depth. This facies is dominated by acanthomorphic (spiny) acritarchs and also contains Prasinophyte alginites similar to organic facies A; minor sporinite macerals may also be present. The proximal organic facies C is representative of shallow water and consists of a maceral assemblage equivalent to that of organic facies B with additional persistent coccoidal alginites and sporinites. Organic facies D consists of variable amounts of radiolarian-derived siliceous microfossils and has wide lateral distribution ranging from basinal to platformal settings; this organic facies has not been observed in this study. Organic facies E represents proximal, shallow-subtidal evaporitic settings such as restricted platforms or lagoons. It consists of laminated amorphinite and/or filamentous alginites indicative of algal mats and may also contain coccoidal alginite, sporinite, funginite and chlorophyllinite. Organic facies E in this study also includes coaly, terrestrial-derived macerals, specifically vitrinite, resinite, and cutinite.

5.4.1 Algal Bloom Organic Facies

Organic-rich deposits that were generated under conditions of elevated, primary phytoplankton productivity (algal blooms) have unique maceral assemblages that distinguish them from those formed under conditions of normal phytoplankton

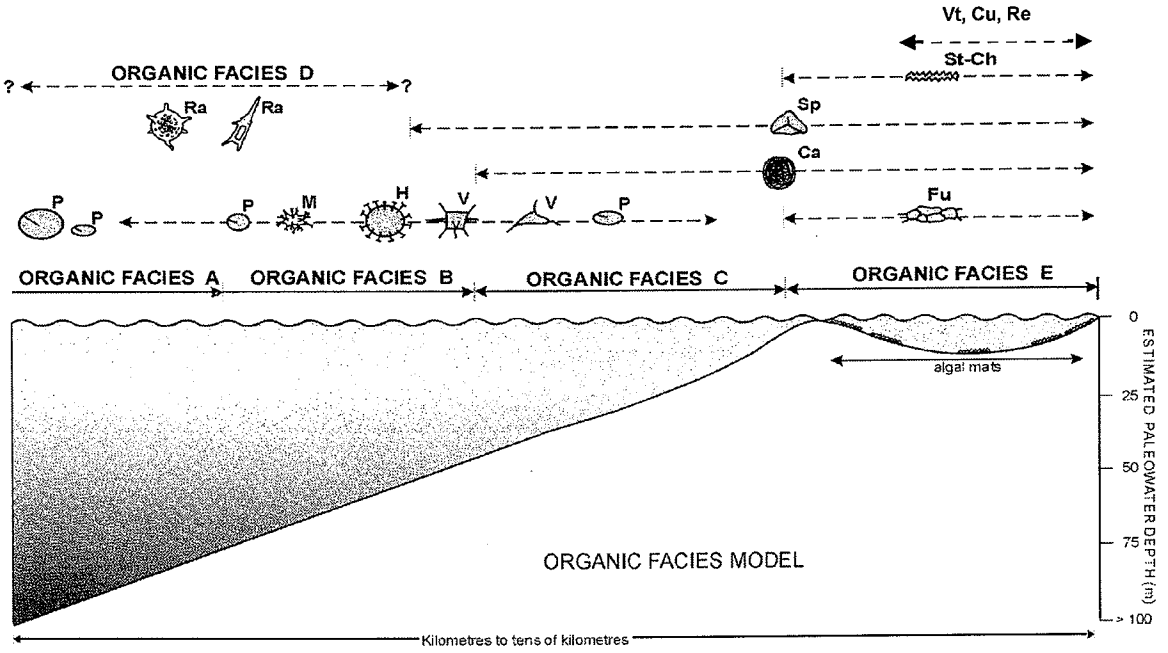


Figure 5.9: Petrographic-based organic facies model for Devonian and Mississippian strata in the Western Canada Sedimentary Basin (modified from Stasiuk and Fowler, 2004). This model shows typical maceral assemblages relative to the paleoshoreline during normal phytoplankton productivity. Organic facies A is basinal, organic facies B is intermediate, organic facies C is proximal, organic facies D is wide-ranging, and organic facies E is lagoonal. Maceral key: P - Prasinophyte alginites, "HMV"- spiny (acanthomorphic) acritarchs, Ca - coccoidal alginite, Sp - sporinite, Ra - Radiolaria, St-Ch – stromatolitic amorphinite/chlorophyllinite, Fu - funginite, Vt - vitrinite, Cu - cutinite, Re - resinite.

productivity as described previously. These algal bloom facies reflect the proliferation of algal cells and the mechanisms that phytoplankton employ for surviving times of environmental stress, such as the generation of resistant, specialized resting or non-motile cells that serve as a refuge population (e.g., South and Whittick, 1987; Sandgren, 1990; Lee, 1999; Stasiuk, 1999). Stresses induced by blooming conditions include depletion of nutrients and carbon dioxide, predation, over-floating due to crowding or turbulence and associated oxygen supersaturation, and intense solar radiation (e.g., Tappan, 1980; Round, 1981; South and Whittick, 1987; Stasiuk, 1991).

Anomalous Prasinophyte productivity may be represented by a maceral assemblage containing abundant large (>50 μm), thickened, mature phycomata (e.g., Chow et al., 1995; Stasiuk, 1999). This interpretation is especially convincing where the occurrence is in a shallow-water deposit as indicated by the sedimentology and cannot be confused with organic facies A. Anomalous, elevated cyanophyte productivity is represented in a maceral assemblage by the presence of akinete cells (e.g., Stasiuk, 1993; Chow et al., 1995; Stasiuk, 1999). Maceral assemblages that contain both akinete cells and abundant, large, mature Prasinophyte alginites may represent either a rapid succession of monospecific blooms or alternatively a single polyspecific bloom. In bloom successions, the initial bloom is likely to be dominated by the algae species with a faster generation time and smaller size (e.g., Margalef, 1978).

Extensive respiration by phytoplankton and heterotrophic bacteria grazing on phytoplankton detritus during blooms may deoxygenate the water column (e.g.,

Demaison and Moore, 1980; Chow et al., 1995; Clegg et al., 1997). Bloom-induced deoxygenation may cause mass kills of zooplankton in the water column resulting in a pelagic fall-out that is recorded as anomalous concentrations of calcareous pelagic organisms, such as cricoconarids, in a bloom assemblage (e.g., Chow et al., 1995). Some cyanophytes are capable of producing potent toxins (cyanotoxins) and where akinete cells and zooclasts are found together in the same assemblage, toxicity may have also played a role in the demise of zooplankton (cf. Lee, 1999). The presence of zooclasts is significant but consequential and not requisite for identifying bloom facies.

Three bloom facies are identified in this study: organic facies BL1 is characterized by the presence of akinete cells with little evidence for enlarged Prasinophyte alginites and is interpreted to represent anomalous, high cyanophyte productivity. Organic facies BL2 is characterized by the presence of akinete cells and abundant enlarged Prasinophyte alginites and is considered to represent anomalous, high cyanophyte and Prasinophyte productivity. Organic facies BL3 is characterized by a plethora of calcispheres within an amorphinite matrix and is interpreted to represent anomalous, high calcisphere-producing phytoplankton productivity, which may be the first documented example of calcareous phytoplankton from Paleozoic strata (pers. comm., L. Stasiuk, 2004).

5.5 Stratigraphic Distribution of Organic Facies

Representative bituminous laminites (lithofacies D) at various stratigraphic positions within the Winnipegosis, Elm Point, and Ratner formations were sampled to determine their maceral assemblages and to delineate organic facies using organic petrographic

methods (Table 5.2; Fig. 5.10, 5.11; refer to Sections 2.3, 2.4, 2.5). Due to the thin nature of the laminites, one sample was collected for each of the laminites examined with the exception of the laminite in 04-33-023-16W1, 205.4-206.1 m (673.8-676.2'), which was anomalously thick and was sampled near its base and the top of its cored interval. The maceral assemblage for each laminite was determined qualitatively by visually estimating the relative abundance of each maceral (abundant, common, rare, trace, or questionable) in the sample and an organic facies was assigned on the basis of their maceral content (Appendix E). Where maceral assemblages did not unequivocally meet all of the criteria to be assigned an organic facies, a "best fit" was found. Laminites that were assigned a bloom facies were also assigned a secondary organic facies based on subordinate macerals that likely represent "background" normal productivity prior to the blooming. The following sections summarize the organic petrology of bituminous laminites (lithofacies D) as described and interpreted in Chapters 3 and 4.

5.5.1 Organic Facies in Ramp-to-Platform/Basin Transition

Bituminous laminites in the ramp-to-platform and the ramp-to-basin transition interval span the uppermost Lower Winnipegosis Member/Elm Point Formation and the lowermost Upper Winnipegosis Member. Bituminous laminites sampled from this interval were found to have varied organic facies indicative of both normal and elevated productivity (Fig. 5.10, 5.11).

Table 5.2: Summary of organic facies recognized in bituminous laminite (lithofacies D) samples.

LOCATION	DEPTH	LAMINITE TYPE	PRIMARY ORGANIC FACIES	SECONDARY ORGANIC FACIES
11-29-001-25W1	1531.85 m (5025.75')	Ramp-to-Platform Transition	BL1	C
11-29-001-25W1	1528.34 m (5014.25')	Platform Slope	BL1	A
05-13-005-22W1	1153.76 m (3785.3')	Platform Interior	BL2	C
05-13-005-22W1	1157.94 m (3799')	Platform Interior	BL2	C
04-12-007-25W1	1198.68m (3932.68')	Onlapping Platform Slope	BL1	C
09-26-007-25W1	1175.46 m (3856.5')	Platform Slope	BL1	B
02-21-007-28W1	1447.7 m (4749.7')	Ramp-to-Basin Transition	A	N/A
03-01-008-18W1	783.95 m (2572')	Platform Interior	E	N/A
03-01-008-18W1	784.55 m (2574')	Platform Interior	E	N/A
103/03-12-011-27W1	1178.57m (3866.70')	Basinal Salina	BL2	C
04-33-023-16W1	205.95 m (675.7')	Onlapping Platform Slope	BL3	C
04-33-023-16W1	205.53 m (674.3')	Onlapping Platform Slope	BL3	C
12-35-024-10W1	17.58 m (57.68')	Ramp-to-Platform Transition	BL1	C

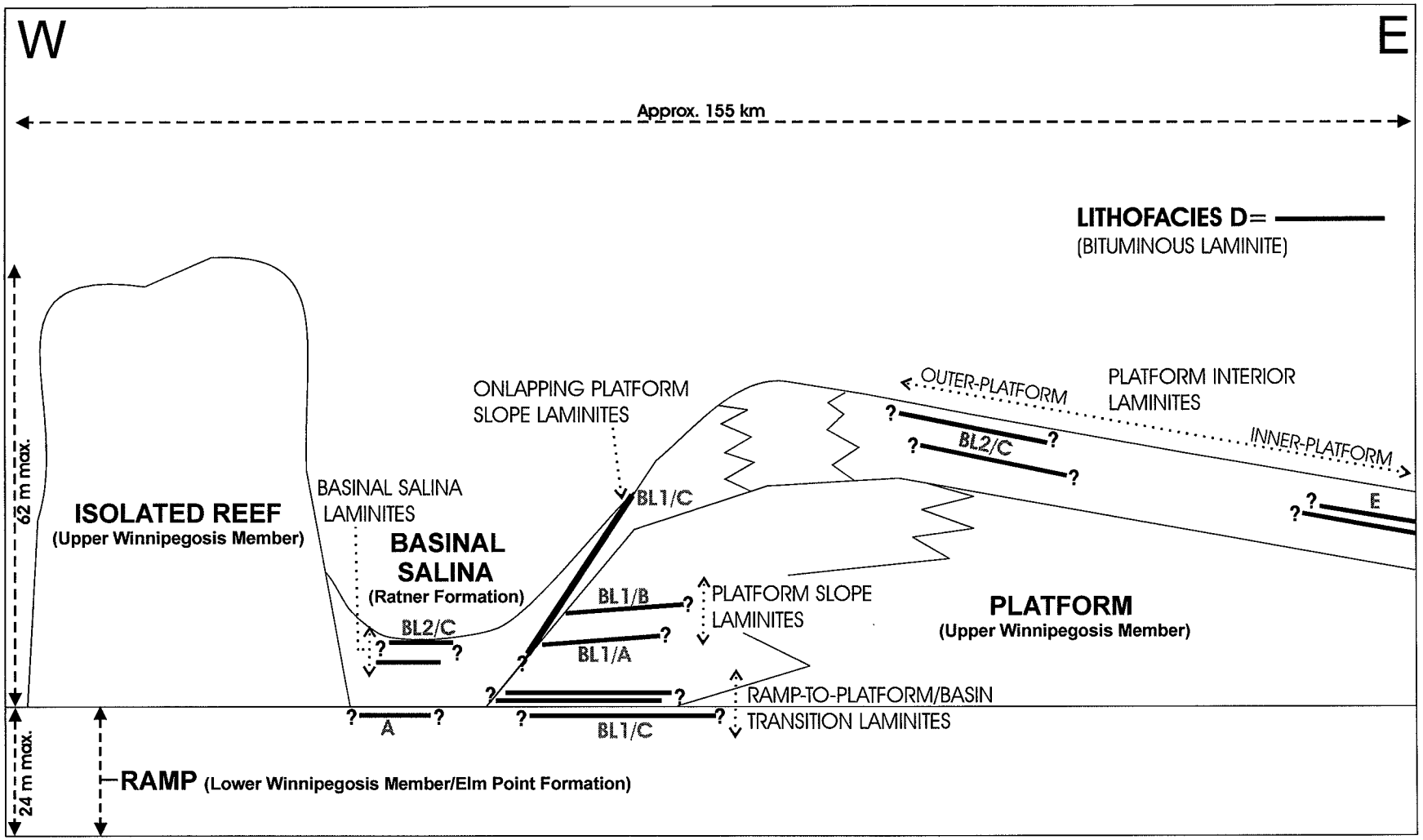


Figure 5.10: Schematic diagram on an W-E axis through the study area illustrating the stratigraphic positions of the various bituminous laminites (lithofacies D) and their constituent organic facies (in red). Question marks indicate unknown lateral extent due to insufficient core control. Scales are approximated and non-linear.

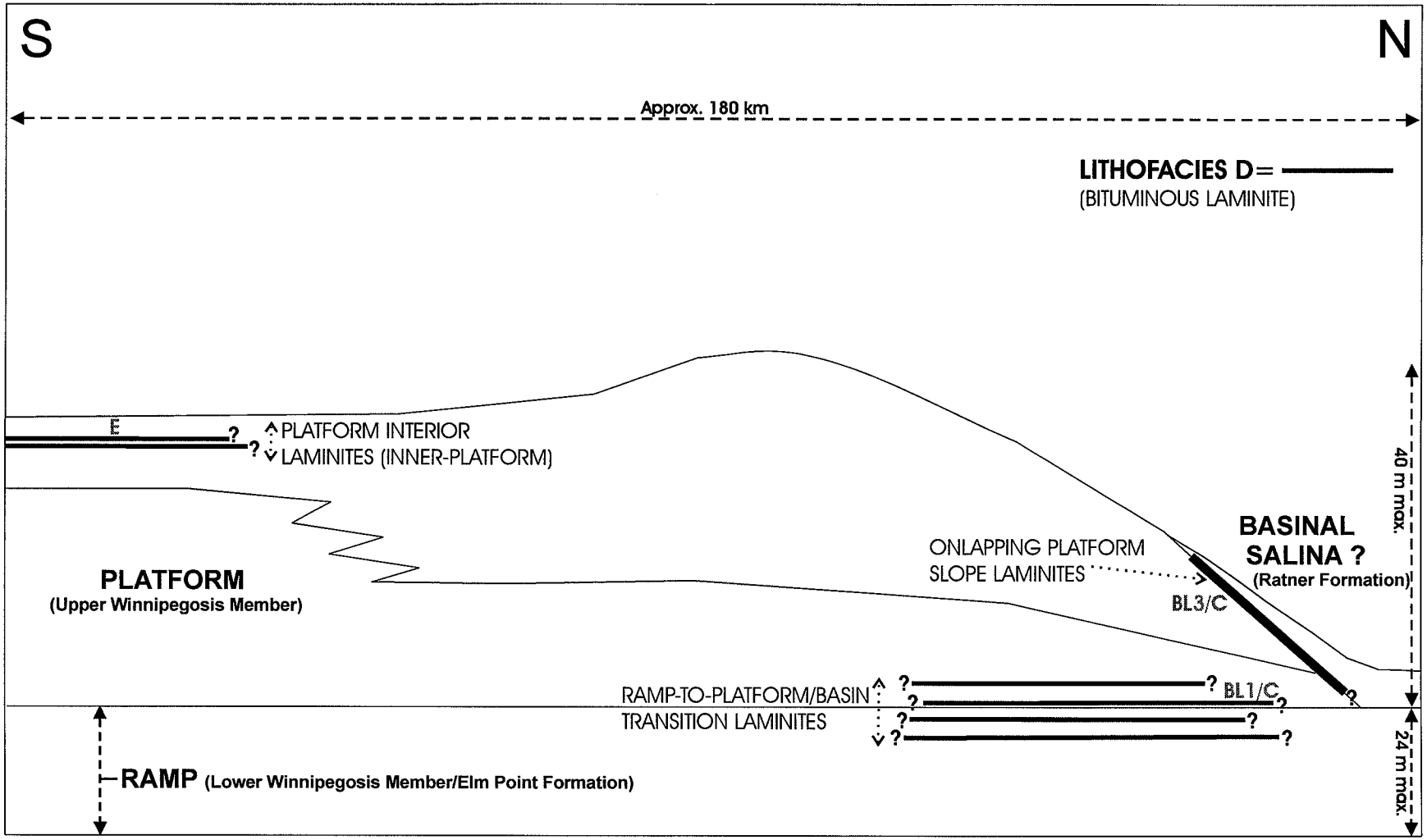


Figure 5.11: Schematic diagram on an S-N axis through the study area illustrating the stratigraphic positions of the various bituminous laminites (lithofacies D) and their constituent organic facies (in red). Question marks indicate unknown lateral extent due to insufficient core control. Scales are approximated and non-linear.

Bituminous laminites in the ramp-to-platform transition interval (wells 11-29-001-25W1, 1531.85 m [5225.75']; 12-35-024-10W1, 17.58 m [57.68']) have primary organic facies consistent with BL1 as indicated by the presence of individual akinete cells (6.2−24 μm in diameter). A secondary organic facies most similar to organic facies C was identified in these laminites by the presence of yellow to yellow-orange-fluorescing Prasinophyte alginites, including common small (10-50 μm long) forms and rare to common, large (50-341 μm long) forms; trace blue-fluorescing acritarchs (11-22 μm in diameter) and orange-fluorescing coccoidal alginites (67-105 μm wide); and trace to rare, blue and dull orange-fluorescing (degraded) sporinites (153-220 μm long). Trace chitinozoan zooclasts (70 μm long) and common cricoconarid (predominantly styliolinid) fragments (100 μm-2.5 mm long and 58-445 μm in diameter) were also observed.

In contrast, a bituminous laminite from well 02-21-007-28W1, 1447.7 m (4749.7'), where the Lower Winnipegosis ramp succession is overlain by the basinal Ratner Formation, has a maceral assemblage in the uppermost ramp succession that is consistent with organic facies A (Fig. 5.10), including common small (26-50 μm) Prasinophyte alginites and rare large (50-70 μm) Prasinophyte alginites, which fluoresce yellow.

5.5.2 Platform Interior Organic Facies

Bituminous laminites in the platform interior lithofacies association in the Upper Winnipegosis Member occur at inner and outer platform locations. Bituminous laminites from the inner platform (well 03-01-008-18W1) were found to have maceral assemblages

consistent with variations of organic facies E. One sample (783.95 m [2572']) includes abundant mat-like, laminated amorphinite containing possible trace filamentous alginites along with trace large (75-100 μm long), yellow-fluorescing Prasinophyte alginites, and trace dull orange-fluorescing and bitumen impregnated sporinite (75 μm long). The other bituminous laminite (784.55 m [2574']) is best described as a marine-influenced coal based on a maceral assemblage containing a mixture of marine and terrestrially derived macerals including: (1) common small (23-30 μm long) Prasinophytes and rare large (53-60 μm long) Prasinophytes which are yellow-fluorescing; (2) rare orange-fluorescing, coccoidal alginite (35-40 μm long); (3) common pale-brown (degraded) to pale-blue fluorescing sporinites (45-85 μm long); (4) common irregular, elongate bodies of vitrinite; and (5) trace possible irregular cutinite and rare resinite, which occurs as globular bodies.

Bituminous laminites located at a more distal position in the platform (well 05-13-005-22W1, 1153.76 m [3785.3'] and 1157.94 m [3799']), were found to have a primary organic facies equivalent to BL2 with maceral assemblages including akinete cells (2-6 μm diameter), which occur individually and aggregated; and abundant, large (50-194 μm long), yellow-fluorescing, Prasinophyte alginites. These laminites also have a secondary organic facies most similar to organic facies C, based on subordinate macerals including common, small (9-50 μm long), yellow-fluorescing Prasinophyte alginites and trace to rare, orange-yellow (degraded) and pale blue-fluorescing sporinites (62−179 μm long). Additionally, trace filamentous alginite within the amorphinite

matrix and common conchostracan zooclasts (10-100 μm long) that occur in layers were observed.

5.5.3 Platform Slope Organic Facies

Bituminous laminites in the platform slope lithofacies association in the Upper Winnipegosis Member have only been observed along the western margin. Two representative samples from wells 11-29-001-25W1 and 09-26-007-25W1 have primary organic facies that are consistent with BL1 as evidenced by the presence of akinete cells (4.3-13 μm diameter). The secondary maceral assemblages in these laminites vary depending on their relative stratigraphic position within the slope succession. The lower laminite (well 11-29-001-25W1, 1528.34 m [5014.25']) has a secondary organic facies that is most similar to A as evidenced by common small (8-38 μm long) and rare large (54-60 μm long), yellow-fluorescing Prasinophyte alginites. However, the higher laminite (well 09-26-007-25W1, 1175.46 m [3856.5']) has a secondary organic facies that is most similar to B as evidenced by abundant small (7-49 μm long) and common large (68-170 μm long), yellow-fluorescing Prasinophyte alginites; rare blue-fluorescing acritarchs (4.8-13 μm diameter); and rare pale blue-fluorescing sporinites (76-110 μm long).

The platform slope succession along the western margin is onlapped by a bituminous laminite (well 04-12-007-25W1, 1198.68 m [3932.68']) which has a primary organic facies consistent with BL1 as evidenced by pyrite spheres (3.4-6.8 μm in diameter) that

are postulated to be pyritized akinete cells. A secondary organic facies most similar to organic facies C consists of abundant small (5-50 μm long) and rare large (50-58 μm long), yellow-fluorescing Prasinophyte alginites; and rare pale blue-fluorescing sporinites (56-113 μm long). Zooclasts include abundant conchostracan fragments (12-229 μm long), which commonly occur in layers.

A bituminous laminite that onlaps the slope succession of the northern platform margin (well 04-33-023-16W1, 205.95 m [675.7'] and 205.53 m [674.3'])has a primary organic facies consistent with BL3 as evidenced by very abundant calcispheres in an amorphinite matrix. The calcispheres are spherical to ovoid and are 5-80 μm in diameter but most are <10 μm (see Section 3.5.1 for a more thorough petrographic description). A weak expression of a secondary organic facies that is most similar to organic facies C includes an orange-fluorescing coccoidal alginite (97 μm in diameter), and a blue-fluorescing arcitarch (10 μm in diameter). Zooclasts consist of trace concentrations of fish bone fragments (up to > 700 μm long).

5.5.4 Basinal Salina Organic Facies

A representative sample of a bituminous laminite (well 103/03-12-011-27W1, 1178.57 m [3866.70']) from the basinal salina succession of the Ratner Formation has a primary organic facies consistent with BL2 including individual and clustered akinete cells (1-18 μm diameter); pyrite spheres (3.3-6.6 μm diameter) postulated to be pyritized akinete cells; and abundant, large (53-76 μm long) Prasinophyte alginites. The

Prasinophytes fluoresce pale blue, which is likely due to absorbed or refractory liquid hydrocarbons in the alginites (cf. Taylor et al., 1998). A secondary organic facies, most similar to organic facies C, is represented by common small (9-49 μm long), pale blue-fluorescing Prasinophyte alginites as well as rare unornamented, large megaspores, 3.5-4.6 mm in length. One megaspore was found to still be connected to a smaller expelled megaspore (0.32 mm long) via a fine filament (Fig. 5.4C).

CHAPTER 6: DEPOSITIONAL HISTORY

6.1 Introduction

This chapter provides an interpretive overview of the depositional history of the Winnipegosis, Elm Point, and Ratner formations within the study area based on a combination of observations and interpretations presented in previous chapters and the findings of previous studies.

6.2 Elm Point Formation and Lower Winnipegosis Member: Ramp Development

During initiation of the second transgressive phase of the Hume-Dawson sequence, low-energy peritidal sediments of lithofacies A (non-fossiliferous mudstone) locally filled in paleotopographic lows on the hiatal surface of the Ashern Formation (Fig. 6.1A) (cf. Norris et al., 1982; Perrin, 1982; Moore, 1988). Topographic highs on the Ashern Formation surface remained subaerially exposed and contributed intraclasts to lithofacies A during this time. As water depth increased, normal, open marine conditions were established in which relatively uniform deposits (lithofacies B: mottled-nodular skeletal wackestone-mudstone) accumulated in a carbonate ramp setting (cf. Perrin, 1982). Locally, low-energy peritidal deposition (lithofacies C: nodular-patterned mudstone) occurred on ephemeral, offshore tidal flat islands (cf. Pratt et al., 1992). At inner-ramp positions, thick occurrences of lithofacies C have been recognized, suggesting that low-energy peritidal deposition was also associated with paleoshoreline(s), which persisted much longer than the ephemeral islands. Bituminous laminite (lithofacies D) was deposited locally in the uppermost part of the ramp succession, interrupting deposition of

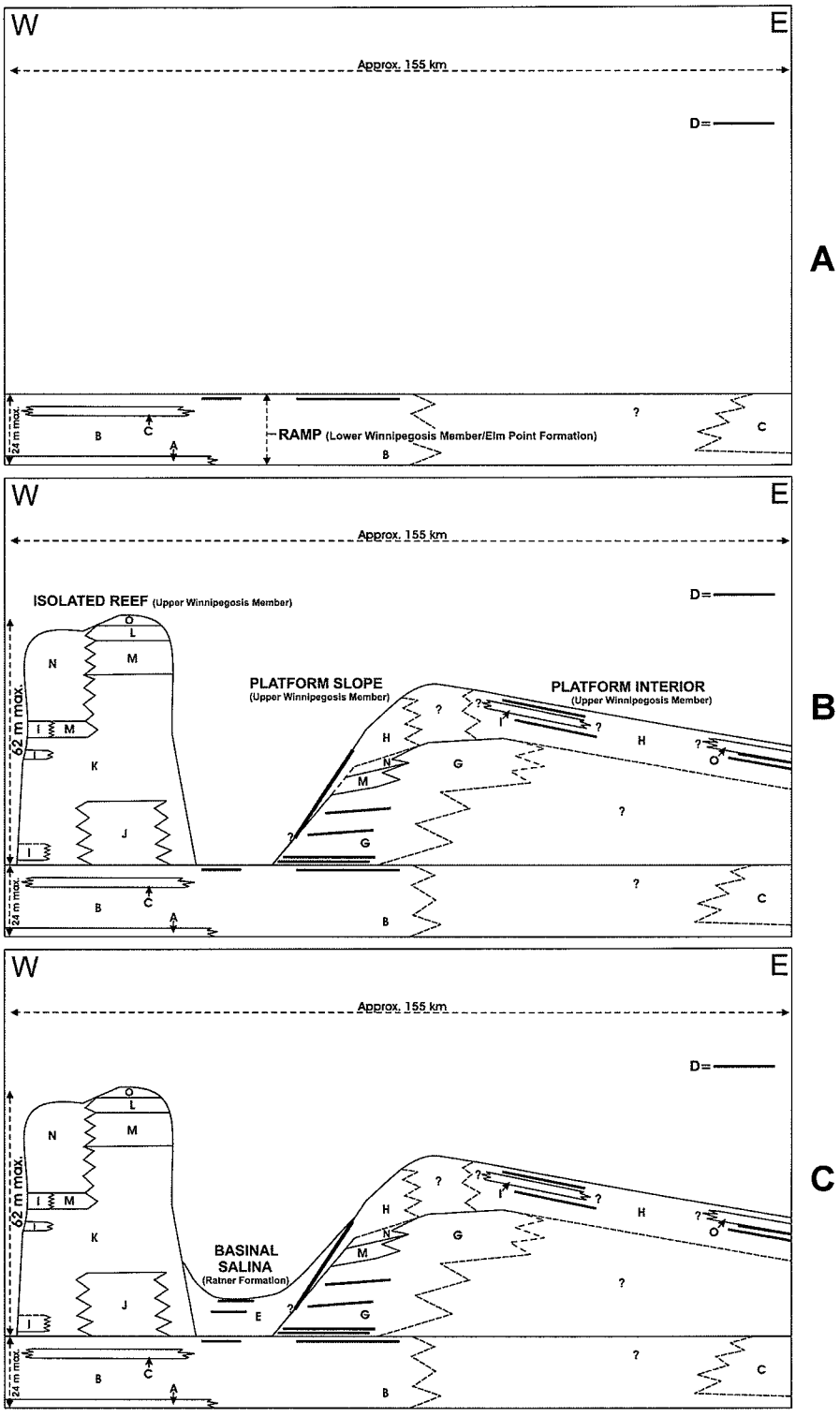


Figure 6.1: Schematic diagram outlining the sequence of lithofacies deposition in the Elm Point, Winnipegosis, and Ratner formations within the study area. A) Development of the carbonate ramp. B) Basin differentiation and development of the carbonate platform and isolated reefs. C) Evaporative drawdown and development of salina(s). Scales are approximated and non-linear; capitalized letters represent lithofacies; question marks indicate no core control.

lithofacies B. The occurrence of organic facies A in this laminite indicates that normal phytoplankton productivity occurred in a distal setting and that water depth was sufficient to permit preservation via intermittent depth-related anoxia.

6.3 Upper Winnipegosis Member: Platform Development

Following deposition of the Lower Winnipegosis Member/Elm Point Formation, the transgression continued and the Elk Point Basin differentiated into two depositional regimes: a shallow fringing carbonate platform and a bathymetrically deeper basin (Fig. 6.1B) (e.g., Perrin, 1982). This differentiation appears to be at least partially tectonically controlled within the study area. The western platform margin lies approximately coincident with the Birdtail-Waskada Axis (Fig. 1.2; Encl. 9), which is a trend manifested as structural and isopach anomalies in Phanerozoic strata that overlie the Precambrian Superior Boundary Zone (e.g., McCabe, 1971). However, if movements occurred along the zone during Winnipegosis time, they were subdued enough so as not to show on the structure of the underlying Ashern Formation. The northern platform margin, which has a peculiar prominent east-west trend, lies roughly coincident with the east-west contact between the Uchi and English River basement domains (Fig. 1.2; Encl. 9). Evidence for reactivation of this contact during the Devonian has not been documented in previous studies; however, it is suspected that this contact was active during the early Paleozoic, at least in the vicinity of the Birdtail-Waskada Axis, based on east-west trending isopach anomalies in the Ordovician Winnipeg Formation (pers. comm., J. Bamburak, 2006). If vertical movement along the Uchi-English River contact occurred during Winnipegosis time, then it is postulated that platformal

deposition within the study area occurred on a basement block that was bounded by the Superior Boundary Zone and the Uchi-English River contact and was uplifted sufficiently to sustain the carbonate factory during transgression. Areas to the north and west of these boundaries essentially became a starved basin where normal carbonate deposition ceased except at locations where isolated reefs initiated.

6.3.1 Ramp-to-Platform and Ramp-to-Basin Transitions

Due to sparse core control, the mode of platform growth remains largely speculative; however, gradational contacts between the ramp (lithofacies B: mottled-nodular skeletal wackestone-mudstone) and platform slopes (lithofacies F: massive-mottled mudstone and G: septarian-type nodular skeletal packstone) suggest that carbonate deposition was not interrupted over the platform area during basin differentiation. If the platform had tectonically imposed boundaries, an initial aggradational mode of growth would be expected because the carbonate factory was presumably maintained over the uplifted area and would have had ample accommodation space.

Organic petrology of bituminous laminites (lithofacies D) from the ramp-to-platform/ basin transition (Fig. 5.10, 5.11) provides additional insight into the environmental conditions in the Elk Point Basin around the time of basin differentiation. Bituminous laminites from the ramp-to-platform transition invariably have primary organic facies consistent with elevated phytoplankton productivity (organic facies BL1) and secondary organic facies, which represents "background" normal phytoplankton productivity, consistent with proximal settings (organic facies C). The presence of organic facies C in

the uppermost ramp and lowermost platform at locations that later evolved into platform slopes substantiates the interpretation that the transgression was still underway at the time of basin differentiation.

The relative abundance of bituminous laminites indicative of elevated phytoplankton productivity at the ramp-to-platform transition and notable absence of bituminous laminites lower in the ramp succession suggest that environmental changes associated with basin differentiation and transgression were conducive for algal bloom initiation. Although it is impossible to know exactly what environmental factors may have triggered the blooms during Winnipegosis time, modern bloom-initiating mechanisms are numerous and vary depending on species. Triggers may include elevated nutrient concentration in the euphotic zone as a result of upwelling, wind-mixing, or eddy-induced vertical mixing; changes in ratios of growth-limiting dissolved nutrients (e.g., Si, N, P); water-column stratification, which is influenced by the extent of solar warming, wind stress, rainfall, and run-off; water temperature changes; and the amount of growth-limiting micronutrients released by the catabolism of dissolved organic matter by bacteria (e.g., Roelke and Buyukates, 2001).

6.3.2 Platform Interior

Evolution of the platform interior remains a matter of speculation because the lower portion was not cored. However, the upper portion appears to have relatively uniform lithology (lithofacies H: bedded-mottled peloidal packstone), and is interpreted to have been deposited in open to slightly restricted, low energy, shallow-marine conditions.

This sedimentation was only episodically interrupted by storm events resulting in deposition of tempestites (lithofacies I: intraclast floatstone). Because the platform fringed the basin, only achieving a maximum thickness of approximately 40 m within the study area, it would have been especially susceptible to relative changes in sea-level. If the rate of transgression had been variable, the mode of platform growth may have alternated between aggradational and progradational, at least locally, as accommodation space waxed and waned (cf. Jones and Desrochers, 1992).

Organic petrology of bituminous laminites (lithofacies D) from the upper part of the platform interior succession and inner-platform positions indicates that normal primary productivity prevailed in a near-shore lagoonal setting. Organic facies E, which has maceral assemblages that are consistent with microbial mats and marine-influenced coal, locally received terrestrial-derived organic matter. Occurrences of bituminous laminites with organic facies E occur in close proximity stratigraphically to lithofacies O (microbial bindstone), which is consistent with the interpreted setting. In contrast, bituminous laminites from outer-platform positions have primary maceral assemblages consistent with elevated phytoplankton productivity (organic facies BL2) and secondary "background" maceral assemblages consistent with normal phytoplankton productivity in a proximal setting (organic facies C). This suggests that water depth at outer platform locations was relatively shallow and occasionally favorable for the initiation of phytoplankton blooms. The lack of observable vertical variability in the organic facies from the platform interior succession may be attributed to the absence of core from the lower portion of the platform interior.

6.3.3 Platform Slope

Deeper platform slope deposits (lithofacies G: septarian-type nodular skeletal packstone and lithofacies F: massive-mottled mudstone) were overlain by shallower deposits (lithofacies H: bedded-mottled peloidal packstone), which appear to have been ubiquitous in the platform interior. Biostromes (lithofacies M: coral-stromatoporoid rudstone-framestone) initiated locally at upper-lower slope positions and laminated sediments (lithofacies N: laminated mudstone-peloidal packstone) were deposited locally at mid-slope positions. A progradational mode of deposition appears likely as the platform approached sea-level, which would be consistent with the interpretations of Ehrets and Kissling (1987) for the Winnipegosis Formation in North Dakota. During this time tempestites/debrites (lithofacies I: intraclast floatstone) were episodically deposited on the platform slopes.

Organic petrology of bituminous laminites within the western platform slope succession indicates that elevated phytoplankton productivity (primary organic facies BL1) episodically occurred over the platform slope in waters that were at distal to intermediate settings relative to the paleoshoreline (secondary "background" organic facies A and B respectively). The change in secondary organic facies from C in the ramp-to-platform transition to A in the lower platform slope indicates increasing distance from the paleoshoreline and is consistent with transgression. The upward progression of secondary organic facies from organic facies A to B represents a shallowing-upward trend which could be a function of platform growth.

Bituminous laminites onlapping both the western and northern platform slopes have primary organic facies consistent with elevated phytoplankton productivity (organic facies BL1 and BL3 respectively). Their secondary "background" organic facies C indicates that the phytoplankton bloom(s) occurred in shallow, proximal waters. The secondary organic facies could be interpreted as resulting from a continuation of the shallowing-upward trend observed in the slope succession, but more likely it was influenced, at least in part, by regression following deposition of the Upper Winnipegosis Member. Increased salinity and possibly basin-water stratification due to evaporative concentration prior to the onset of Ratner Formation deposition could conceivably have been influential in triggering the phytoplankton blooms (cf. Davies and Ludlam, 1973). This hypothesis is supported by the presence of anhydrite laths at the base of the bituminous laminite onlapping the northern slope in well 04-33-023-16W1, 205.95 m (675.7').

6.3.4 Platform Termination

Platform growth was terminated by an eustatic sea-level fall known as the Black Creek event, which caused the Elk Point Basin to become restricted and eventually led to the deposition of the Prairie Evaporite Formation (e.g., Moore, 1988). Within the study area, intertidal to supratidal conditions led to the deposition of lithofacies O (microbial bindstone) locally both in the uppermost platform interior succession and over the slopes during the regression near the end of Winnipegosis time (cf. Perrin, 1982).

6.4 Upper Winnipegosis: Isolated Reef Development

Upon basin differentiation, isolated reefs initiated on top of the ramp succession (Fig. 6.1B). One of the enigmatic features of the Winnipegosis Formation that largely remains unknown and has implications for petroleum exploration is why the isolated reefs initiated where they did in the basin. Although the reefs occur throughout the basin, Gendzwill and Wilson (1987) noted that isolated reefs in southern Saskatchewan are not uniformly distributed but clustered in some areas and are largely absent in others. The prevailing opinion among previous workers is that the reefs initiated on antecedent topographic highs on the ramp (e.g., Precht, 1986; Perrin, 1987; Rosenthal, 1988; Kent and Minto, 1991). Based on their work in the Manitoba outcrop belt, Kent and Minto (1991) suggested that positive relief on the sea floor was possibly an expression of paleokarstic hills on the underlying Silurian strata or localized depositional thickening of the ramp. Martindale and MacDonald (1989) concluded that isolated reefs in the Tableland area of Saskatchewan likely initiated on structural features because of thinning of the ramp under the reefs and absence of faunal differentiation between reef and basinal areas. Likewise, Martindale et al. (1991) did not observe a bioconstructed foundation in the Hitchcock area of Saskatchewan. Perrin (1987) suggested that reef initiation in North Dakota may also have been facilitated by moderate shallowing of the sea caused by a temporary reduction in the rate of transgression at the end of ramp deposition.

In the study area, some isolated reefs do occur over ramp deposits that are thicker than those in adjacent inter-reef areas, while others occur over ramp deposits that are actually thinner. Isolated reefs generally trend parallel to the platform margin and are

concentrated at the southern end of the study area (Encl. 9). This spatial arrangement may be attributed to reef initiation on sea-floor structures related to reactivation of the Superior Boundary Zone. McCabe (1988) also noted that isolated reef swarms occur in the Swan River and Dawson Bay areas which are along the same trend north of the study area.

Once initiated, the isolated reefs within the study area appear to have continued to grow throughout the transgression as there is no evidence for drowned reefs (Fig. 4.5). However, most isolated reefs did not achieve sea level until late in their depositional history as evidenced by the preferred occurrence of lithofacies M (coral-stromatoporoid rudstone-framestone) near the top of the reefs and the absence of subaerial exposure features within the isolated reef lithofacies associations (cf. Fu et al, 2004; Fu et al., 2006). Isolated reef growth was terminated by the eustatic sea-level fall near the end of Winnipegosis time, which resulted in the deposition of lithofacies O (microbial bindstone) as intertidal to supratidal conditions formed locally over the isolated reefs (cf. Perrin, 1982; Moore, 1988).

6.5 Brightholme Member: Basin Deposition

The Brightholme Member has long been considered to be the basinal equivalent of the Upper Winnipegosis Member isolated reefs and by association the platform, based largely on the fact that it commonly contains non-bituminous interbeds of reef detritus which were presumably emplaced during reef growth (e.g., Kendall, 1975; Stoakes et al., 1987; Rosenthal, 1988; Jin and Bergman, 2001). However, Rosenthal (1988) reported

that bituminous laminites extend below some isolated reefs in the Swan River and Mafeking areas north of the study area but are not present below the larger reefs and interpreted them to represent an extensive euxinic sedimentation event.

Bituminous laminites (lithofacies D) were not observed below isolated reefs in the study area. However, following the observations made by Rosenthal (1988) it is suggested that the onset of Brightholme deposition predated reef initiation in some areas of the basin and therefore some of the bituminous laminites in the platform portion (lowermost Upper Winnipegosis Member) of the ramp-to-platform transition in the study area may also be stratigraphically equivalent to the lowermost Brightholme Member. It is further postulated that the bituminous laminites onlapping the platform slopes may extend into the basin and would therefore constitute the uppermost Brightholme Member. If so, evidence for elevated phytoplankton productivity in the Brightholme Member (organic facies BL1 and BL3) in the study area would be consistent with the organic petrological observations made by Stasiuk (1993) on the Brightholme Member in Saskatchewan. Onlapping platform-slope bituminous laminites mark the end of Upper Winnipegosis Member platform deposition and presumably isolated reef deposition as well. Non-bituminous interlaminae/beds in lithofacies D onlapping the western platform slope may represent periods of intervening normal carbonate deposition or may be derived from small-scale sediment gravity flows. Either way, the onlapping platform-slope laminites were either emplaced at the end of platform growth or entirely postdate it and the phytoplankton blooms from which they originated may have been triggered by elevated

salinity or stratification associated with evaporative drawdown near the end of Winnipegosis time (refer to Section 6.3.3).

The discontinuous nature of the Brightholme Member in basinal areas (e.g., Jin and Bergman, 1999) is likely a function of the interplay between productivity and preservation. The member would only have been deposited in areas subjected to elevated phytoplankton productivity and would only have been preserved where the environment at the sediment-water interface was conducive for the preservation of organic matter.

6.6 Ratner Formation: Evaporative Drawdown and Salina Development

After cessation of platform and isolated reef growth, evaporative drawdown in the Elk Point Basin persisted to the point where deposition of interlaminated carbonate and anhydrite (lithofacies E in the study area) of the Ratner Formation began in basinal areas (Fig. 6.1C) (e.g., Maiklem, 1971; Kent and Christopher, 1994; Jin and Bergman, 1999). Presumably the anhydrite would have been originally deposited as gypsum. The water depth in which the Ratner Formation was deposited and its temporal relationship to the Winnipegosis Formation have been debated among workers for decades (refer to Section 3.6.2). The stratigraphic relationship between the Upper Winnipegosis Member, Brightholme Member, and the Ratner Formation in the study area cannot be commented on because of the poor core control. The occurrence of the Ratner Formation overlying the Lower Winnipegosis Member ramp in basinal areas does not provide any insight as to the timing of Ratner Formation deposition. However, the Ratner Formation was found to thinly onlap the western platform slope indicating that the Ratner Formation postdates the

Upper Winnipegosis Member platform and by association the isolated reefs. This observation is consistent with the conclusions of Jin and Bergman (2001), which were based on the absence of skeletal reef debris in the Ratner Formation, draping of the Ratner Formation over drowned isolated reefs, and the apparent relation between the Ratner Formation and vadose diagenesis of isolated reefs in Saskatchewan.

Organic petrology provides insight into water depth during deposition of the Ratner Formation in the study area. A primary organic facies BL2 and a secondary organic facies C was found in a bituminous laminite (lithofacies D) from the uppermost Ratner Formation indicating that elevated phytoplankton productivity occurred in a near-shore setting. Because this laminite is interbedded with the lithofacies E, it likely represents a transient "freshening" event that introduced nutrients and triggered elevated cyanophyte and Prasinophyte productivity. This interpretation is similar to that proposed by Stasiuk (1999) for the lower member of the Prairie Evaporite Formation in east-central Alberta. A "freshening" event in the study area is also supported by the presence of a peloidal packstone interbed in the bituminous laminite indicating higher energy conditions. Additionally, one large megaspore in the laminite, possibly a sporangium-like structure, was found still connected to a smaller expelled megaspore via a fine filament. This attests to minimal transport of terrestrial macerals (cf. Stasiuk, 1999) and suggests that near-desiccation of the basin floor occurred towards the end of Ratner Formation deposition.

CHAPTER 7: ORGANIC GEOCHEMISTRY OF BITUMINOUS LAMINITES

7.1 Introduction

Whole rock pyrolysis was conducted on the same samples used for organic petrology to determine the geochemical kerogen type, extent of thermal maturation, and the petroleum generative potential of bituminous laminites (lithofacies D) as source rocks within the study area (Appendix F). Rock-Eval employs temperature-programmed heating of pulverized small rock samples, first in an inert (helium gas) and then oxygen-combustive atmosphere and gives output in the form of a pyrogram (e.g., Peters, 1986). This plot shows the detector response as a function of increasing time and heat to determine both the amount of volatized free hydrocarbons (S1 peak) as well as the quantity of hydrocarbons (S2 peak) and oxygen-containing compounds (S3 peak) that are generated from the kerogen in the sample during pyrolysis (e.g., Peters, 1986; Lafargue et al., 1998). Pyrolysis is followed by oxidation to determine the dry weight percent total organic carbon (TOC), which is the sum of extractable organic matter carbon, reactive carbon, and inert carbon content of the sample (e.g., Jarvie, 1991; Lafargue et al., 1998). Refer to Appendix F for a more comprehensive description of the Rock-Eval technique.

7.1.1 Kerogen Types

Kerogen is the disseminated organic matter in sedimentary rocks that forms during diagenesis and is not extractable by common organic solvents (e.g., Hunt, 1996). When the atomic hydrogen/carbon and oxygen/carbon ratios of kerogens are plotted on a van Krevelen diagram (atomic H/C vs. O/C), three main kerogen types are recognized for

thermally immature rocks (e.g., Tissot et al., 1974). These kerogen types are also recognized on modified or pseudo-van Krevelen diagrams, which plot the hydrogen index (HI) against the oxygen index (OI) as determined by pyrolysis (e.g., Tyson, 1995; Peters, 1986).

Type I (very oil prone) kerogens are rare, accounting for only 2.7% of the world's original oil and gas reserves (e.g., Klemme and Ulmishek, 1991). They are typically derived from fine-grained, laminated lacustrine facies and are characterized by high initial H/C ratios and low initial O/C ratios (e.g., Tissot and Welte, 1984; Demaison, 1993). However, kerogens classified as Type I can originate from a variety of biological precursors, sedimentary environments, and preservation conditions in both marine and fresh-water paleosettings (e.g., Vandenbroucke, 2003). Type I kerogen is highly oil prone and typically generates distinctive aromatic-poor oils (e.g., Katz, 1988).

Type II kerogen is oil prone and the most common type of kerogen, likely accounting for over 90% of all oil source rocks (e.g., Jones and Demaison, 1982). It is characterized by high initial H/C ratios and low initial O/C ratios. Type II kerogen-rich rocks are generally associated with marine facies and mainly derived from autochthonous marine organic matter including phytoplankton, +/-zooplankton, and microbes (e.g., Tissot and Welte, 1984; Tyson, 1995). In marginal marine to inner-middle shelf settings Type II kerogen can include variable amounts of terrestrial organic matter such as leaves (cuticles) and spores (e.g., Tissot and Welte, 1984; Wignall, 1994). Type II kerogen

dominantly generates naphthene and aromatic-rich oil; however it also generates more gas than Type III kerogen (e.g., Wignall, 1994; Hunt, 1996).

Type III kerogen is mainly gas prone but also generates condensate and subordinate quantities of waxy oil (e.g., Hunt, 1996). It is distinguished by low initial H/C ratios and high initial O/C ratios (Tyson, 1995). According to "classical definition" it is typically derived mainly from continental lignaceous, vascular plants, and thus it has a composition close to woody organic matter but can also contain abundant identifiable vegetal matter (e.g., Tissot and Welte, 1978; Tissot and Welte, 1984). However, Type III kerogen can also form from hydrogen-rich organic matter during early diagenesis as a result of partial aerobic degradation of amorphous organic matter, which removes hydrogen and adds oxygen, or from extensive oxidation of amorphous kerogen by sulphate-reducing and methanogenic bacteria, thereby producing a Type III geochemical signature that is not indicative of origin (e.g., Durand and Monin, 1980; Stasiuk and Goodarzi, 1988; Tyson, 1995).

Type IV (inert) kerogen is also recognized on modified van Krevelen diagrams (e.g., Tissot, 1984; Peters, 1986; Hunt, 1996). Type IV kerogen has very low hydrogen content and relatively high oxygen and carbon content (e.g., Tyson, 1995). It has the appearance of charred woody or opaque coaly particles and is derived from organic matter that was recycled from exposed older sediments, from forest-fire burnt wood matter, or highly oxidized during transport and/or in subaerial depositional settings

(e.g., Powell and Snowdon, 1980; Tissot, 1984; pers. comm., L. Stasiuk, 2006). Type IV kerogen has limited potential for dry generation of hydrocarbon gases (pers. comm., L. Stasiuk, 2006).

7.2 Total Organic Carbon (TOC)

Overall, the bituminous laminite samples show remarkably varied total organic carbon (TOC) values ranging from 0.84 to 52.25%. TOC variability within the various laminite types, as described in Chapter 5, are as follows: ramp-to-platform/basin transition laminites 2.61-6.05%; platform interior laminites 0.84-52.25%; platform slope laminites 2.09-36.55%; onlapping platform slope laminites 2.20-13.09%; and basinal salina laminites 5.98% (Table 7.1). Variability in TOC is dependent on many factors including sedimentation rate, extent of palaeoproductivity, and redox state (e.g., Hunt, 1996; Tyson, 1995).

7.3 Kerogen Hydrogen Index versus Oxygen Index

Rock-Eval data for the samples in this study were plotted on a hydrogen index versus oxygen index diagram (HI vs. OI), which is also known as a "modified van Krevelen diagram" (Fig. 7.1). The hydrogen and oxygen indices are defined as the ratios of milligrams of hydrocarbons (HC) per grams of TOC and milligrams of carbon dioxide (CO_2) per grams of TOC respectively (Behar et al., 1998). This diagram illustrates the kerogen evolution pathways which can indicate the original composition of kerogen and the manner in which it is gradually altered during weathering, biochemical oxidation, or temperature related thermal maturation (e.g., Tyson, 1995). The composition of the

Table 7.1: Summary of total organic carbon (TOC) values for the bituminous laminites as determined by the Rock-Eval technique.

Location	Depth	Stratigraphic Unit	Laminite Type	TOC (Wt %)
11-29-001-25W1	1531.85 m (5025.75')	Lower Winnipegosis	Ramp-to-Platform Transition	2.61
02-21-007-28W1	1447.7 m (4749.7')	Lower Winnipegosis	Ramp-to-Basin Transition	2.87
12-35-024-10W1	17.58m (57.68')	Upper Winnipegosis Member	Ramp-to-Platform Transition	6.05
03-01-008-18W1	783.95 m (2572')	Upper Winnipegosis Member	Platform Interior	0.84
03-01-008-18W1	784.55 m (2574')	Upper Winnipegosis Member	Platform Interior	52.25
05-13-005-22W1	1157.94 m (3799')	Upper Winnipegosis Member	Platform Interior	41.55
05-13-005-22W1	1153.76 m (3785.3')	Upper Winnipegosis Member	Platform Interior	10.7
09-26-007-25W1	1175.46 m (3856.5')	Upper Winnipegosis Member	Platform Slope	36.55
11-29-001-25W1	1528.34 m (5014.25')	Upper Winnipegosis Member	Platform Slope	2.09
04-12-007-25W1	1198.68m (3932.68')	Upper Winnipegosis Member	Onlapping Platform Slope	12.71
04-33-023-16W1	205.95 m (675.7')	Upper Winnipegosis Member	Onlapping Platform Slope	2.2
04-33-023-16W1	205.53 m (674.3')	Upper Winnipegosis Member	Onlapping Platform Slope	13.09
103/03-12-011-27W1	1178.57m (3866.70')	Ratner Formation	Basinal Salina	5.98

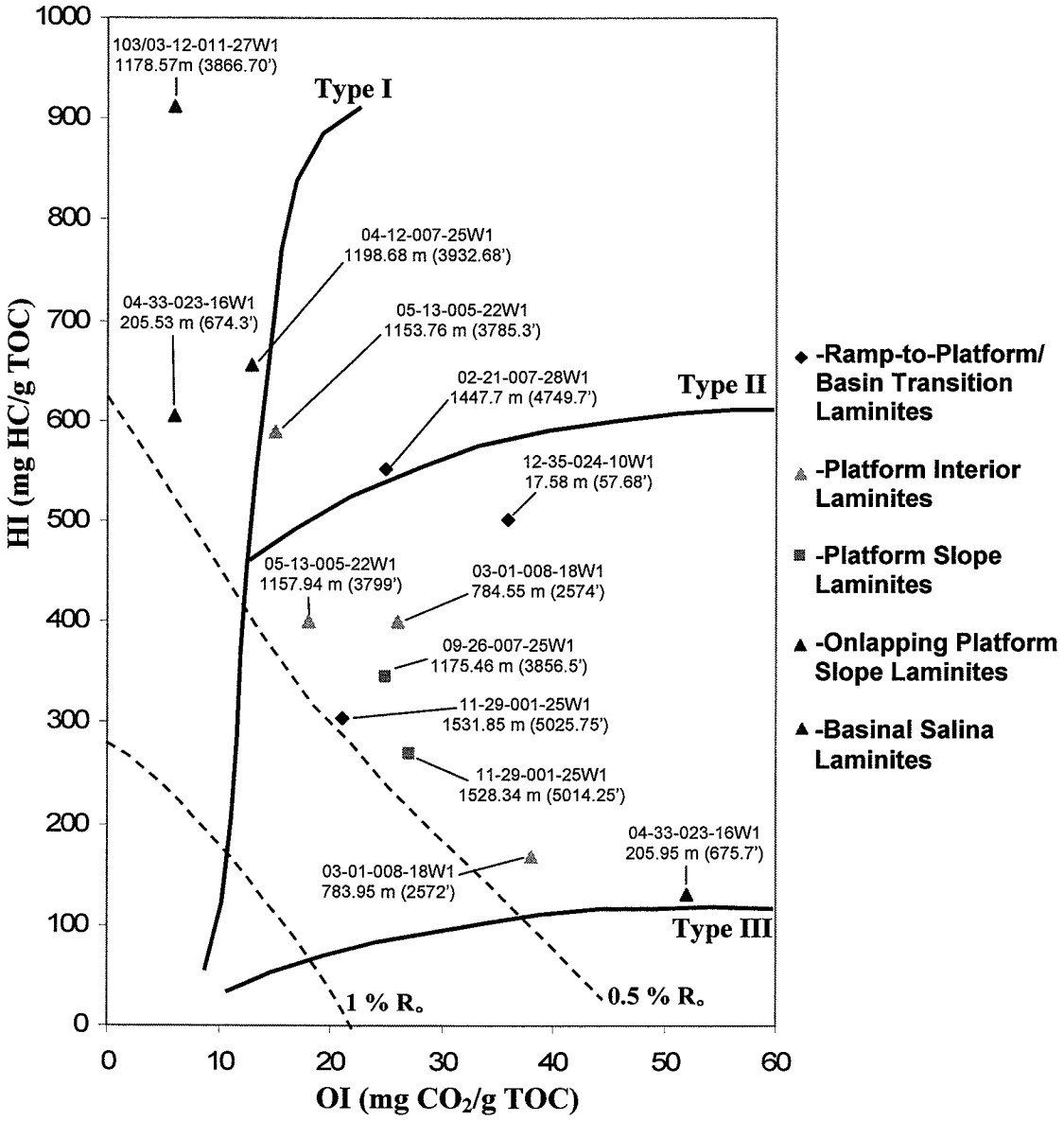


Figure 7.1: A plot of HI vs. OI (modified Van Krevelen diagram) for samples from the study area. Evolution pathways for Types I, II, and III kerogen (solid lines) are from Peters (1986); dashed lines indicating thermal maturity as determined by vitrinite reflectance (R_o) are from Tyson (1995). Increasing thermal maturity is indicated by progression down the converging pathways to the lower left.

kerogen types changes progressively towards the lower left corner of the diagram with increasing alteration. Following deposition, early diagenesis of thermally immature kerogen initially results in a slight decrease in hydrogen content and a large decrease in oxygen content through the loss of water and carbon dioxide (e.g., Tissot and Welte, 1984).

Catagenesis, which is the thermal cracking of kerogen chemical bonds and generation of liquid hydrocarbons, begins at a vitrinite reflectance in oil (R_o) of approximately 0.5% (Fig 7.1) (e.g., Tissot and Welte, 1984; Hunt, 1996). Here the kerogen evolution pathways show a break in slope as a result of substantial hydrogen loss through hydrocarbon generation and later expulsion. Metagenesis, which involves significant conversion to gas and begins at a vitrinite reflectance of approximately 2%, is represented at the lower left corner of the diagram where the pathways merge and the rate of loss of hydrogen decreases markedly. It is important to understand that the four kerogen type pathways are considered idealized end-members and variations in source, synsedimentary and diagenetic preservation state, effects of weathering, levels of maturation, and mixing of kerogen cause scatter and overlap (e.g., Tyson, 1995). An evolution track for Type IV kerogen is generally not drawn on plots because Type IV kerogen is refractory or largely inert and thermal maturation has little effect on its composition.

Bituminous laminite samples from the Winnipegosis, Elm Point, and Ratner formations in this study show highly varied kerogen compositions with most samples plotting between the Type II and III fields and some outliers in the Type I and Type III fields

(Fig. 7.1). All samples are thermally immature with respect to hydrocarbon generation except for one bituminous laminite from the ramp-to-platform transition interval in the Lower Winnipegosis Member in well 11-29-001-25W1, 1531.85 m (5025.75'). This laminite is the most southwestern and the deepest one in the study area and may represent the onset of catagenesis.

Only one platform interior sample (well 03-01-008-18W1; 784.55 m [2574']) contains terrestrial-derived macerals (vitirinite; refer to Section 5.3.6), and would be expected to produce a Type III geochemical signature. However, this sample plots closer to the Type II pathway than the Type III pathway, most likely because the kerogen contains both vitrinite macerals and ample liptinite macerals. For unknown reasons, some coals derived from higher plants respond to pyrolysis in an unpredictable manner and plot between Type II and Type III kerogens on modified van Krevelen diagrams (e.g., Peters, 1986). All the other samples that plot close to the Type III kerogen pathway are interpreted to have modified compositions as a result of aerobic degradation prior to burial since they do not contain vitrinite macerals, as described in Sections 5.5.1, 5.5.2, and 5.5.3.

Two samples from the base and top of the bituminous laminite which onlaps the northern platform slope in well 04-33-023-16W1 (205.95 m [675.7'] and 205.53 m [674.3']), plot as a Type III and Type I kerogen respectively. Based on organic petrology this laminite is interpreted to have resulted from bloom(s) of calcisphere-producing phytoplankton (see Section 5.5.3). The sample at the base of the laminite is interpreted to represent the

initial phase of the bloom(s) when degradation occurred under largely an oxic water column and consequently plots as a Type III kerogen, although the organic matter is marine and not derived from terrestrial plants. The upper sample is interpreted to represent the latter phase of the bloom(s) when phytoplankton settled following bloom-related de-oxygenation of the water column and is more representative of the original composition of the kerogen. It is proposed that kerogen geochemistry may have captured a rapid paleoenvironmental transition that occurred during laminite deposition.

It is significant to note that all of the samples with a Type I kerogen signature, with the exception of a platform interior sample from well 05-13-005-22W1, 1153.76 m (3785.3'), are from bituminous laminites that either onlap the platform slope succession in the Upper Winnipegosis Member or are from the basinal salina succession in the Ratner Formation, which is succeeded by the Prairie Evaporite (see Chapter 2). This association suggests that environmental conditions between the end of Winnipegosis time and Ratner time, which is characterized by variable but overall increasing salinity (see Chapters 3 and 5), provided the best preservation potential with minimal aerobic degradation of kerogen.

7.4 Hydrogen Index versus T_{max}

Rock-Eval data for the samples were also plotted on a hydrogen index versus maximum temperature (HI vs. T_{max}) diagram (Fig. 7.2). The maximum temperature is the temperature at which the maximum amount of volatile hydrocarbons is generated from kerogen during pyrolysis and is an indirect measurement of thermal maturation

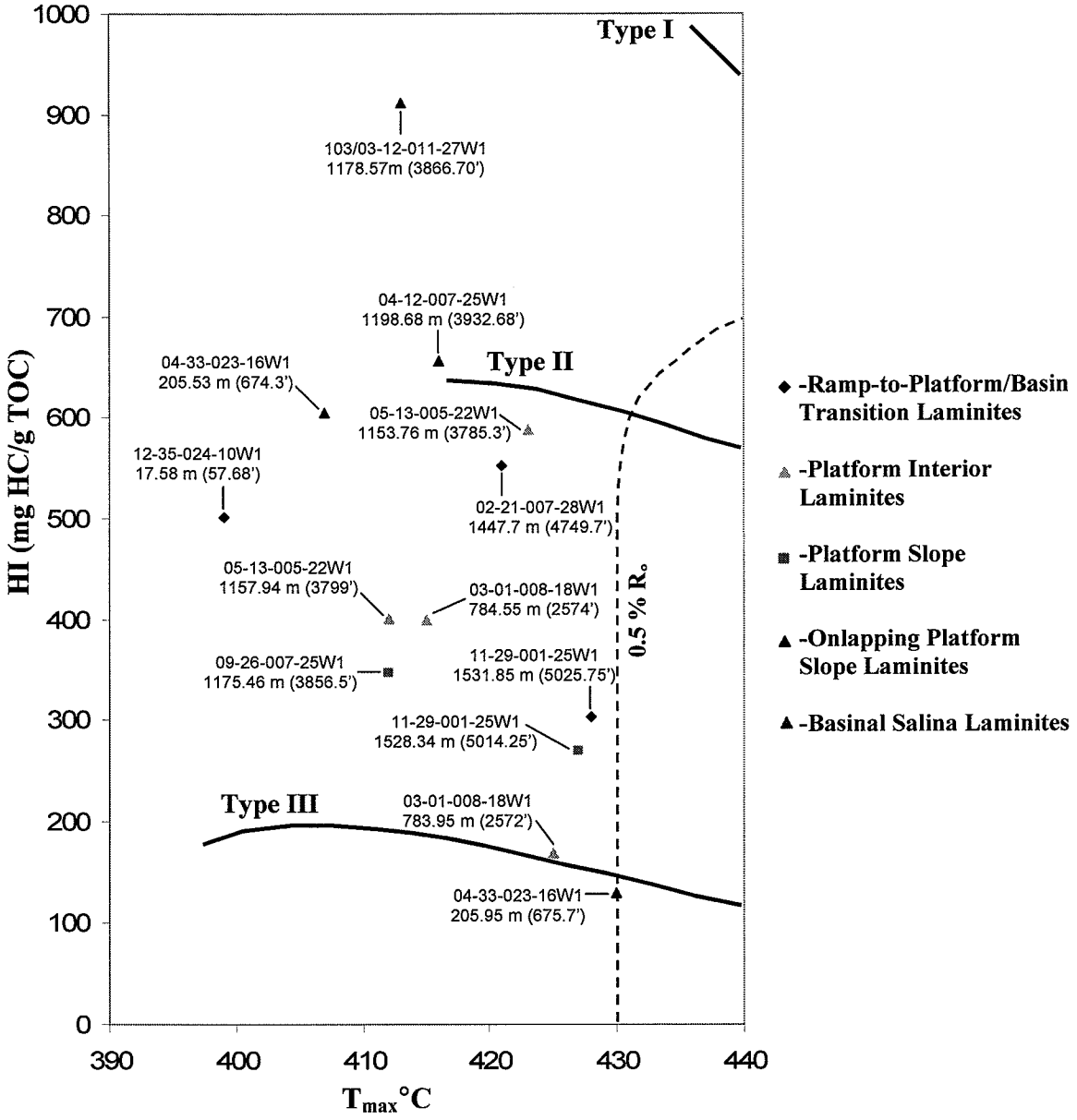


Figure 7.2: A plot of HI vs. T_{max} for samples from the study area. Evolution pathways (solid lines) for Types I, II, and III kerogen and dashed line indicating thermal maturity as determined by vitrinite reflectance (R_o) are from Mukhopadhyay et al. (1995). Increasing thermal maturity is indicated by progression down the converging pathways to the lower right.

(e.g., Peters, 1986). This type of plot has become a common way to display pyrolysis data because it avoids uncertainties associated with the oxygen index (e.g., Tyson, 1995). The oxygen index can be an unreliable parameter because it is derived from the S3 peak, which can be influenced by carbon dioxide derived from the low temperature breakdown of carbonate minerals in whole rock samples during pyrolysis or by adsorbed carbon dioxide or oxygen (e.g., Peters, 1986). Similar to the modified van Krevelen diagram, the HI vs. T_{max} diagram has evolution pathways for Type I, II, and III kerogen; however, increasing maturity is represented by a progression to the lower right along the pathways (e.g., Hunt, 1996). Kerogen is generally considered to be thermally immature if the T_{max} value is less than 435°C, which generally represents the top of the oil window.

As in the modified van Krevelen diagram, the HI vs. T_{max} plot shows that the bituminous laminite samples in this study have highly variable compositions, ranging from Type I to Type III and are all thermally immature. The Type III kerogens are again interpreted to have suffered hydrogen loss as a result of oxidation prior to burial.

7.5 Source Rock Potential

As previously described, the Rock Eval data indicate that the bituminous laminites within the study area are thermally immature regardless of kerogen type (Sections 7.3, 7.4) and therefore should not be expected to have generated significant petroleum. However, bitumen and oil were observed in some of the laminites in the course of carbonate and organic petrography and these laminites warrant further discussion.

According to Hunt (1996), bitumen is defined as nonvolatile organic matter that is soluble in organic solvents (extractable) and formed in source rocks during initial heating. Bitumen was observed in thin-sectioned samples from a ramp-to-basin transition laminite in well 02-21-007-28W1, 1447.7 m (4749.7'), an onlapping platform slope laminite in well 04-12-007-25W1, 1198.68m (3932.68'), and from a basinal salina laminite in well 103/03-12-011-27W1, 1178.57 m (3866.70') (Fig. 7.3). The presence of expelled transparent, orange bitumen in porosity within and adjacent to kerogen in these samples suggests that these laminites have been influenced by the onset of thermal maturation despite their low maturity as indicated by the geochemical plots.

Fluorescing, free oil was also observed in intercrystalline and micro-vuggy porosity in the basinal salina laminite in well 103/03-12-011-27W1, 1178.57 m (3866.70') (Fig. 7.4). According to Peters (1986), immature rocks with T_{max} values less than 435°C that have S1/TOC ratios greater than 0.3 or production index (PI) values greater than 0.2, where PI=S1/(S1+S2), are likely to have been contaminated by oil-based mud or migrated oil. This sample has a S1/TOC ratio of 0.32 and a PI value of 0.03 and therefore has likely been contaminated. According to the tour reports this well was drilled with water-based mud, ruling out mud contamination; however, additional geochemistry and/or petrology are needed to determine possible sources.

Fluorescing, free oil was also observed in intercrystalline porosity in non-bituminous carbonate inter-laminae/beds in a platform interior laminite in well 03-01-008-18W1, 783.95 m (2572') and in an onlapping platform slope laminite in well 04-12-007-25W1,

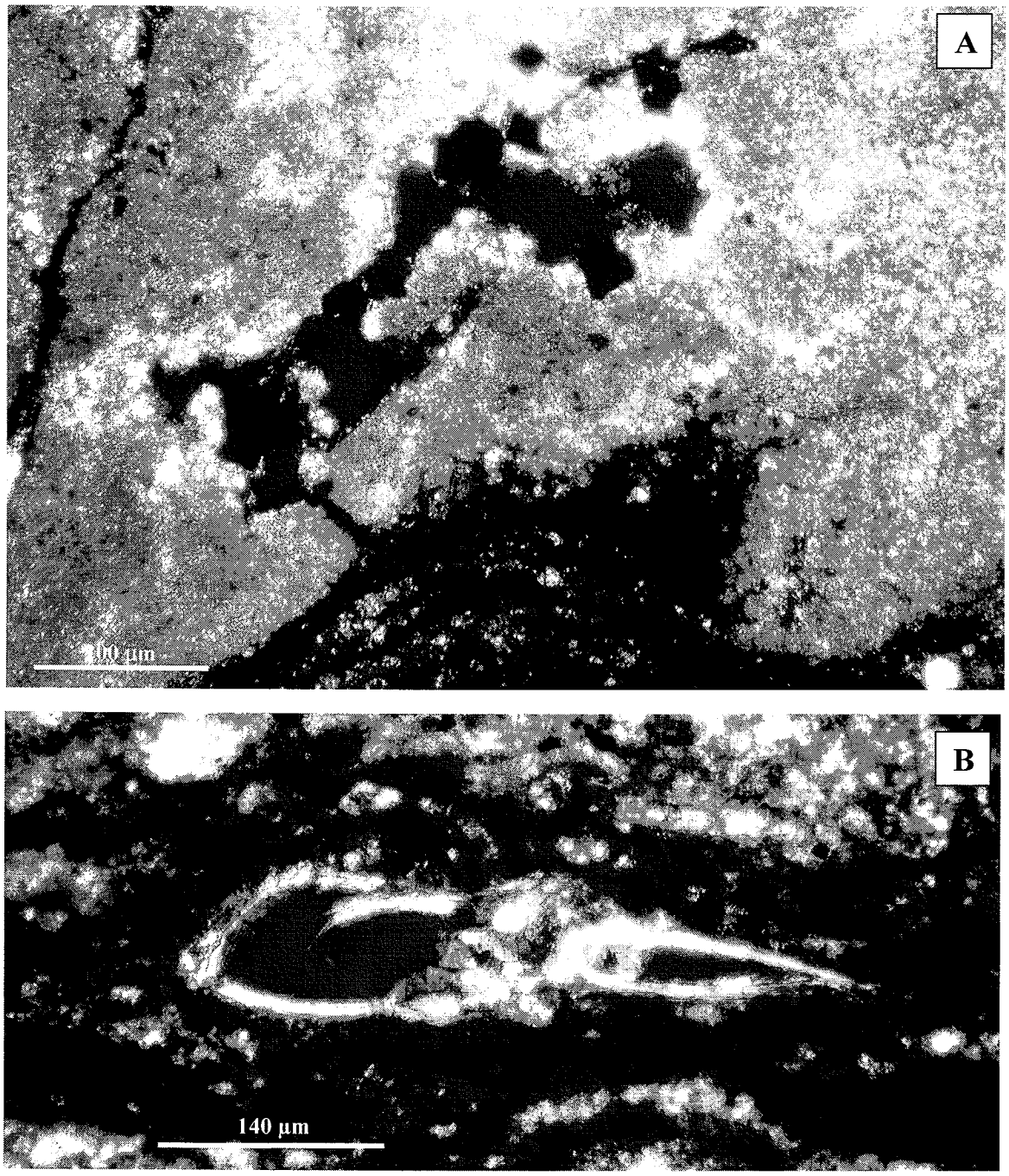


Figure 7.3: Photomicrographs showing bitumen associated with thermally immature bituminous laminites in the Winnipegosis Formation. A) Orange bitumen in micro-vuggy and fracture porosity in dolostone associated with an onlapping platform slope bituminous laminite in the Upper Winnipegosis Member; plane polarized light. 04-12-007-25W1, 1198.68 m (3932.68'). B) Broken cricoconarid filled with orange bitumen in a ramp-to-basin bituminous laminite in the Lower Winnipegosis Member; plane polarized light. 02-21-007-28W1, 1447.70 m (4749.7').

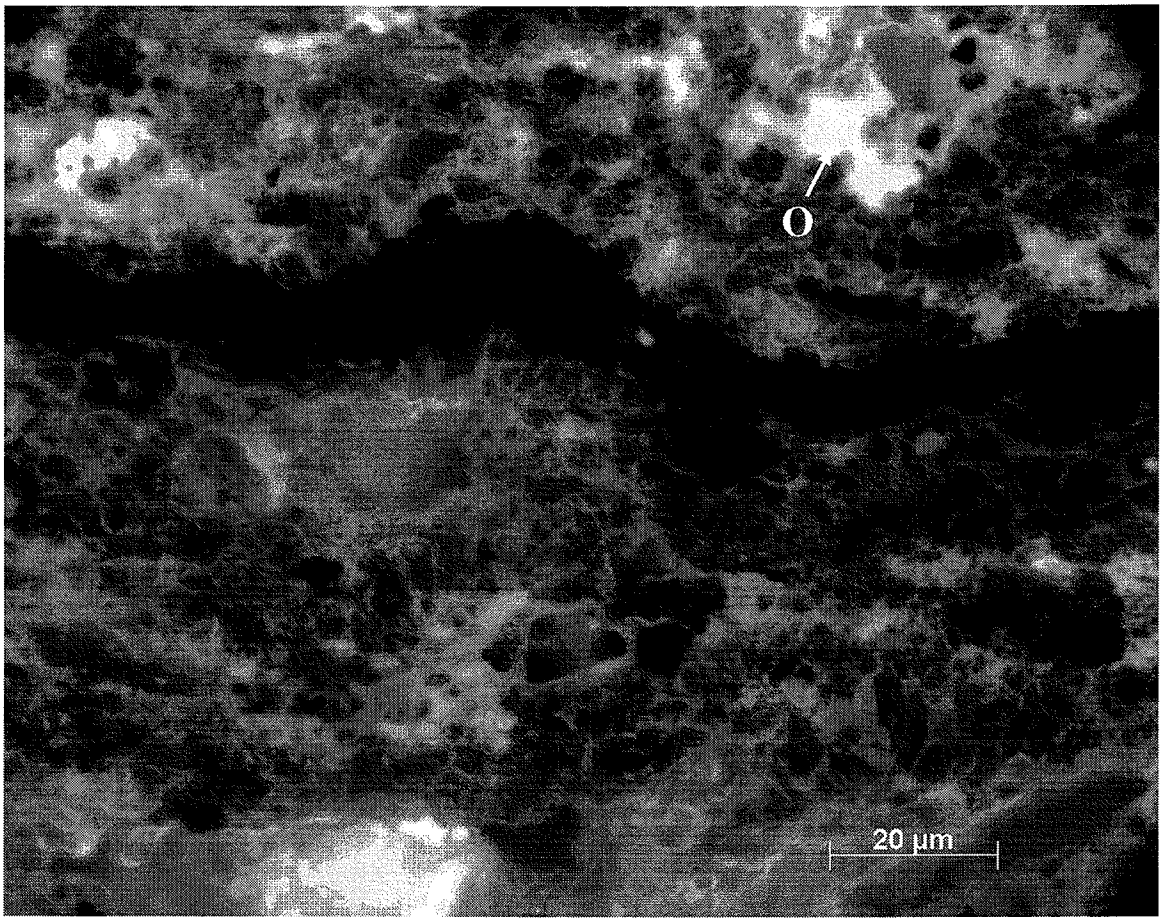


Figure 7.4: Photomicrograph showing fluorescent oil (O) in micro-vuggy and intercrystalline porosity in immature bituminous laminite from the Ratner Formation; UV fluorescence, oil-immersion. 103/03-12-011-27W1, 1178.57 m (3866.70').

1198.68 m (3932.68'). The S1/TOC and PI values for these samples are not indicative of contamination and the sample from well 03-01-008-18W1 has Type III kerogen, suggesting that the carbonate laminae/beds contain migrated oil that was expelled during sample preparation; these occurrences are considered further in Sections 8.3 and 8.4.

Fluorescing, free oil was also observed in localities at the northern platform margin in an onlapping platform slope laminite in well 04-33-023-16W1, 205.95 m (675.7') and 205.53 m (674.3') and in a ramp-to-platform transition laminite in core M-4-90, 12-35-024-10W1, 17.58m (57.68') (Fig. 7.5). These occurrences are especially enigmatic because they are at very shallow burial depths and the S1/TOC and PI values are not indicative of contamination. It is postulated that the free oil in these samples is phytoplankton lipid-derived oils that did not transform into insoluble kerogen during diagenesis. Similar biological oils are known from bloom-derived kerogen in recent sediments (e.g., Stasiuk and Sanei, 2001; Sanei et al., 2005), and have also been reported in Permo-Triassic algal cysts (pers. comm., L. Stasiuk, 2006).

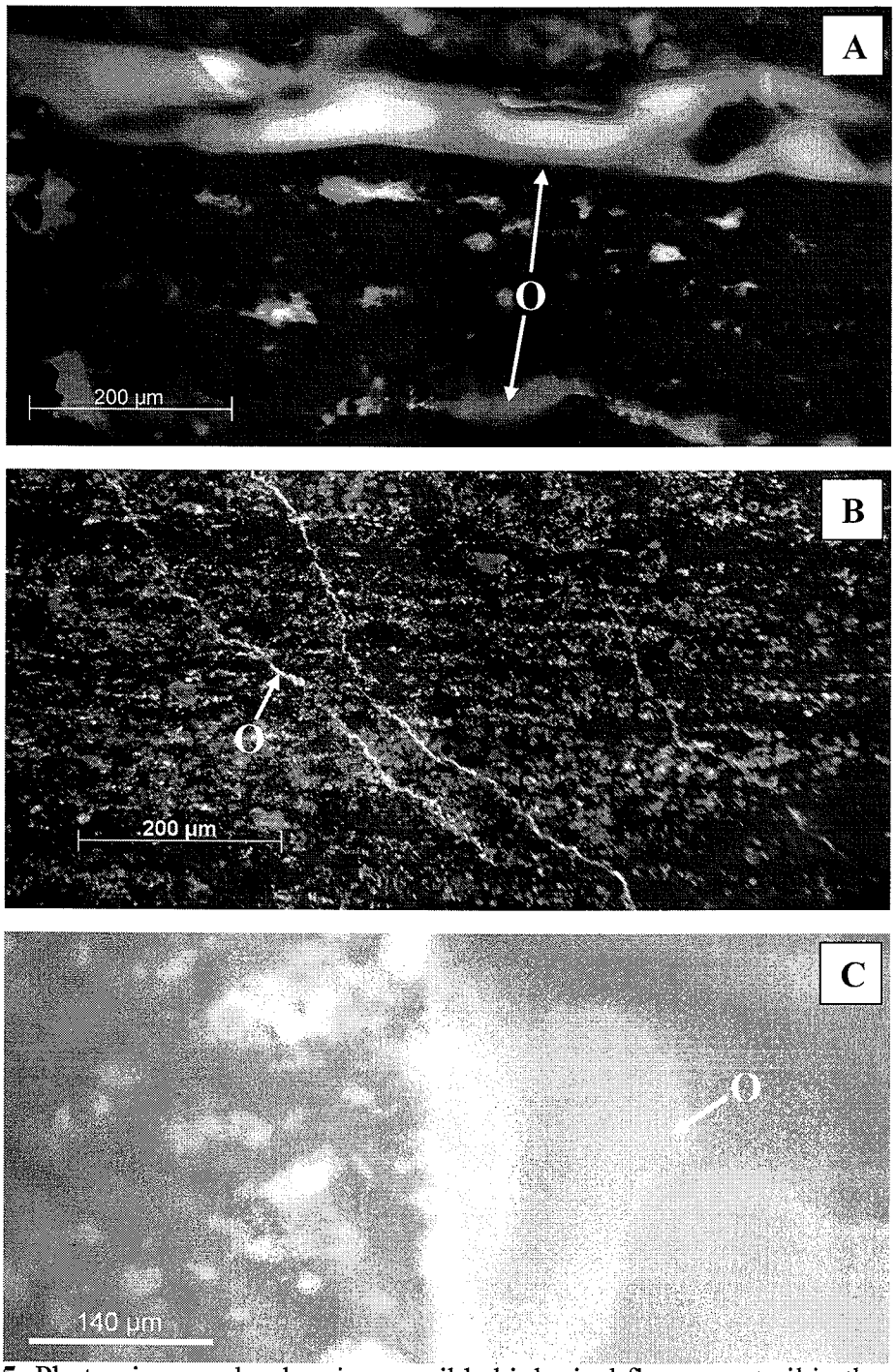


Figure 7.5: Photomicrographs showing possible biological fluorescent oil in thermally immature bituminous laminites in the Upper Winnipegosis Member. A) Milky-yellow-fluorescing oil (O) streaming from isolated layers within the laminite; UV fluorescence, oil immersion. 04-33-023-16W1, 205.95 m (675.7'). B) Blue-fluorescing oil (O) within sub-vertical fractures in laminite; UV fluorescence, oil immersion. 04-33-023-16W1, 205.53 m (674.3'). C) Purple-fluorescing oil (O) in epoxy at the margin of the thin-sectioned sample from a ramp-to-platform transition bituminous laminite; UV fluorescence. 12-35-024-10W1, 17.58 m (57.68').

CHAPTER 8: PETROLEUM PLAYS AND POTENTIAL

8.1 Introduction

The Winnipegosis Formation is perhaps best known for its isolated reef plays in basinal areas in Saskatchewan and North Dakota (e.g., Ehrets and Kissling, 1987; Fischer and Burke, 1987; Rosenthal, 1988; Martindale and MacDonald, 1989; Martindale et al., 1991). However, at least three other petroleum play types exist, including platform margin, platform interior, and basin laminites (Ratner Formation). Although potential source rocks in the study area are thermally immature (refer to Chapter 7) and most of them are likely too thin to be economically significant, the possibility exists for long distance, up-dip, petroleum migration from mature areas in Saskatchewan and/or North Dakota. Examples of long distance migration are known from shallower producing Paleozoic formations in southwestern Manitoba (e.g., Bakken, Lodgepole, and Mission Canyon formations; Martiniuk and Barchyn, 1993; Martiniuk et al., 2002). Previously documented and newly discovered oil shows from cores and cuttings suggest that at least sub-economic quantities of petroleum have migrated through parts of the study area (Table 8.1); wells penetrating the Winnipegosis Formation in Manitoba are not reported to have been drilled with oil-based muds and there is no apparent source of contamination (pers. comm., B. Dunning, 2006). Oil shows observed under UV excitation have yellow to purple fluorescence indicating high API gravity (cf. Wyman and Castano, 1974); however, to date there has been no production from the Winnipegosis Formation in the study area and all of the wells that have oil shows and were drill-stem tested only recovered salt water.

Table 8.1: Oil shows from the Winnipegosis and Ratner formations within the study area; those with an asterisk have been previously documented by the Manitoba Petroleum Branch (www.gov.mb.ca/iedm/petroleum/pubcat/l_paleozoic.pdf, accessed March, 2006). So=oil saturation.

WELL LOCATION	LICENCE #	STRATIGRAPHIC UNIT	PLAY TYPE	CORE INTERVAL/ SAMPLE DEPTH	SHOW COMMENTS
10-09-001-28W1*	4115	Upper Winnipegosis Member	isolated reef	1724.94-1742.71 m (5659.3-5717.6')	oil staining on core, So=3-6.7%, oil fluorescence observed in thin section epoxy
08-13-005-29W1*	2696	Upper Winnipegosis Member	isolated reef	1521.5-1526.73 m (4991.8-5009')	oil staining on core, So=0-5.7%, oil fluorescence observed in thin section epoxy
14-13-009-28W1*	3083	Upper/Lower Winnipegosis Members	isolated reef	1280.87-1321.45 m (4202.3-4335.5')	oil staining on core; oil fluorescence observed in thin section epoxy
04-30-018-26W1*	300	Upper Winnipegosis Member	isolated reef	932.7 m (3060')	dead oil stain in samples (cuttings)
09-06-002-26W1	2610	Upper Winnipegosis Member	isolated reef	1531.8 m (5025.59')	possible oil fluorescence observed in thin section epoxy
04-17-019-29W1	2162	Upper Winnipegosis Member	isolated reef	955.58 m (3135.1')	possible oil fluorescence observed in thin section epoxy
09-13-001-26W1	184	Upper Winnipegosis Member	isolated reef	1545.48 m (5070.5')	possible oil fluorescence observed in thin section epoxy
05-03-004-25W1	1876	Upper Winnipegosis Member	isolated reef	1545.48 m (5070.5')	possible oil fluorescence observed in thin section epoxy
09-26-007-25W1*	217	Upper Winnipegosis Member	platform margin	1174.39-1182.6 m (3853-3880')	some oil staining along fractures in core
04-33-023-16W1	2474	Upper Winnipegosis Member	platform margin	205.4-213.36 m (674-700')	spotty oil staining on core
04-12-007-25W1	2986	Upper Winnipegosis Member	platform margin	1198.6 m (3932.41')	possible oil fluorescence observed in thin section epoxy
11-29-001-25W1	2543	Upper Winnipegosis Member	platform margin	1520.2 m/1530.63 m (4987.55'/5021.75')	possible oil fluorescence observed in thin section epoxy
04-27-011-22W1	1228	Upper Winnipegosis Member	platform interior	849.78-865 m (2788-2838')	possible oil fluorescence observed in thin section epoxy
05-13-005-22W1	320	Upper Winnipegosis Member	platform interior	1150.3-1160.98 m (3774-3809')	oil fluorescence observed in thin section epoxy; cut fluorescence from core samples
01-25-004-23W1*	4859	Upper Winnipegosis Member	platform interior	1221.8-1228 m (4008.5-4028.9')	occasional bitumen stain in cuttings
03-01-008-18W1	44	Upper Winnipegosis Member	platform interior	784.55-785.77 m (2574-2578')	possible oil fluorescence observed in thin section epoxy; slight cut fluorescence from core samples
04-12-007-25W1	2986	Ratner Formation	basin laminites	1198.52 m (3932.2')	possible oil fluorescence observed in thin section epoxy
103/03-12-011-27W1	4948	Ratner Formation	basin laminites	1178.5-1180.51 m (3866.5-3873.1')	possible oil fluorescence observed in thin section epoxy
02-21-007-28W1	91	Ratner Formation	basin laminites	1445.36-1447.49 m (4742-4749')	possible oil fluorescence observed in thin section epoxy

8.2 The Isolated Reef Play

Although exploration efforts began as early as 1953, commercial quantities of petroleum were first produced in 1986 from a Winnipegosis Formation isolated reef in the basinal setting in the Tableland area of southeastern Saskatchewan (Township 2, Range 9W2) (Fritz, 1988; Martindale and MacDonald, 1989). The Tableland reef is 60 m high and encased in anhydrite of the lowermost Prairie Evaporite thereby forming a stratigraphic trap. The reef is completely dolomitized and has heterogeneous reservoir characteristics with optimal porosity exceeding 15% in the grainstone interior. Of the eight wells drilled into the reef, only three produced attesting to the reservoir's heterogeneous nature. The Tableland pool covers approximately 1.2 km^2 and has estimated recoverable reserves of $2.5x10^5$ m^3.

The success at Tableland was followed by other discoveries in southeastern Saskatchewan including four analogous isolated reefs located north of Tableland in the Hitchcock area (Township 3, Range 9W2) (Martindale et al., 1991). Geochemical analyses indicate that the oil in both the Tableland and Hitchcock reefs belongs to the Family D oils, as defined by Osadetz et al. (1990), and therefore are correlative with a Brightholme Member source (Martindale et al., 1991). Although the Brightholme Member is present in the area, the API gravity of the oil is too high to have been sourced entirely locally given the depth of the Brightholme Member at these locations. Therefore, the oil is interpreted to have migrated in part from a location deeper in the basin. In North Dakota, six isolated reefs were drilled but only two contained free oil (Ehrets and Kissling, 1987). The Shell Golden #34X-34 well produced 270 m^3 oil and a

small amount of oil was recovered from the Inexco Erickson #1-18 well; however, both reefs were almost entirely water charged. There has not been any reef exploration in North Dakota since the late 1980's (pers. comm., J. LeFever, 2006).

No discoveries have been made in isolated reefs within the study area, even though the reefs have ample porosity and permeability, and show oil staining (Fig. 8.1) (e.g., Martiniuk and Barchyn, 1993). Local source rocks are thermally immature (refer to Chapter 7), and presumably the minor amount of petroleum in the isolated reef reservoirs migrated from deeper basin locations (cf. Martindale et al., 1991). Therefore, significant petroleum accumulation in isolated reefs within the study area would likely only be possible if up-dip petroleum migration occurred in concentrated pathways, perhaps channelized by diagenetic patterns in carrier beds (e.g., Ratner Formation), and reefs were situated in the path. However, it should be noted that individual reefs in the study area have only been penetrated by one or two wells and as shown with the Tableland example, wells in producing reefs must be strategically located. Additionally, the paucity of rudstone/framestone encountered in the cores suggests that reef margins and therefore maximum thicknesses were frequently missed.

8.3 The Platform Margin Play

The best documented example of a platform margin play in the Winnipegosis Formation is the Temple Field Winnipegosis pool in northeastern Williams County, North Dakota, which is situated along a subordinate structural limb on the northwestern flank of the Nesson Anticline (Ehrets and Kissling, 1987). The reservoir is 1.6 to 4.8 km wide,

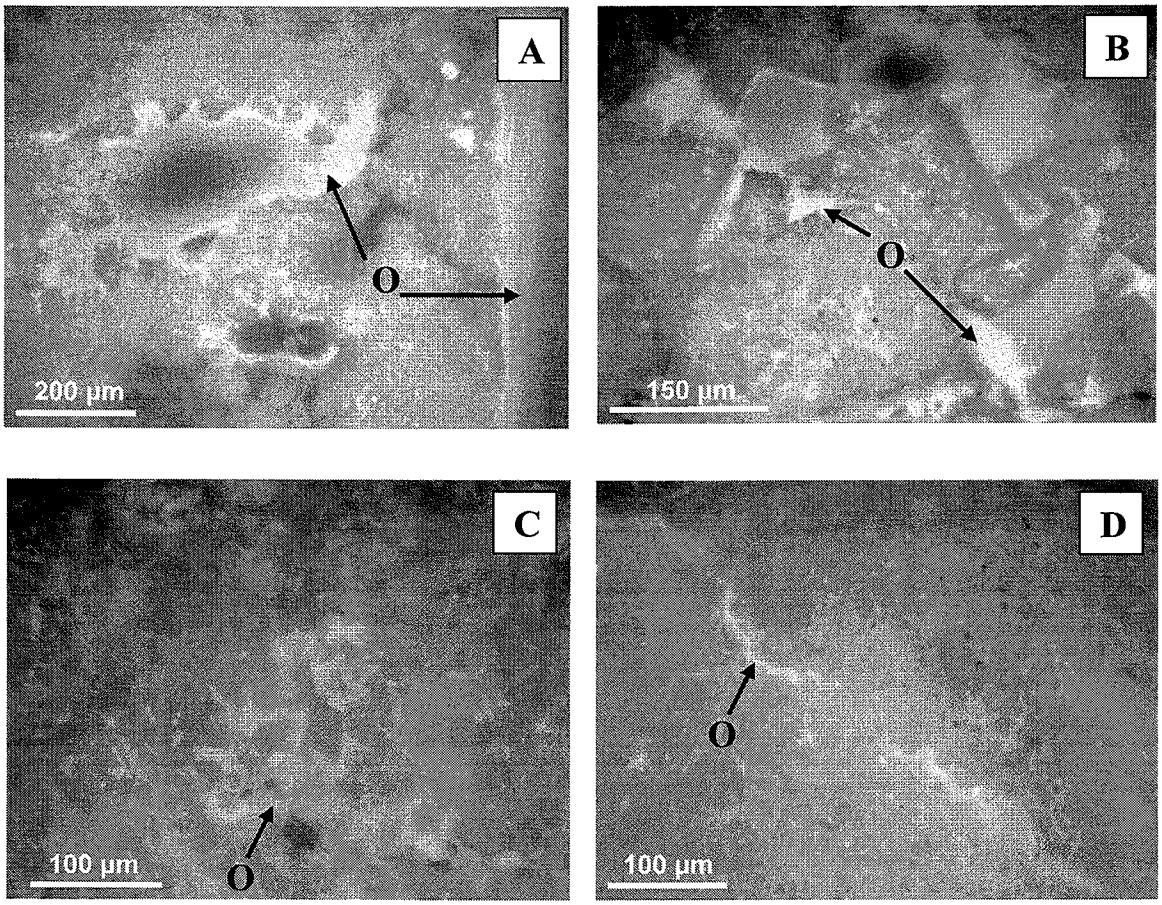


Figure 8.1: Photomicrographs showing fluorescent oil staining (O) in porosity from Upper Winnipegosis Member isolated reefs. A) Purple-fluorescing oil in epoxy within vuggy porosity in lithofacies N (laminated mudstone-peloidal packstone) and at the margin of the thin section; UV fluorescence. 14-13-009-28W1, 1282 m (4206'). B) Yellow-fluorescing oil in epoxy in intercrystalline porosity in lithofacies K (peloidal-udoteacean packstone); UV fluorescence. 09-13-001-26W1, 1545.50 m (5070.5'). C) Yellow-fluorescing oil in epoxy in intercrystalline porosity in lithofacies N (laminated mudstone-peloidal packstone); UV fluorescence. 09-06-002-26W1, 1531.80 m (5025.6'). D) Yellow-fluorescing oil in epoxy in a fracture in lithofacies L (stromatoporoid floatstone); UV fluorescence. 08-13-005-29W1, 1521.57 m (4992').

trending along the platform margin of the Upper Winnipegosis Member. It has a net pay thickness averaging 4.6 m at 8% porosity cutoff and occurs in partly to completely dolomitized, muddy slope facies with enhanced secondary porosity. The trapping style is structural-stratigraphic with the reservoir capped by a platform margin reef facies, which remains largely limestone and is occluded by halite cement in its upper half. The platform slope has undergone structural reversal so that the reservoir is tilted to the southwest and up-dip porosity pinches out in an irregular, lobate fashion. The Temple Field has been the most prolific Winnipegosis reservoir in North Dakota, producing $7.94x10^5$ m^3 oil (Kissling and Slingsby, 1999). The Temple Field is charged with Family D oils, as defined by Osadetz et al. (1992), which are sourced from Winnipegosis Formation bituminous laminites (Martiniuk and Barchyn, 1993).

Within the study area, oil staining was observed in core from the northern platform slope deposits and in thin sections from the western platform slope deposits (Fig. 8.2). Spotty oil staining found in the northern slope in well 04-33-023-16W1, 208.2-213.2 m (683.1-699.5') occurs in porous dolostones in lithofacies F, H, and I below a thick, thermally immature bituminous laminite, which onlaps the slope. Oil in this laminite is interpreted to be phytoplankton lipid-derived biological oil (see Chapter 7) and this is likely the source of the staining in the slope deposits as well. Therefore this oil occurrence appears to have little implication for petroleum exploration.

The western platform slope succession in the study area is completely dolomitized and does not have a limestone cap to restrict evaporite cementation associated with deposition

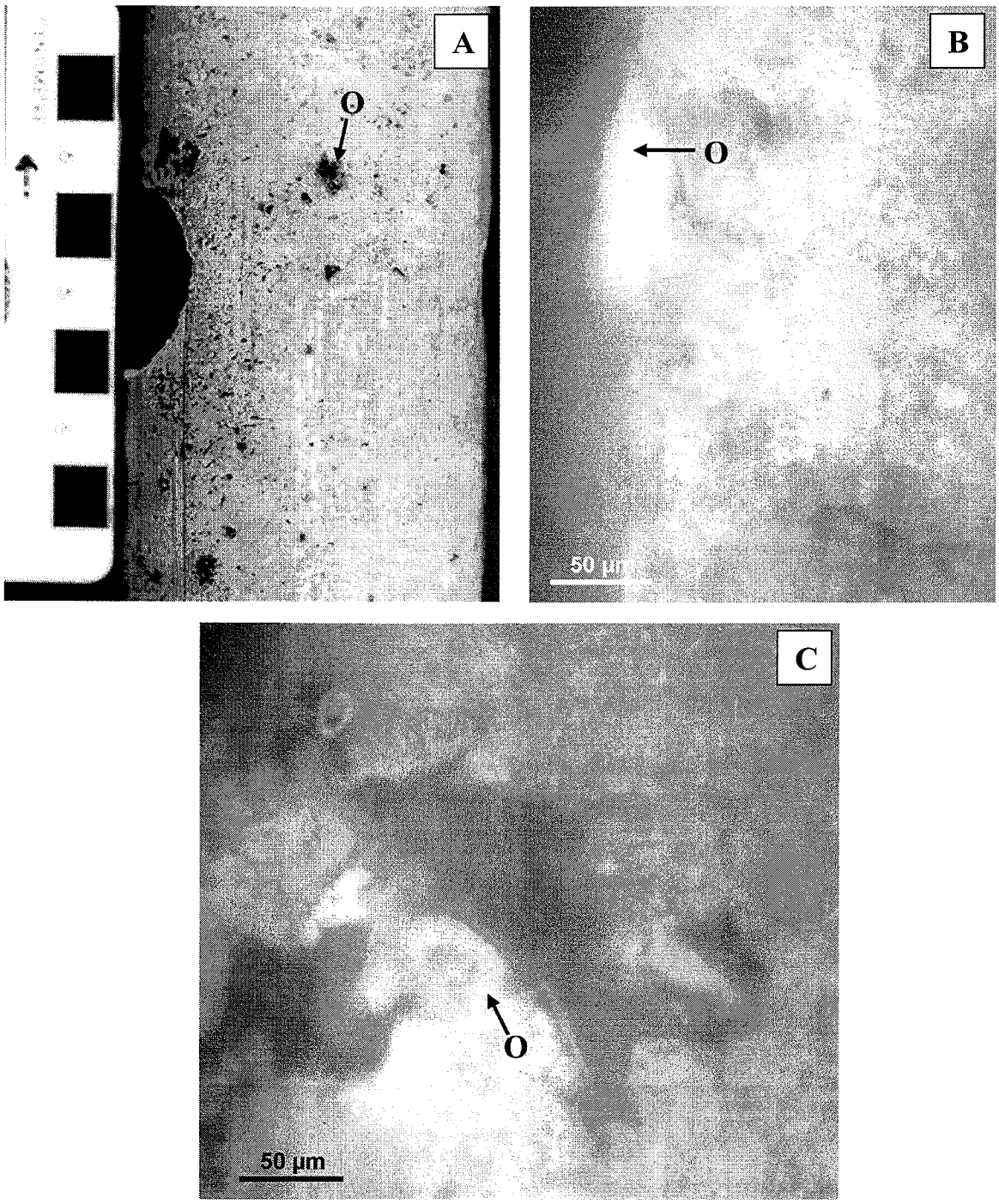


Figure 8.2: Oil staining (O) in core and thin sections from platform slope deposits in the Upper Winnipegosis Member. A) Core photograph showing oil staining in vuggy/moldic porosity in lithofacies H (bedded-mottled peloidal packstone). 04-33-023-16W1, 211.5 m (694'), scale bar divisions are in centimeters. B) Photomicrograph showing purple-fluorescing oil in epoxy at the margin of lithofacies N (laminated mudstone-peloidal packstone); UV fluorescence. 11-29-001-25W1, 1520.20 m (4987.55'). C) Photomicrograph showing purple-fluorescing oil in epoxy in micro-vuggy porosity in lithofacies H (bedded-mottled peloidal packstone); UV fluorescence. 4-12-007-25W1, 1200.30 m (3938').

of the Ratner Formation and Prairie Evaporite. However, anhydrite cement is variable and in places restricted to fractures, and open porosity up to 20% was observed in the upper half of the slope deposits. A stratigraphic trap could occur where elevated reef or shoal deposits with open porosity exist at the platform margin. Alternatively, structural or structural-stratigraphic traps may exist along the platform margin if parts of it were affected by post-Winnipegosis basement movement along the Birdtail-Waskada axis and capping evaporites or insoluble residues remained intact (cf. Martiniuk and Barchan, 1993; Dietrich and Magnusson, 1998).

8.4 The Platform-Interior Play

On the western side of the Elk Point Basin, several oil pools occur within the platform interior of the Upper Winnipegosis Member along a NW-SE trend that extends 200 km from Fairview in east-central Montana to Minton in south-central Saskatchewan (Potter and St. Onge, 1991; Kissling and Slingsby, 1999). In Montana, Winnipegosis producers along the trend include the Bainville North, Fairview, Honker, Medicine Lake, Medicine Lake North, Outlook, Outlook Middle, Singletree, Reserve, and Raymond fields (e.g., Lewis, 1958; Parker and Powe, 1982; Ames, 1984a; 1984b; 1984c; 1984d; Ehrenzeller, 1984; Basinski, 1985; Hargrove, 1985; Ingram, 1985; Kleeman, 1985). Structural closure is common to all previously known Winnipegosis reservoirs in platform interior successions.

The Minton pool (Township 3, Range 21W2) is located in the platform, 58 km southwest of the platform margin, which trends northwesterly, and 160 km from the Williston Basin

depocenter (Potter and St. Onge, 1991). In the Minton pool, structural closure is related to conjugate wrench faults which occur along zones of weakness in the basement and are known to have been active during late Devonian and early Mississippian time. However, in the Winnipegosis Formation, the structural crest is crowned by a coral-stromatoporoid bank facies, suggesting structural control during deposition. Enhanced porosity, up to 10% and including fractures, occurs within the structural closure. The platform facies is sealed by a peritidal facies, consisting of densely laminated dolomudstone to dolopackstone with interbeds of anhydrite, which in turn is overlain by the Prairie Evaporite. It is noteworthy that in the analogous Outlook Middle Field, the Prairie Evaporite has been dissolved above the fractured reservoir but the remaining insoluble residues serve as an effective seal (e.g., Basinski, 1985).

Oil sampled from the Winnipegosis Formation in the Minton pool is derived from a kerogenite source rock in the Ordovician Red River Formation and was emplaced via vertical fractures (pers. comm., K. Osadetz as cited in Potter and St. Onge, 1991). A Red River Formation source has also been proposed for Winnipegosis reservoirs along the producing trend in Montana (e.g., Leenheer and Zumberge, 1987).

Within the study area, oil staining was observed in thin sections of core samples from three wells (Fig. 8.3). However, without further geochemical analyses the source of these oils is unknown. Although vertical fracturing is not pervasive in any of the platform interior cores in this study, there is still potential for structural closure as vast areas remain undrilled and a structural/seismic analysis of the platform is required to determine

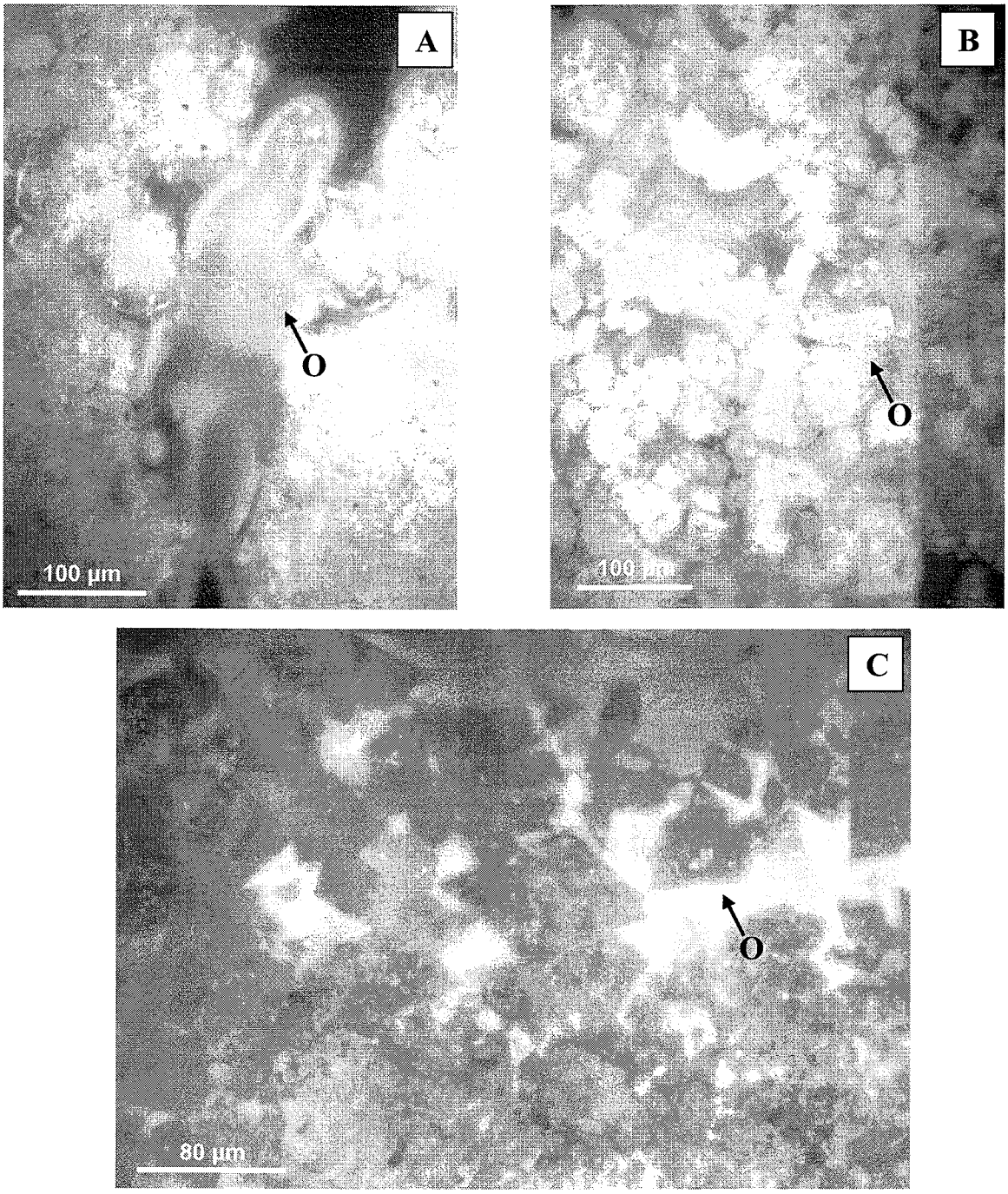


Figure 8.3: Photomicrographs showing fluorescent oil staining (O) in thin sections from platform interior deposits in the Upper Winnipegosis Member. A) Purple-fluorescing oil in epoxy within a fracture in lithofacies G (septarian-type nodular skeletal packstone); UV fluorescence. 04-27-011-22W1, 864.9 m (2837.65'). B) Purple-fluorescing oil in epoxy within intercrystalline porosity in lithofacies H (bedded-mottled peloidal packstone); UV fluorescence. 03-01-008-18W1, 783.95 m (2572'). C) Yellow-fluorescing oil in epoxy within intercrystalline porosity in lithofacies I (intraclast floatstone); UV fluorescence. 05-13-005-22W1, 1154.83 m (3788.8').

if post-Winnipegosis basement faulting may have affected the platform succession. Furthermore, the possibility of platform interior reservoirs should not be discounted in areas where dissolution of the Prairie Evaporite has occurred because insoluble residues can serve as an effective seal provided that dissolution preceded petroleum migration as shown in the Outlook Middle Field (cf. Basinski, 1985). The platform succession at the southern end of the study area has localized E-W trending dissolution of the Prairie Evaporite over it which may have been facilitated by fracturing/faulting in the underlying strata (e.g., Bezys and McCabe, 1996; Dietrich and Magnusson, 1998). This area may be a prospective location to search for platform interior reservoirs.

8.5 The Basin Laminites (Ratner Formation) Play

The least well known reservoirs associated with the Winnipegosis Formation occur in dolomitized portions of the basinal Ratner Formation laminites, which make excellent candidates for horizontal well development (Kissling and Slingsby, 1999). Although predominantly limestone, the upper 1 to 5 m of Ratner Formation laminites in the southern Elk Point Basin are dolomitized with lenses of secondary porosity up to 28%, which show oil staining and minor oil recoveries.

The only commercial production from the Ratner Formation has been in the Stoneview Field in North Dakota from three wells that were drilled between 1972 and 1980 (Kissling and Slingsby, 1999). This field is situated on a south-southeast plunging nose on the eastern flank of the Nesson Anticline, which intersects a zone of good porosity in the Ratner Formation. The trapping style is structural-stratigraphic and occurs from a

combination of subtle structural closure above and a northward up-dip loss of porosity and permeability associated with less extensive dolomitization. Production from these wells cumulatively produced approximately $4.77x10^4$ m^3 oil.

In southeastern Saskatchewan there has been production from the Ratner Formation in the Dome Scurry Tableland 11-14-002-9W2 well, which was drilled in 1975 (Kissling and Slingsby, 1999). This well produced $4.77x10^3$ m^3; however, communication with an adjacent oil-charged isolated reef was suspected. The Ratner Formation has also produced in the Kingsford Winnipegosis Pool where oil recoveries during drill stem and extended flow tests in the discovery well (Richland Northrock Kingsford 31/8-14-004-7W2) led to the drilling of the Richland Northrock Kingsford 41/8-14-004-7W2 well in 1997, which produced $1.97x10^4$ m^3 oil to March 1999. At this location, the upper two-thirds of the Ratner Formation are dolomitized with porosity ranging between 14 and 22% and trapping occurs via structural closure.

All three cores of the Ratner Formation examined in this study are partly to completely dolomitized and were found to contain oil staining as revealed in thin section by epi-fluorescence microscopy (Fig. 8.4). However, if the previously described examples of Ratner Formation oil production are any indication, an element of structural closure, for which there is presently no evidence, would be required for the accumulation of economic quantities of petroleum in the Ratner Formation within the study area.

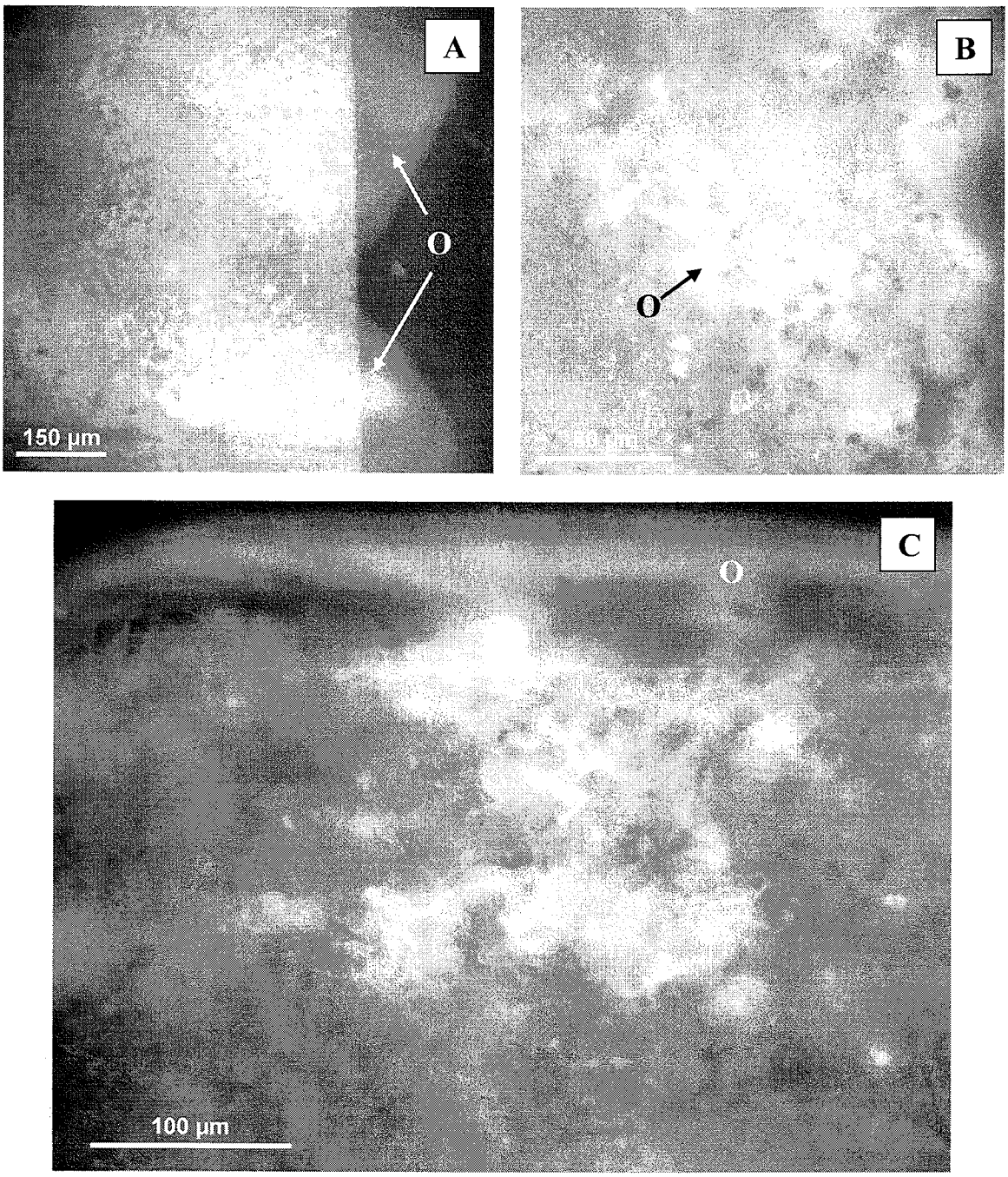


Figure 8.4: Photomicrographs showing fluorescent oil staining (O) in thin sectioned samples of lithofacies E (interlaminated mudstone-anhydrite) from the Ratner Formation. A) Yellow-fluorescing oil in intercrystalline porosity and streaming into epoxy at the margin of the thin section; UV fluorescence. 04-12-007-25W1, 1198.6 m (3932.41'). B) Purple-fluorescing oil in intercrystalline porosity UV fluorescence. 103/03-12-011-27W1, 1180.46 m (3872.9'). C) Purple-fluorescing oil in intercrystalline porosity and streaming into epoxy at the margin of the thin section; 02-21-007-28W1, 1445.57 m (4742.7').

CHAPTER 9: CONCLUSIONS AND FUTURE WORK

9.1 Lithofacies

Based on core examination, fifteen lithofacies were identified in the ramp, platform, and isolated reefs of the Elm Point, Winnipegosis, and Ratner formations.

1. Lithofacies A, non-fossiliferous mudstone, is a varicolored off-white, light gray and light purple, non-fossiliferous dolomudstone which is slightly calcareous in places. This lithofacies is interpreted to have been deposited in a low-energy, restricted, intertidal to shallow-subtidal environment.
2. Lithofacies B, mottled-nodular skeletal wackestone-mudstone, is composed of non-bedded, mottled to nodular, dolomitic limestone to dolostone, ranging from skeletal wackestone to mudstone. This lithofacies is interpreted to have been deposited in an open subtidal environment with normal salinity as indicated by a faunal assemblage dominated by brachiopods, crinoids, bryozoans, and mollusks.
3. Lithofacies C, nodular-patterned mudstone, consists of thick to very thick bedded dolomudstone with irregular blotchy, locally leopard-like, maroon to purple colored patterning in an otherwise tan or light brown lithology. This lithofacies is interpreted to have been deposited in a lower intertidal to supratidal setting.
4. Lithofacies D, bituminous laminite, consists of light to dark reddish brown to black, finely laminated, bituminous mudstone to grainstone. This lithofacies is interpreted to have been deposited in low energy, anoxic, subtidal conditions below fair-weather wave base.

5. Lithofacies E, interlaminated mudstone-anhydrite, consists of laminated mudstone and interlaminated or interbedded mudstone and anhydrite. This lithofacies is interpreted to have been deposited in subtidal conditions under progressively shallowing and increasingly saline conditions in a salina-like setting.
6. Lithofacies F, massive-mottled mudstone, consists of tan to light brown or grey mudstone to dolomudstone that is massive, sparsely fossiliferous, and locally faintly mottled and finely laminated. This lithofacies is interpreted to have been deposited in a low energy, subtidal setting between fair-weather wave base and storm wave base.
7. Lithofacies G, septarian-type nodular skeletal packstone, consists of thin to very thickly bedded, nodular skeletal dolopackstone to locally dolowackstone. The nodules possess septarian fractures and the matrix is variably bituminous. This lithofacies is interpreted to have been deposited in a dysoxic to anoxic, subtidal setting below storm wave base.
8. Lithofacies H, bedded-mottled peloidal packstone, consists of laminated to thickly bedded, peloidal (dolo)packstone and subordinate very thin to medium beds of dolograinstone and *Amphipora* dolofloatstone with dolopackstone matrix. This lithofacies is interpreted to have been deposited in a subtidal setting between fair-weather and storm wave base in open to slightly restricted waters.
9. Lithofacies I, intraclast floatstone, consists of pervasively dolomitized, medium to very thick beds of poorly sorted, intraclast floatstones. This lithofacies is interpreted to be either tempestites or subtidal debris flow deposits.

10. Lithofacies J, bituminous skeletal wackestone-floatstone, consists of medium to very thickly bedded, dark-brown to black, bituminous skeletal dolowackestone to dolofloatstone. This lithofacies is interpreted to have been deposited in a semi-restricted, quiet subtidal lagoonal setting.
11. Lithofacies K, peloidal-udoteacean packstone, consists of tan to light brown, peloid-udoteacean dolopackstone to dolograinstone, with dolopackstone being the dominant lithology. Very thin to very thick beds are massive to faintly mottled. This lithofacies is interpreted to have been deposited in an open subtidal environment below fair-weather wave base but within the photic zone.
12. Lithofacies L, stromatoporoid floatstone, consists of mottled to crudely thin to medium bedded, skeletal dolofloatstone. Bioclasts comprise 10 to 15% of this lithofacies and are predominantly angular to sub-rounded, stromatoporoid fragments. This lithofacies is interpreted to have been deposited in an open subtidal setting below fair-weather wave base.
13. Lithofacies M, coral-stromatoporoid rudstone-framestone, consists of thin to very thick beds of dolorudstone and possible doloframestone composed of encrusting or tabular stromatoporoids and tabulate corals with a dolopackstone matrix. This lithofacies is interpreted to have been deposited in a high-energy, subtidal environment above fair-weather wave base.
14. Lithofacies N, laminated mudstone-peloidal packstone, consists of pervasively dolomitized, thinly interlaminated to thinly interbedded mudstone and peloidal packstone. Bedding plane orientations vary from horizontal to a maximum

apparent dip of 21°. This lithofacies is interpreted to have been deposited in a moderately deep-subtidal, slope setting with slightly restricted conditions.

15. Lithofacies O, microbial bindstone, consists of tan, light brown or yellow, pervasively dolomitized microbial bindstone. This lithofacies is interpreted to be stromatolitic in origin having formed from the trapping, binding, and cementation of carbonate sediments, dominantly mud, by cyanobacterial mats in an intertidal to supratidal setting.

9.2 Lithofacies Associations

The lithofacies were genetically grouped into lithofacies associations; however, limited core control precludes a detailed study of these associations and their distribution but a notable absence of cyclicity was observed. Five lithofacies associations are recognized:

1. The ramp lithofacies association includes lithofacies A, B, C, and D, and comprises the Elm Point Formation and Lower Winnipegosis Member. This ramp lithofacies association represents deposition from mid-ramp (between fair-weather and storm wave base), low-energy inner ramp, and offshore tidal flat island settings.
2. The platform interior lithofacies association includes lithofacies D, H, I, and O, and comprises in part the Upper Winnipegosis Member. The platform interior is interpreted as an open to slightly restricted lagoonal setting that developed on the platform. The platform interior is relatively homogenous both laterally and vertically and is dominated by lithofacies H.

3. The platform slope lithofacies association includes lithofacies D, F, G, H, I, M, N, and O, and comprises in part the Upper Winnipegosis Member. Platform slopes represent the seaward termination of carbonate platforms and are recognized in the study area at the western and northern margins of the platform succession where tightening of contour lines on the isopach map occur. Lower to upper slope deposits are represented.
4. The isolated reef lithofacies association includes lithofacies I, J, K, L, M, N, and O, and comprises in part the Upper Winnipegosis Member. The isolated reef lithofacies association represents deposition from early "proto-reefs" to mature reefs in basinal areas. This association is complex showing increased lithofacies diversity upsection as well as an overall shoaling-upwards trend. Insufficient data are available to determine precise reef size and morphology.
5. The basinal salina lithofacies association includes lithofacies D and E. It comprises the Ratner Formation and occurs adjacent to the isolated reef lithofacies association on the basin floor to the west of the western platform margin. This association is interpreted to have been deposited in large, perennial salina(s) associated with evaporitic drawdown in the basinal area following deposition of the Upper Winnipegosis Member.

9.3 Organic Petrology

Based on organic petrology, organic facies were identified in bituminous laminites (lithofacies D) from various stratigraphic positions within the Winnipegosis, Elm Point, and Ratner formations.

1. Bituminous laminites in the ramp-to-platform and ramp-to-basin transition intervals span the uppermost Lower Winnipegosis Member/Elm Point Formation and the lowermost Upper Winnipegosis Member. Bituminous laminites from the ramp-to-platform transition were interpreted as organic facies BL1, characterized by the presence of akinete cells, indicating elevated phytoplankton productivity. A bituminous laminite from the uppermost ramp at the ramp-to-basin transition was interpreted as organic facies A, which is typical of normal phytoplankton production in a distal setting and characterized by common small and rare large Prasinophyte alginites.
2. Bituminous laminites in the platform interior succession in the Upper Winnipegosis Member occur at inner and outer platform locations. Bituminous laminites from the inner platform were interpreted as organic facies E, which is typical of restricted platforms and lagoons and is characterized by: mat-like, laminated amorphinite; trace to rare, large, Prasinophyte alginites; common small Prasinophytes; rare coccoidal alginite; trace to common sporinites; common bodies of vitrinite; and trace possible irregular cutinite and rare resinite. Bituminous laminites from the outer platform were interpreted as organic facies BL2, characterized by the presence of akinete cells and abundant, large Prasinophyte alginites, indicating elevated phytoplankton productivity.
3. Bituminous laminites in the platform slope succession in the Upper Winnipegosis Member along the western margin were interpreted as organic facies BL1, characterized by the presence of akinete cells, indicating elevated phytoplankton productivity.

4. Bituminous laminites onlapping the platform slope succession in the Upper Winnipegosis Member along the western and northern margins were interpreted as organic facies BL1 and BL3 as evidenced by pyrite spheres that are postulated to be pyritized akinete cells and by very abundant calcispheres in an amorphinite matrix respectively, both indicative of elevated phytoplankton productivity.
5. A bituminous laminite from the basinal salina succession of the Ratner Formation was interpreted as organic facies BL2, characterized by the presence of akinete cells and abundant large Prasinophyte alginites indicating elevated phytoplankton productivity.

9.4 Depositional History

The Winnipegosis, Elm Point, and Ratner formations were deposited during the second transgressive-regressive cycle of the Hume-Dawson sequence.

1. Initially, low-energy peritidal sediments of the Lower Winnipegosis Member and Elm Point Formation were deposited in paleotopographic lows on the surface of the Ashern Formation. Water depth increased and a carbonate ramp developed which had fairly uniform deposition in a normal marine setting.
2. As the transgression progressed the Elk Point Basin differentiated into a shallow fringing carbonate platform and a bathymetrically deeper basin. This differentiation appears to be tectonically controlled within the study area as the platform margin to the west coincides with the Birdtail-Waskada Axis and to the north with the contact between the Uchi and English River basement domains. Areas seaward of these boundaries became a starved basin floor except at

locations where isolated reefs initiated. Both normal and elevated phytoplankton productivity occurred at the ramp-to-platform/basin transition and over the platform interior. Elevated phytoplankton productivity occurred in the basin over the platform slope during and at the end of platform growth possibly triggered by elevated salinity.

3. Upon basin differentiation, isolated reefs initiated on the basin floor. The isolated reefs within the study area appear to have grown throughout the transgression as there is no evidence for drowned reefs. However, most isolated reefs did not achieve sea level until late in their depositional history. It is not known why isolated reefs initiated where they did; however, some may have been influenced by reactivation of sea-floor structures.
4. The Brightholme Member in the study area where it overlies the Lower Winnipegosis Member ramp was not cored. The onlapping platform slope bituminous laminites (lithofacies D) may extend into the basin and constitute in part, the uppermost Brightholme Member. The Brightholme Member may be coeval with the entire Upper Winnipegosis Member.
5. Winnipegosis reef/platform growth was terminated by an eustatic sea-level fall, which caused the Elk Point Basin to become restricted. Evaporative drawdown in the Elk Point Basin persisted to the point where deposition of the Ratner Formation began in basinal areas. Near-desiccation of the basin floor likely occurred near the end of Ratner Formation deposition based on organic petrological observations.

9.5 Organic Geochemistry

Whole rock pyrolysis was conducted to determine the geochemical kerogen type, extent of thermal maturation, and the petroleum generative potential of bituminous laminites (lithofacies D) as source rocks within the study area.

1. The hydrogen index versus oxygen index diagram (HI vs. OI) shows highly varied kerogen compositions with most samples plotting between the Type II and III fields and some outliers in the Type I and Type III fields. All samples are thermally immature with respect to hydrocarbon generation except for one that approaches 0.5% R_o.
2. The hydrogen index versus maximum temperature (HI vs. T_{max}) diagram similarly shows highly variable kerogen compositions and thermal immaturity.

9.6 Petroleum Plays and Potential

The Winnipegosis Formation is best known for its isolated reef plays in basinal areas in Saskatchewan and North Dakota; however, at least three other petroleum play types exist.

1. Isolated reef play. Commercial quantities of petroleum have been produced from isolated reefs in the Tableland and Hitchcock areas of southeastern Saskatchewan. The reefs are encased in anhydrite forming a stratigraphic trap. In North Dakota, two out of six isolated reefs that were drilled contained free oil. No discoveries have been made in isolated reefs within the study area; however, the reefs have ample porosity and permeability, and show oil staining.
2. Platform margin play. The best documented example of a platform margin play is the Temple Field Winnipegosis Pool in North Dakota which occurs along a

subordinate structural limb on the northwestern flank of the Nesson Anticline. The trapping style is structural-stratigraphic with the reservoir capped by a platform margin reef facies. Within the study area, oil staining was observed in core (04-33-023-16W1) from the northern platform slope deposits and in thin sections (04-12-007-25W1; 11-29-001-25W1) from the western platform slope deposits.

3. Platform interior play. On the western side of the Elk Point Basin, several oil pools occur within the platform interior of the Upper Winnipegosis Member along a NW-SE trend that extends 200 km from Fairview in east-central Montana to Minton in south-central Saskatchewan. Structural closure is common to all previously known Winnipegosis reservoirs in platform interior successions. Within the study area, oil staining was observed in thin sections of core samples from the upper platform interior succession in three wells (04-27-011-22W1; 05-13-005-22W1; 03-01-008-18W1).
4. Basin laminites play. The least known reservoirs associated with the Winnipegosis Formation occur in dolomitized portions of the basinal Ratner Formation laminites. The only commercial production from the Ratner Formation has been in the Stoneview Field in North Dakota where the trapping style is structural-stratigraphic. The Ratner Formation has also produced in the Kingsford Winnipegosis Pool in Saskatchewan. All three cores of the Ratner Formation examined in this study (04-12-007-25W1; 103/03-12-011-27W1; 02-21-007-28W1) are partly to completely dolomitized and contain oil staining as revealed in thin section by epi-fluorescence microscopy.

9.7 Recommendations for Future Work

1. The single largest impediment to a better understanding of the sedimentology and stratigraphy of the Winnipegosis, Elm Point, and Ratner formations within the study area is a lack of core control. Any future coring of these formations would greatly facilitate the determination of the lateral and vertical extent of their constituent lithofacies and their associations.
2. Improved stratigraphic age control in the study area could be obtained with conodont biostratigraphy.
3. With respect to organic petrology more detailed study should be undertaken on the calcisphere-bearing bituminous laminite (organic facies BL3) including more thorough vertical sampling of the laminite, as this may be the first documented example of calcareous phytoplankton from the Paleozoic. Additionally, dissolving organic matter/oil from some samples prior to thin-sectioning would facilitate more detailed carbonate petrography/micropaleontology of the calcispheres.
4. With respect to organic geochemistry, an attempt should be made to extract and "fingerprint" oil from cores that were determined to contain oil shows as determined by epi-fluorescence microscopy. This work should be conducted to differentiate biological from thermogenic oils and to correlate to source rocks if possible. Correlation to source rocks would help to delineate migration pathways and lead to a better understanding of petroleum potential within the study area.

5. The structural evolution of the study area remains poorly understood. A detailed interpretive study of existing seismic lines may provide a better understanding of the structural history and petroleum potential of the study area.

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APPENDIX A: STRATIGRAPHIC TOPS USED FOR ISOPACH MAPS

This appendix contains three tables presenting the stratigraphic tops used to construct the isopach maps for the Lower Winnipegosis Member and Elm Point Formation (Enclosure 8) and the Upper Winnipegosis Member and Ratner Formation (Enclosure 9). Table A.1 presents the stratigraphic tops used for the Manitoba portion of the maps, which were obtained from the stratigraphic database of Manitoba Science, Technology, Energy and Mines; tops shown in red were adjusted for this study. Table A.2 presents the stratigraphic tops used for the Saskatchewan portion of the maps, which were provided by Saskatchewan Industry and Resources. Table A.3 presents the stratigraphic tops used for the North Dakota portion of the maps, which were provided by the North Dakota Geological Survey. Table A.1 and A.2 are arranged by well location in ascending order and Table A.3 is arranged by well number in ascending order.

Table A.1: Manitoba stratigraphic tops obtained from the stratigraphic database of Manitoba Science, Technology, Energy and Mines. Depths in red were adjusted for this study. TVD=true vertical depth.

Well Location	Kelly Bushing (K.B.) elevation (m)	Kelly Bushing (K.B.) elevation (ft.)	Upper Winnipegosis Member/Ratner Formation TVD (m)	Upper Winnipegosis Member/Ratner Formation TVD (ft.)	Lower Winnipegosis Member/Elm Point Formation TVD (m)	Lower Winnipegosis Member/Elm Point Formation TVD (ft.)	Ashern Formation TVD (m)	Ashern Formation TVD (ft.)
100/11-29-001-25W1/00	474	1555.1	1508.6	4949.5	1532.1	5026.6	1542.6	5061.0
100/09-13-001-26W1/00	467.6	1534.1	1540.0	5052.5	1560.2	5118.8	1570.0	5150.9
100/16-16-001-27W1/00	456.3	1497.0	1631.0	5351.0	1660.4	5447.5	1668.0	5472.4
100/05-20-001-27W1/00	454.5	1491.1	1655.0	5429.8	1673.6	5490.8	1682.0	5518.4
100/10-09-001-28W1/00	459.2	1506.6	1724.0	5656.2	1758.3	5768.7	1766.3	5794.9
100/14-15-001-28W1/00	460.6	1511.2	1715.0	5626.6	1733.1	5686.0	1742.0	5715.2
100/13-05-002-15W1/00	475.9	1561.4	884.0	2900.3	906.7	2974.7	914.0	2998.7
100/08-15-002-20W1/00	583.4	1914.0	1234.0	4048.6	1262.6	4142.4	1274.9	4182.7
102/08-15-002-20W1/00	584.5	1917.7	1235.2	4052.5	1262.1	4140.7	1275.8	4185.7
102/08-31-002-23W1/00	502.6	1649.0	1345.6	4414.7	1385.0	4544.0	1395.0	4576.8
100/09-06-002-26W1/00	438.9	1440.0	1521.0	4990.2	1556.6	5107.0	1566.2	5138.5
100/05-24-002-26W1/00	472.7	1550.9	1482.0	4862.2	1520.0	4986.9	1530.0	5019.7
100/02-28-002-26W1/00	467.4	1533.5	1480.0	4855.6	1531.8	5025.6	1544.5	5067.3
100/09-15-002-27W1/00	453.5	1487.9	1577.0	5173.9	1590.7	5218.8	1601.0	5252.6
100/04-04-003-15W1/00	470	1542.0	848.0	2782.2	870.3	2855.3	881.5	2892.1
100/15-36-003-22W1/00	499.3	1638.1	1197.2	3927.8	1227.3	4026.6	1239.0	4065.0
100/15-20-003-25W1/00	468.5	1537.1	1437.4	4715.9	1446.6	4746.1	1457.6	4782.2
100/04-32-003-25W1/00	463.6	1521.0	1388.4	4555.1	1429.4	4689.6	1440.1	4724.7
100/03-09-004-11W1/00	471.2	1545.9	618.5	2029.2	625.5	2052.2	631.0	2070.2
100/16-33-004-13W1/00	434.9	1426.8	666.5	2186.7	672.6	2206.7	686.9	2253.6
100/07-34-004-15W1/00	456.6	1498.0	765.3	2510.8	781.5	2564.0	787.2	2582.7
100/13-36-004-19W1/00	496.2	1628.0	1002.8	3290.0	1025.7	3365.2	1041.0	3415.4
100/01-25-004-23W1/00	501.8	1646.3	1226.7	4024.6	1261.6	4139.1	1272.5	4174.9
100/05-03-004-25W1/00	462.7	1518.0	1344.6	4411.4	1388.7	4556.1	1401.2	4597.1
100/02-17-004-25W1/00	454.8	1492.1	1350.4	4430.4	1382.2	4534.8	1393.8	4572.8
100/02-35-005-08W1/00	441.7	1449.1	430.0	1410.8	435.6	1429.1	444.0	1456.7
100/16-13-005-12W1/00	458	1502.6	615.3	2018.7	626.8	2056.4	632.0	2073.5
100/01-27-005-14W1/00	429.2	1408.1	683.0	2240.8	701.2	2300.5	707.0	2319.6

Well Location	Kelly Bushing (K.B.) elevation (m)	Kelly Bushing (K.B.) elevation (ft.)	Upper Winnipegosis Member/Ratner Formation TVD (m)	Upper Winnipegosis Member/Ratner Formation TVD (ft.)	Lower Winnipegosis Member/Elm Point Formation TVD (m)	Lower Winnipegosis Member/Elm Point Formation TVD (ft.)	Ashern Formation TVD (m)	Ashern Formation TVD (ft.)
100/13-11-005-16W1/00	479.1	1571.9	835.3	2740.5	851.5	2793.6	857.7	2814.0
100/16-16-005-21W1/00	484.6	1589.9	1092.6	3584.6	1122.3	3682.1	1134.5	3722.1
100/05-13-005-22W1/00	498.2	1634.5	1150.2	3773.6	1184.2	3885.2	1193.2	3914.7
100/08-13-005-29W1/00	489	1604.3	1521.5	4991.8	1583.3	5194.6	1591.0	5219.8
100/09-35-005-25W1/00	434.3	1424.9	1231.8	4041.3	1249.6	4099.7	1255.2	4118.1
102/15-31-005-29W1/00	515	1689.6	1560.2	5118.8	1623.4	5326.1	1631.6	5353.0
100/01-27-006-11W1/00	512.5	1681.4	622.0	2040.7	635.0	2083.3	638.0	2093.2
100/13-16-006-12W1/00	405.7	1331.0	567.0	1860.2	587.2	1926.5	593.0	1945.5
100/04-25-006-26W1/00	436.2	1431.1	1249.0	4097.8	1278.1	4193.2	1289.0	4229.0
100/16-34-006-29W1/00	511.1	1676.8	1524.2	5000.7	1534.7	5035.1	1543.0	5062.3
100/16-22-007-10W1/00	431.2	1414.7	481.6	1580.1	497.4	1631.9	502.0	1647.0
100/13-05-007-15W1/00	383.4	1257.9	679.4	2229.0	700.0	2296.6	710.2	2330.1
100/04-12-007-25W1/00	437.8	1436.4	1198.0	3930.4	1215.9	3989.2	1224.0	4015.7
100/09-26-007-25W1/00	433.1	1420.9	1169.8	3837.9	1182.6	3879.9	1190.2	3904.9
100/14-10-007-26W1/00	446	1463.3	1238.6	4063.6	1286.9	4222.1	1298.0	4258.5
100/05-33-007-27W1/00	451.8	1482.3	1335.0	4379.9	1339.5	4394.7	1347.0	4419.3
100/02-21-007-28W1/00	493.2	1618.1	1441.7	4730.0	1447.2	4748.0	1458.2	4784.1
100/13-07-008-09W1/00	367.3	1205.1	390.8	1282.2	405.8	1331.4	413.0	1355.0
100/16-21-008-12W1/00	349	1145.0	463.9	1522.0	486.8	1597.1	493.5	1619.1
100/08-36-008-14W1/00	319.1	1046.9	485.6	1593.2	510.3	1674.2	514.8	1689.0
100/07-35-008-15W1/00	371.8	1219.8	587.6	1927.8	609.7	2000.3	616.9	2024.0
100/10-17-008-17W1/00	389.5	1277.9	728.5	2390.1	754.4	2475.1	762.9	2503.0
100/03-01-008-18W1/00	415.9	1364.5	782.7	2567.9	808.8	2653.5	815.6	2675.9
100/01-18-008-25W1/00	435.5	1428.8	1151.2	3776.9	1191.2	3908.1	1202.5	3945.2
100/13-10-009-11W1/00	361.8	1187.0	421.2	1381.9	442.6	1452.1	450.8	1479.0
100/15-12-009-12W1/00	365.2	1198.2	450.2	1477.0	468.3	1536.4	480.9	1577.8
100/10-02-009-16W1/00	377.6	1238.8	625.8	2053.1	646.3	2120.4	654.4	2147.0
100/10-24-009-16W1/00	372.8	1223.1	604.9	1984.6	622.1	2041.0	631.8	2072.8
100/03-05-009-19W1/00	418.8	1374.0	822.6	2698.8	848.5	2783.8	856.8	2811.0
100/16-27-009-19W1/00	405.1	1329.1	760.8	2496.1	787.2	2582.7	794.6	2607.0

Well Location	Kelly Bushing (K.B.) elevation (m)	Kelly Bushing (K.B.) elevation (ft.)	Upper Winnipegosis Member/Ratner Formation TVD (m)	Upper Winnipegosis Member/Ratner Formation TVD (ft.)	Lower Winnipegosis Member/Elm Point Formation TVD (m)	Lower Winnipegosis Member/Elm Point Formation TVD (ft.)	Ashern Formation TVD (m)	Ashern Formation TVD (ft.)
100/16-22-009-20W1/00	415.3	1362.5	826.0	2710.0	854.4	2803.1	863.5	2833.0
100/15-06-009-23W1/00	435.6	1429.1	1016.8	3336.0	1053.3	3455.7	1064.0	3490.8
100/15-08-009-25W1/00	434.6	1425.9	1099.3	3606.6	1141.2	3744.1	1148.2	3767.1
102/09-32-009-25W1/00	439.3	1441.3	1069.1	3507.5	1112.1	3648.6	1119.0	3671.3
100/14-13-009-28W1/00	488.6	1603.0	1277.5	4191.3	1310.9	4300.9	1322.0	4337.3
100/02-12-010-09W1/00	306.8	1006.6	255.7	838.9	274.2	899.6	278.6	914.0
100/05-03-010-10W1/00	360.3	1182.1	357.5	1172.9	375.1	1230.6	381.0	1250.0
100/11-09-010-16W1/00	377.3	1237.9	606.5	1989.8	634.4	2081.4	640.6	2101.7
100/16-10-010-18W1/00	369.1	1211.0	666.9	2188.0	697.1	2287.1	702.9	2306.1
100/02-17-010-18W1/00	372.1	1220.8	686.0	2250.7	712.1	2336.3	718.9	2358.6
100/06-18-010-18W1/00	395.3	1296.9	722.5	2370.4	751.6	2465.9	759.0	2490.2
100/14-16-010-19W1/00	402	1318.9	747.9	2453.7	777.4	2550.5	783.1	2569.2
100/03-24-010-21W1/00	434.8	1426.5	842.0	2762.5	868.4	2849.1	876.0	2874.0
100/13-04-010-22W1/00	422.8	1387.1	908.3	2980.0	942.0	3090.6	952.2	3124.0
100/15-18-010-27W1/00	491.9	1613.8	1262.5	4142.1	1267.4	4158.1	1273.4	4177.8
100/13-21-010-28W1/00	515.3	1690.6	1302.5	4273.3	1315.4	4315.6	1326.5	4352.0
100/09-17-010-29W1/00	536.3	1759.5	1381.2	4531.5	1399.1	4590.2	1408.0	4619.4
100/02-16-011-10W1/00	297.6	976.4	289.6	950.1	313.2	1027.6	325.8	1068.9
100/05-31-011-13W1/00	397.1	1302.8	489.2	1605.0	517.8	1698.8	524.3	1720.1
100/10-25-011-17W1/00	396.9	1302.2	602.3	1976.0	632.8	2076.1	639.0	2096.5
100/07-26-011-17W1/00	399.7	1311.4	617.9	2027.2	642.8	2108.9	650.6	2134.5
100/04-27-011-22W1/00	420.9	1380.9	849.5	2787.1	884.1	2900.6	890.0	2919.9
100/02-20-011-24W1/00	458.1	1503.0	993.9	3260.8	1033.0	3389.1	1041.2	3416.0
102/14-27-011-26W1/00	461.3	1513.5	1091.9	3582.3	1101.9	3615.2	1109.2	3639.1
103/03-12-011-27W1/00	477.6	1566.9	1178.5	3866.5	1180.5	3873.0	1192.0	3910.8
100/07-08-011-29W1/00	543.5	1783.1	1372.8	4503.9	1379.2	4524.9	1388.1	4554.1
100/10-28-012-23W1/00	494.2	1621.4	925.7	3037.1	962.5	3157.8	970.2	3183.1
100/03-17-012-24W1/00	472.4	1549.9	984.5	3230.0	1013.0	3323.5	1022.6	3355.0
100/15-11-012-26W1/00	454	1489.5	1051.0	3448.2	1064.9	3493.8	1072.0	3517.1
100/16-29-012-29W1/00	524.4	1720.5	1283.2	4210.0	1285.7	4218.2	1295.1	4249.0

Well Location	Kelly Bushing (K.B.) elevation (m)	Kelly Bushing (K.B.) elevation (ft.)	Upper Winnipegosis Member/Ratner Formation TVD (m)	Upper Winnipegosis Member/Ratner Formation TVD (ft.)	Lower Winnipegosis Member/Elm Point Formation TVD (m)	Lower Winnipegosis Member/Elm Point Formation TVD (ft.)	Ashern Formation TVD (m)	Ashern Formation TVD (ft.)
100/16-20-013-09W1/00	260	853.0	164.3	539.0	192.6	631.9	197.4	647.6
100/13-17-013-14W1/00	396.2	1299.9	478.5	1569.9	508.7	1669.0	515.7	1691.9
100/03-19-013-15W1/00	391.7	1285.1	512.9	1682.7	539.6	1770.3	545.3	1789.0
100/05-29-014-14W1/00	348.1	1142.1	397.6	1304.5	429.7	1409.8	437.6	1435.7
100/15-29-014-14W1/00	354.2	1162.1	394.7	1294.9	424.6	1393.0	429.8	1410.1
100/16-26-014-18W1/00	556	1824.1	712.0	2336.0	742.5	2436.0	750.1	2461.0
100/02-07-014-20W1/00	556	1824.1	837.0	2746.1	874.6	2869.4	880.9	2890.1
100/02-28-014-24W1/00	525.8	1725.1	931.2	3055.1	962.3	3157.2	972.0	3189.0
100/12-10-014-25W1/00	500.8	1643.0	959.3	3147.3	991.4	3252.6	1001.6	3286.1
100/13-12-015-16W1/00	417.9	1371.1	490.1	1607.9	520.6	1708.0	527.9	1732.0
100/02-21-015-18W1/00	591.5	1940.6	746.4	2448.8	774.0	2539.4	780.3	2560.0
100/12-34-015-26W1/00	514.4	1687.7	940.9	3086.9	980.9	3218.2	988.9	3244.4
100/12-13-016-13W1/00	294.4	965.9	256.0	839.9	286.6	940.3	295.7	970.1
100/08-34-016-21W1/00	606.9	1991.1	816.9	2680.1	852.5	2796.9	860.5	2823.2
100/02-07-016-26W1/00	510.8	1675.9	990.4	3249.3	1006.6	3302.5	1012.6	3322.2
100/02-14-016-28W1/00	392.9	1289.0	896.0	2939.6	934.4	3065.6	941.9	3090.2
100/16-11-017-15W1/00	371.3	1218.2	372.4	1221.8	401.8	1318.2	408.4	1339.9
100/15-31-017-17W1/00	633.4	2078.1	702.6	2305.1	732.9	2404.5	741.9	2434.1
100/12-23-017-20W1/00	627.9	2060.0	779.4	2557.1	811.2	2661.4	819.3	2688.0
100/06-23-017-23W1/00	567.5	1861.9	823.9	2703.1	859.6	2820.2	865.6	2839.9
100/01-27-017-26W1/00	545.9	1791.0	944.0	3097.1	966.1	3169.6	971.7	3188.0
102/04-18-018-04W1/00	251.5	825.1			0.0	0.0	5.8	19.0
100/13-13-018-21W1/00	605.9	1987.9	761.9	2499.7	789.3	2589.6	797.6	2616.8
100/02-17-018-22W1/00	578.7	1898.6	796.4	2612.9	822.7	2699.1	834.8	2738.8
100/04-21-018-26W1/00	545.3	1789.0	893.9	2932.7	940.3	3085.0	950.0	3116.8
100/04-30-018-26W1/00	551.2	1808.4	907.7	2978.0	949.8	3116.1	960.1	3149.9
100/02-14-018-29W1/00	484.5	1589.6	967.4	3173.9	977.9	3208.3	987.3	3239.2
100/16-18-018-29W1/00	486.8	1597.1	951.0	3120.1	1001.3	3285.1	1011.0	3316.9
100/05-19-019-23W1/00	624.5	2048.9	848.2	2782.8	883.4	2898.3	890.6	2921.9
100/10-04-019-26W1/00	555.2	1821.5	912.2	2992.8	929.8	3050.5	938.2	3078.1

Well Location	Kelly Bushing (K.B.) elevation (m)	Kelly Bushing (K.B.) elevation (ft.)	Upper Winnipegosis Member/Ratner Formation TVD (m)	Upper Winnipegosis Member/Ratner Formation TVD (ft.)	Lower Winnipegosis Member/Elm Point Formation TVD (m)	Lower Winnipegosis Member/Elm Point Formation TVD (ft.)	Ashern Formation TVD (m)	Ashern Formation TVD (ft.)
100/09-11-019-29W1/00	497.4	1631.9	959.5	3148.0	962.4	3157.5	971.7	3188.0
100/04-17-019-29W1/00	489.5	1606.0	935.7	3069.9	975.1	3199.1	984.8	3231.0
100/16-32-019-27W1/00	555	1820.9	938.8	3080.1	938.8	3080.1	951.0	3120.1
100/04-20-020-15W1/00	336.8	1105.0	273.7	898.0	310.0	1017.1	317.9	1043.0
100/16-31-020-26W1/00	596.3	1956.4	872.5	2862.5	908.5	2980.6	925.5	3036.4
100/16-19-021-11W1/00	275.8	904.9	93.3	306.1	133.1	436.7	142.3	466.9
100/15-14-021-15W1/00	300.2	984.9	197.5	648.0	235.7	773.3	244.4	801.8
100/14-22-021-15W1/00	296.6	973.1	192.0	629.9	227.1	745.1	235.9	774.0
100/04-19-021-27W1/00	572.1	1877.0	914.4	3000.0	918.2	3012.5	926.6	3040.0
100/13-30-022-08W1/00	249.9	819.9	0.0	0.0	6.6	21.7	27.0	88.6
100/15-22-022-27W1/00	630.6	2068.9	912.0	2992.1	918.2	3012.5	929.0	3047.9
100/04-33-023-16W1/00	286.2	939.0	203.6	668.0	220.7	724.1	241.4	792.0
100/06-33-023-16W1/00	287.4	942.9	210.0	689.0	235.4	772.3	244.4	801.8
100/05-35-024-10W1/00	249.3	817.9	0.0	0.0	19.2	63.0	42.4	139.1
100/12-35-024-10W1/00	249.3	817.9	3.3	10.8	17.9	58.7	42.3	138.8
100/01-11-024-26W1/00	555.5	1822.5	713.2	2339.9	751.1	2464.2	760.5	2495.1
100/13-04-024-27W1/00	573.3	1880.9	823.5	2701.8	831.1	2726.7	840.8	2758.5
100/01-24-025-21W1/00	337.1	1106.0	326.1	1069.9	350.6	1150.3	360.3	1182.1
102/04-28-025-26W1/00	568.1	1863.8	703.5	2308.1	736.4	2416.0	744.3	2441.9
100/04-30-027-20W1/00	320	1049.9	286.5	940.0	294.0	964.6	302.4	992.1
100/10-03-029-10W1/00	249.9	819.9			0.0	0.0	6.4	21.0
100/02-12-029-29W1/00	618.3	2028.5	771.1	2529.9	780.9	2562.0	792.5	2600.1
102/10-22-030-16W1/00	258	846.5	67.7	222.1	78.6	257.9	95.7	314.0
100/15-20-030-17W1/00	266	872.7	46.2	151.6	95.8	314.3	120.4	395.0
100/15-09-031-18W1/00	257.6	845.1	117.0	383.9	123.0	403.5		
102/15-09-031-18W1/00	257.6	845.1	102.5	336.3	121.3	398.0	138.0	452.8
100/02-02-031-25W1/00	702.6	2305.1	659.4	2163.4	712.4	2337.3	727.6	2387.1
102/01-05-033-19W1/00	262.1	859.9	113.2	371.4	119.6	392.4	138.5	454.4
100/16-35-034-26W1/00	558.9	1833.7	522.7	1714.9	532.8	1748.0	544.6	1786.7
100/13-03-035-29W1/00	417.3	1369.1	383.7	1258.9	465.8	1528.2	478.5	1569.9

Well Location	Kelly Bushing (K.B.) elevation (m)	Kelly Bushing (K.B.) elevation (ft.)	Upper Winnipegosis Member/Ratner Formation TVD (m)	Upper Winnipegosis Member/Ratner Formation TVD (ft.)	Lower Winnipegosis Member/Elm Point Formation TVD (m)	Lower Winnipegosis Member/Elm Point Formation TVD (ft.)	Ashern Formation TVD (m)	Ashern Formation TVD (ft.)
100/03-29-036-25W1/00	313.6	1028.9	235.9	774.0	240.8	790.0	259.4	851.0
100/15-32-036-26W1/00	309.1	1014.1	192.0	629.9	255.1	836.9	269.4	883.9
100/09-01-037-28W1/00	361.5	1186.0	265.6	871.4	321.9	1056.1	336.5	1104.0
100/02-21-041-24W1/00	259	849.7	96.0	315.0	106.1	348.1	119.9	393.4
102/09-33-043-24W1/00	269.1	882.9	17.5	57.4	89.7	294.3	100.3	329.1
100/06-17-044-24W1/00	274	899.0	17.6	57.7	93.8	307.7	109.7	359.9
100/06-21-044-24W1/00	266.7	875.0	15.4	50.5	79.3	260.2	95.9	314.6
100/03-01-044-25W1/00	225	738.2	31.0	101.7	79.8	261.8	95.7	314.0
100/05-13-044-25W1/00	254.5	835.0	47.2	154.9	75.8	248.7	92.3	302.8
100/07-14-044-25W1/00	275.8	904.9	39.3	128.9	41.5	136.2		
100/08-14-044-25W1/00	254.6	835.3	55.4	181.8	77.5	254.3	93.7	307.4
102/08-14-044-25W1/00	254.5	835.0	57.9	190.0	79.3	260.2		
100/10-31-044-26W1/00	269.7	884.8	113.7	373.0	117.3	384.8	132.0	433.1
100/11-08-045-25W1/00	266.7	875.0	10.7	35.1	94.5	310.0	106.1	348.1
100/10-11-045-26W1/00	265	869.4	79.4	260.5	94.2	309.1	114.6	376.0
100/14-12-045-26W1/00	265	869.4	78.9	258.9	89.6	294.0	100.3	329.1
100/03-17-045-25W1/00	270	885.8	24.6	80.7	97.3	319.2	109.2	358.3
100/02-28-045-25W1/00	261	856.3	9.9	32.5	26.0	85.3		
100/01-35-045-25W1/00	259.1	850.1	29.8	97.8	66.6	218.5	81.6	267.7
100/07-35-045-25W1/00	258.5	848.1	0.0	0.0	38.8	127.3		
102/07-35-045-25W1/00	262.2	860.2	8.6	28.2	56.8	186.4	84.9	278.5
105/08-35-045-25W1/00	262.1	859.9	31.9	104.7	53.0	173.9	81.2	266.4
100/09-16-046-22W1/00	261	856.3	16.8	55.1	28.0	91.9	42.9	140.7

Table A.2: Saskatchewan stratigraphic tops obtained from Saskatchewan Industry and Resources. TVD=true vertical depth.

Well Location	Kelly Bushing (K.B.) Elevation (m)	Kelly Bushing (K.B.) Elevation (ft.)	Upper Winnipegosis Member/Ratner Formation TVD (m)	Upper Winnipegosis Member/Ratner Formation TVD (ft.)	Lower Winnipegosis Member TVD (m)	Lower Winnipegosis Member TVD (ft.)	Ashern Formation TVD (m)	Ashern Formation TVD (ft.)
121/02-07-001-31W1/00	504.40	1654.9	2021.00	6630.6	2074.10	6804.8	2080.30	6825.1
141/16-19-001-32W1/00	518.80	1702.1	2118.40	6950.1	2131.70	6993.8	2137.80	7013.8
131/03-27-001-32W1/00	502.60	1649.0	2039.10	6690.0	2051.10	6729.3	2057.50	6750.3
101/02-34-001-32W1/00	512.40	1681.1	2046.10	6712.9	2057.80	6751.3	2063.20	6769.0
101/16-04-003-32W1/00	515.10	1690.0	1987.20	6519.7	2005.00	6578.1	2016.30	6615.2
101/03-18-003-32W1/00	528.20	1732.9	2013.90	6607.3	2031.70	6665.7	2042.50	6701.1
131/07-01-003-33W1/00	531.10	1742.5	1988.40	6523.6	2064.10	6772.0	2074.80	6807.1
101/09-11-005-30W1/00	517.90	1699.1	1630.60	5349.7	1690.00	5544.6	1698.70	5573.2
101/08-05-005-32W1/00	551.60	1809.7	1896.70	6222.8	1908.60	6261.8	1915.70	6285.1
101/10-26-006-31W1/00	566.00	1857.0	1710.90	5613.2	1721.10	5646.7	1728.20	5669.9
101/16-07-006-32W1/00	594.10	1949.1	1779.50	5838.3	1875.90	6154.5	1886.40	6189.0
101/12-28-007-30W1/00	569.40	1868.1	1630.40	5349.1	1637.80	5373.4	1645.90	5399.9
111/06-11-008-31W1/00	579.60	1901.6	1613.10	5292.3	1648.40	5408.1	1657.50	5438.0
101/14-19-008-32W1/00	637.60	2091.9	1729.60	5674.5	1770.90	5810.0	1779.40	5837.9
101/06-23-008-32W1/00	603.80	1981.0	1665.50	5464.2	1700.00	5577.4	1718.50	5638.1
101/16-36-008-32W1/00	605.30	1985.9	1663.00	5456.0	1668.60	5474.4	1683.40	5523.0
101/08-30-008-33W1/00	646.50	2121.1	1786.70	5861.9	1823.70	5983.3	1833.40	6015.1
141/07-01-009-34W1/00	660.10	2165.7	1814.90	5954.4	1820.90	5974.1	1833.20	6014.4
101/04-22-010-33W1/00	637.60	2091.9	1662.90	5455.7	1686.00	5531.5	1693.80	5557.1
121/12-13-012-31W1/00	578.50	1898.0	1383.40	4538.7	1416.90	4648.6	1430.70	4693.9
191/05-31-013-32W1/00	556.80	1826.8	1347.00	4419.3	1404.20	4607.0	1415.20	4643.0
131/01-32-014-30W1/00	521.60	1711.3	1228.30	4029.9	1233.10	4045.6	1238.00	4061.7
101/16-32-015-31W1/00	534.90	1754.9	1247.50	4092.8	1251.80	4107.0	1258.80	4129.9
101/04-20-017-32W1/00	545.90	1791.0	1167.80	3831.4	1211.20	3973.8	1226.50	4024.0
141/01-16-020-30W1/00	502.00	1647.0	981.40	3219.8	986.40	3236.2	994.00	3261.2
101/04-10-022-32W1/00	534.90	1754.9	967.70	3174.9	1011.50	3318.6	1022.60	3355.0
141/09-13-026-33W1/00	532.80	1748.0	865.70	2840.2	893.50	2931.4	904.00	2965.9
111/04-05-035-31W1/00	488.90	1604.0	596.30	1956.4	602.80	1977.7		

Table A.3: North Dakota stratigraphic tops obtained from the North Dakota Geological Survey. TVD=true vertical depth.

Well Number	WELL LOCATION	Kelly Bushing (K.B.) Elevation (m)	Kelly Bushing (K.B.) Elevation (ft.)	Upper Winnipegosis Member/Ratner Formation TVD (m)	Upper Winnipegosis Member/Ratner Formation TVD (ft.)	Lower Winnipegosis Member TVD (m)	Lower Winnipegosis Member TVD (ft.)	Ashern Formation TVD (m)	Ashern Formation TVD (ft.)
37	5 ND - SWNW 26-162N-64W	496.82	1630.0	700.80	2299.2	716.00	2349.1	729.8	2394.4
64	5 ND - SWNW 18-163N-77W	463.30	1520.0	1514.00	4967.2	1526.80	5009.2	1542	5059.1
83	5 ND - SENW 23-161N-73W	495.91	1627.0	1280.90	4202.4	1298.90	4261.5	1314.2	4311.7
110	5 ND - NWNW 23-163N-75W	672.08	2205.0	1524.60	5002.0	1551.90	5091.5	1568.2	5145.0
170	5 ND - SESW 2-163N-77W	508.71	1669.0	1480.20	4856.3	1512.90	4963.6	1526.3	5007.5
286	5 ND - CNWNE 32-164N-78W	469.09	1539.0	1534.70	5035.1	1569.80	5150.3	1581	5187.0
359	5 ND - SWSE 36-164N-74W	687.63	2256.0	1442.00	4731.0	1471.00	4826.1	1486.2	4876.0
524	5 ND - SENW 19-161N-81W	463.91	1522.0	1929.70	6331.0	1956.90	6420.3	1965.3	6447.8
685	5 ND - SWSW 32-163N-73W	642.21	2107.0	1395.10	4577.1	1417.00	4649.0	1433.6	4703.4
806	5 ND - NESE 14-163N-73W	664.46	2180.0	1388.80	4556.4	1412.50	4634.2	1423.8	4671.3
1102	5 ND - SWNE 2-161N-74W	507.19	1664.0	1336.70	4385.5	1358.90	4458.3	1372.9	4504.3
1630	5 ND - NWSE 19-161N-72W	497.43	1632.0	1259.30	4131.6	1281.50	4204.4	1292.4	4240.2
1968	5 ND - SWNW 30-163N-78W	461.16	1513.0	1588.70	5212.3	1611.70	5287.7	1622	5321.5
2638	5 ND - SWSE 12-162N-78W	455.68	1495.0	1536.00	5039.4	1567.80	5143.7	1576	5170.6
3980	5 ND - SWSE 7-162N-68W	536.75	1761.0	1016.80	3336.0	1033.10	3389.4	1042.4	3419.9
4347	5 ND - NESW 9-163N-78W	466.95	1532.0	1535.60	5038.1	1575.80	5169.9	1586.3	5204.4
4655	5 ND - SESW 31-162N-78W	452.93	1486.0	1631.20	5351.7	1648.80	5409.4	1659.5	5444.6
4670	5 ND - NESE 1-161N-80W	453.54	1488.0	1705.30	5594.8	1751.70	5747.0	1765.2	5791.3
4844	5 ND - NESW 15-161N-81W	460.55	1511.0	1886.60	6189.6	1905.40	6251.3	1915.2	6283.5
4846	5 ND - NENW 8-163N-81W	462.69	1518.0	1806.20	5925.9	1822.20	5978.3	1832	6010.5
4918	5 ND - NWSW 33-161N-82W	475.79	1561.0	1983.10	6506.2	2048.80	6721.8	2059.2	6755.9
4924	5 ND - NENE 2-161N-81W	461.47	1514.0	1798.20	5899.6	1851.00	6072.8	1861.7	6107.9
5141	5 ND - SWNE 33-164N-77W	487.07	1598.0	1462.80	4799.2	1496.40	4909.4	1511.1	4957.7
5184	5 ND - SENE 14-162N-77W	473.05	1552.0	1483.40	4866.8	1516.30	4974.7	1531.7	5025.3
5277	5 ND - SWSW 11-162N-77W	470.31	1543.0	1489.20	4885.8	1521.60	4992.1	1536.7	5041.7
6021	5 ND - SWNW 27-161N-82W	473.35	1553.0	2006.80	6584.0	2022.90	6636.8	2034	6673.2
6126	5 ND - SWNW 36-163N-80W	456.90	1499.0	1685.90	5531.2	1705.50	5595.5	1713.8	5622.7
6257	5 ND - SWNW 34-161N-82W	471.53	1547.0	2016.50	6615.8	2034.20	6673.9	2043.4	6704.1
9522	5 ND - SWNW 21-161N-77W	449.28	1474.0	1534.50	5034.4	1567.90	5144.0	1583.7	5195.9

APPENDIX B: LITHOLOGICAL CORE LOGS

This appendix contains the core logs for all of the core intervals that were described in the studied wells. The logs are arranged by well location in ascending order.

Well Location	Core Interval Examined	Page #'s
100/11-29-001-25W1/00	4986.45-5029.45'	B3-B4
100/09-13-001-26W1/00	5060.8-5070.8'	B5
100/10-09-001-28W1/00	1724.94-1742.94 m	B6-B9
100/09-06-002-26W1/00	1524.5-1534.5 m	B10-B12
100/16-33-004-13W1/00	2223-2238'	B13
100/05-03-004-25W1/00	4413.4-4506.4'	B14-B17
100/05-13-005-22W1/00	3774-3809'	B18-B19
100/07-27-005-24W1/00	3695-3705'	B20
100/16-33-005-24W1/00	3675-3700'	B21
100/08-13-005-29W1/00	1520.15-1526.73 m	B22-B23
100/04-12-007-25W1/00	1193.08-1211.08 m	B24-B27
100/09-26-007-25W1/00	3848-3858'	B28
100/02-21-007-28W1/00	4727.7-4752.7'	B29-B30
100/03-01-008-18W1/00	2568-2578'	B31
100/14-13-009-28W1/00	1280.87-1286.87 m	B32-B40
100/15-18-010-27W1/00	4175-4192'	B41
100/04-27-011-22W1/00	2788-2838'	B42-B44
103/03-12-011-27W1/00	1177.32-1185.19 m	B45-B46
100/07-08-011-29W1/00	4517-4537'	B47
100/01-27-017-26W1/00	3104-3107'	B48
100/16-18-018-29W1/00	3147-3157' 3295-3299'	B49
100/04-17-019-29W1/00	3132.08-3192.08'	B50-B52
100/04-33-023-16W1/00	674-717'	B53-B54
16-26-024-10W1 (M-01-72)	0.60-25.80 m	B55-B60
03-35-024-10W1 (M-03-90)	4.40-43.78 m	B61-B69
05-35-024-10W1 (M-02-87)	2.60-42.40 m	B70-B78
06-35-024-10W1 (M-02-90)	1.60-45.00 m	B79-B87
12-35-024-10W1 (M-04-90)	3.00-42.18 m	B88-B95

LEGEND

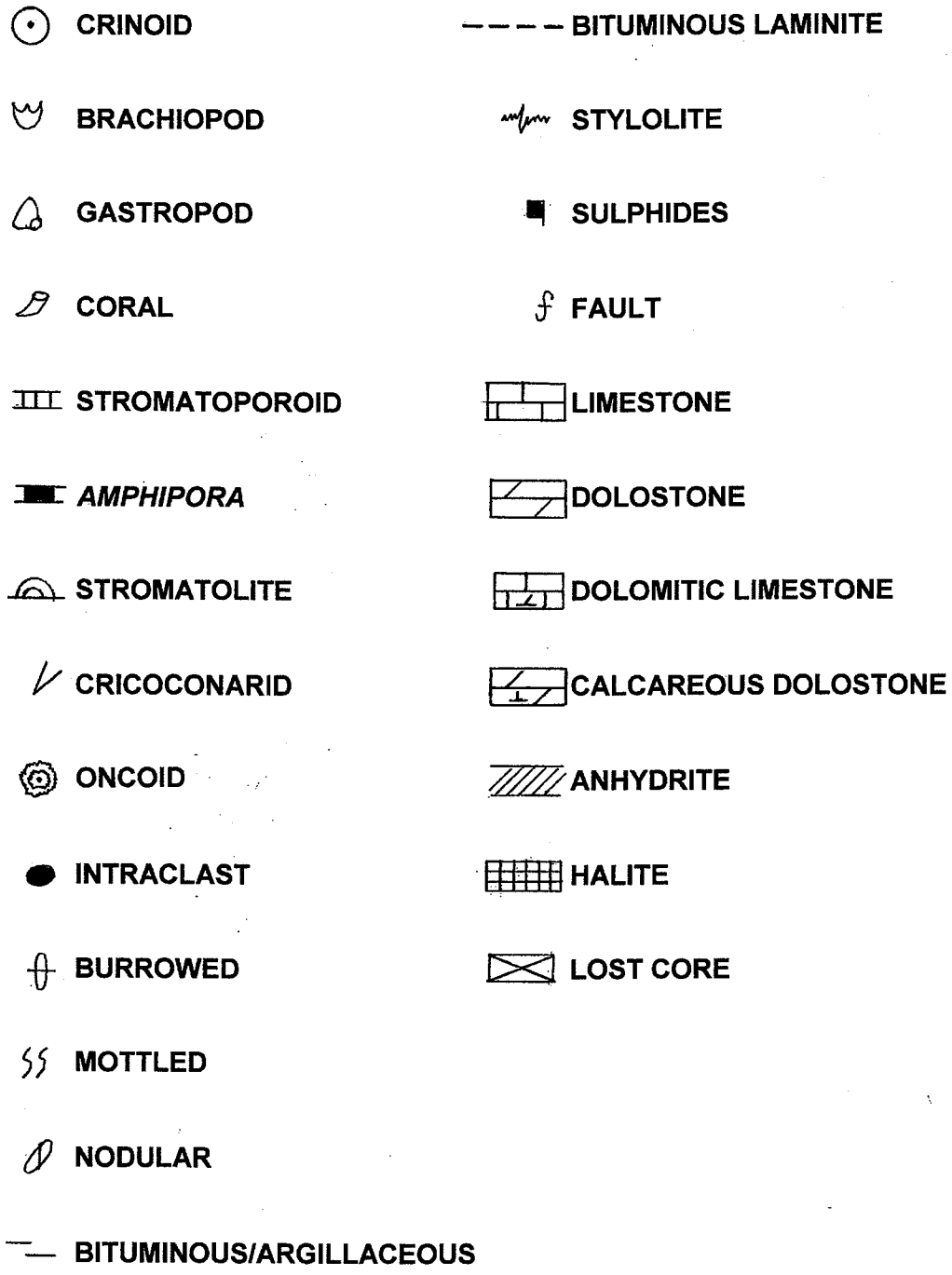


Figure B1: Legend for core log sheets.

Logged by: Date:

Core Interval: 4988-5031' ADJUSTED TO 4986.45-5029.45'

Well Location: 100/11-29-001-25W1/00 (Lic.#2543)

Correction Factor (Log to Core Conversion): -1.55'

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
4985																												
86																												
87				X			X		X								X									X		
88				X			X		X								X				X					X	- Thinly interlaminated to thinly interbedded dolomudstone-dolopackstone. Bedding plane dipping 15°, contacts microstylolitized.	N
89				X					X		X						X		X							X		M/G
4990				X					X		X						X		X							X		G
91				X							X						X		X							X		M
92				X					X								X		X							X		
93				X							X						X		X							X	- Thin to thickly interbedded nodular dolopackstone and skeletal dolorudstone, contacts generally sharp and irregular. Nodular dolopackstone - as below but bituminous/argillaceous content decreases upwards and nodules become less well-defined. Skeletal dolorudstone - bioclasts consist of massive tabulate coral (including favositids) and possible stromatoporoid fragments, angular, white, 1mm->10cm diameter. Internal structures poorly preserved. Dolopackstone matrix. Rare intraskelelal porosity, fair intercrystalline and minor scattered pinpoint porosity in dolopackstone.	G
94	tan/lt. brown			X					X								X		X							X		M
4995				X							X						X		X							X		G
96				X							X						X		X							X		M
97				X					X								X		X		X					X		G
98				X					X								X		X		X					X		
99				X					X								X		X		X					X		
5000				X					X								X		X		X					X		
01				X					X		X						X		X		X					X		M
02				X					X								X		X		X					X		G
03				X							X						X		X		X					X		M
04				X					X								X				X					X		G
5005	tan/dk brown			X					X								X				X					X		

Logged by: Date:

Well Location: 100/11-29-001-25W1/00 (Lic.#2543)

Core Interval: 4988-5031' ADJUSTED TO 4986.45-5029.45'

Correction Factor (Log to Core Conversion): -1.55'

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
06				X					X								X									X	- Nodular dolopackstone - pervasively dolomitized, appears skeletal. Nodules have septarian fractures filled with argillaceous / bituminous matter and range from 1mm-3cm diameter. Nodules consist of tan sucrosic dolomite - some partly replaced with anhydrite. Internodular matrix fairly bituminous/argillaceous. Rare pyrite nodules. Scattered pinpoint porosity and poor intercrystalline porosity in matrix, good intercrystalline porosity in nodules.	
07				X					X								X									X		
08				X					X								X				X					X		
09				X					X								X				X					X		
5010	Tan/dk. brown			X					X								X				X					X		G
11			⊙	X					X								X									X		
12				X					X								X									X		
13				X					X								X									X		
14				X					X								X				X					X		
5015			≈	X					X								X				X					X	← Bituminous laminite (2mm thick).	D
16	lt./dk. brown			X					X								X		X		X					X	← slickensides	
17				X					X								X		X		X					X		G
18			≈	X					X								X		X		X					X	← Sub-vertical slickensided surface.	
19				X					X								X		X		X					X		
5020	dark brown		⊙	X					X								X		X		X					X		
21				X					X								X		X		X					X	← Bituminous laminites (2-5mm thick).	D
22				X		X			X								X		X		X					X		G
23	tan/ lt.&dk. brown		⊙	X		X			X	X							X		X							X	← Gradational lithofacies change. U. Winnipegosis Member L. Winnipegosis Member.	D
24			≈	X		X											X		X							X		G
5025				X		X											X		X							X	← 0.7' brecciated interval with slickensides.	
26				X		X											X		X							X	← Bituminous laminite (1.5cm thick), burrowed.	D
27	lt./dk. brown		≈	X		X											X		X		X					X	- Mottled-nodular dolomudstone. Sparse bioclasts - brachs and crinoids. Scattered intraclasts (1mm-1cm), mudstone, angular to sub-rounded, have a dark sulphide rim.	B
28			≈	X		X											X		X							X		
29			Ry ⊙ ≈	X		X											X		X							X		
5030				X		X											X		X							X	Scattered pinpoint porosity, rare vugs (up to 3mm diam)	

Logged by: Date: Core Interval: 5060.8-5070.8'

Well Location: 100/09-13-001-26W1/00(Lic.#184) Correction Factor (Log to Core Conversion):

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
5060																											Upper Winnipegosis Member	
61				X					X							X		X			X					X	
62	↑		–	X					X							X		X			X					X	– Dolopackstone, skeletal in part, pervasively dolomitized.
63	Tan			X					X							X		X			X					X	Rare thamnoporid's, sparse sub-rounded to rounded dolo-
64	↑		●	X					X							X		X			X					X	packstone intraclasts (1-2cm diam.) Bituminous/argillaceous
5065			–	X					X							X		X								X	whisps common. Minor replacive anhydrite bodies (7mm-
66	Tan/lt. brown		● –	X					X							X		X								X	2.5cm diam.). Abundant pinpoint porosity and good
67	↑		● –	X					X							X		X								X	intercrystalline porosity throughout.
68	Tan		● –	X					X							X		X			X					X	
69	↑		● –	X					X							X		X			X					X	
5070	lt. brown		–	X					X							X		X			X					X	– Lower 40cm fractured/brecciated, abundant microstylolites.
71	↓		–	X					X							X		X								X	Anhydrite-occluded large fracture.
72																												
73																												
74																												
5075																												

Logged by: Date:

Core Interval: 1724.60-1742.60m ADJUSTED TO 1724.94-1742.94m

Well Location: 100/10-09-001-28W1/00 (Lic.#4115)

Correction Factor (Log to Core Conversion): +0.34m

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
1724																												
.20																												
.40																												
.60																												
.80																												
1725				X			X		X								X		X							X		
.20	↑		—	X			X		X								X									X	Upper Winnipegosis Member	
.40			—	X			X		X								X		X							X	- Bedding plane becomes nearly horizontal in uppermost 40cm.	
.60			—	X			X		X								X									X		
.80			—	X			X		X								X		X							X		
1726			—	X			X		X								X									X		
.20			—	X			X		X								X									X	- Thinly interlaminated to thinly interbedded dolomudstone and dolopackstone (as below).	
.40	lt./dk. brown		—	X			X		X								X									X		N
.60			—	X			X		X								X									X		
.80			—	X			X		X								X									X		
1727			—	X			X		X								X									X		
.20			—	X			X		X								X									X		
.40			—	X			X		X								X									X		
.60			—	X			X		X								X									X		
.80			—	X			X		X								X									X	Small-scale, high-angle fault, ~1cm displacement, occluded with anhydrite.	
1728	↓		—	X			X		X								X				X					X		

Logged by: Date: Core Interval: 1724.60-1742.60m ADJUSTED TO 1724.94-1742.94m

Well Location: 100/10-09-001-28W1/00 (Lic #4115) Correction Factor (Log to Core Conversion): +0.34m

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol: Low	Moderate	High	Comments	Lithofacies
.20				X	X	X		X								X		X								X		
.40				X	X	X		X								X										X		
.60				X	X	X		X								X										X		
.80				X	X	X		X								X										X		
1729				X	X	X		X								X										X	- Thinly interlaminated to thinly interbedded dolomudstone and dolopackstone (peloidal?), pervasively dolomitized, variably argillaceous/bituminous. Bedding plane dipping ~21°. Intercrystalline porosity throughout, scattered pinpoint porosity restricted to dolopackstone laminae/beds.	
.20				X	X	X		X								X										X		
.40				X	X	X		X								X										X		
.60				X	X	X		X								X										X		
.80				X	X	X		X								X										X		
1730				X	X	X		X								X										X		
.20	lt./dk. brown			X	X	X		X								X										X		
.40				X	X	X		X								X										X		
.60				X	X	X		X								X										X	← Pyrite nodule (1cm diam.).	
.80				X	X	X		X								X										X		
1731				X	X	X		X								X										X		
.20				X	X	X		X								X										X		
.40				X	X	X		X								X										X		
.60				X	X	X		X								X										X		
.80				X	X	X		X								X										X		
1732				X	X	X		X								X										X		
.20				X	X	X		X								X										X		
.40				X	X	X		X								X										X		
.60				X	X	X		X								X										X		
.80				X	X	X		X								X										X		
1733				X	X	X		X								X										X		

N

B7

Logged by: Date:

Core Interval: 1724.60-1742.60m ADJUSTED TO 1724.94-1742.94m

Well Location: 100/10-09-001-28W1/00 (Lic#4115)

Correction Factor (Log to Core Conversion): +0.34m

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
.20				X			X		X								X					X				X		N
.40				X					X								X	X				X				X		
.60				X					X								X	X				X				X	- Medium to thickly interbedded dolopackstone and skeletal dolorudstone, pervasively dolomitized, sharp contacts, minor argillaceous content. Scattered pinpoint and poor intercrystalline porosity. Rare vugs occluded with anhydrite.	K
.80				X					X								X	X				X				X		
1734				X							X						X	X				X				X		M
.20				X					X								X	X				X				X		K
.40				X							X						X	X				X				X		M
.60			S	X					X								X	X				X				X		K
.80			S	X					X								X	X				X				X		
1735				X							X						X	X				X				X		M
.20				X							X						X	X				X				X		
.40	Lt./dk. brown			X							X						X	X				X				X		
.60				X							X						X	X				X				X		
.80				X						X	X						X	X				X				X		
1736			S	X					X								X	X				X				X	- Dolopackstone - pervasively dolomitized (skeletal in part).	K
.20			S	X					X								X	X				X				X		
.40			S	X					X								X	X				X				X		
.60			S	X					X								X	X				X				X		
.80				X							X						X	X				X				X		M
1737				X							X						X	X				X				X		
.20				X							X						X	X				X				X		
.40				X							X						X	X				X				X	- Skeletal dolorudstone - pervasively dolomitized, likely stromatoporoid fragments with dolopackstone matrix. Scattered pinpoint and poor intercrystalline porosity. Rare fractures and vugs (2mm-3cm) occluded with anhydrite (some may be replacive).	
.60				X							X						X	X				X				X		
.80				X							X						X	X				X				X		
1738				X							X						X	X				X				X		

B8

Logged by: Date:

Core Interval: 1724.60-1742.60m ADJUSTED TO 1724.94-1742.94m

Well Location: 100/10-09-001-28W1/00 (Lic.#4115)

Correction Factor (Log to Core Conversion): +0.34m

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20				X					X								X		X			X				X	- Dolopackstone - (as below).	K
.40				X					X								X		X			X				X		
.60				X					X								X		X			X				X		
.80				X					X								X		X			X				X		
1739				X					X		X						X		X			X				X	- Thin skeletal dolorudstone bed, sharp irregular contacts (as below).	M
.20				X					X								X		X			X				X		K
.40				X					X		X						X		X			X				X	- Medium skeletal dolorudstone bed, sharp irregular contacts (as below).	M
.60				X					X								X		X			X				X		
.80				X					X								X		X			X				X	- Dolopackstone - (as below).	K
1740				X					X								X		X			X				X		
.20				X					X								X		X			X				X		
.40				X					X								X		X			X				X	- Thin skeletal dolorudstone bed (as below).	M
.60	Lt./dk. brown			X					X								X		X			X				X	- Dolopackstone	K
.80				X					X								X		X			X				X		
1741				X					X		X						X		X			X				X	- Medium skeletal dolorudstone bed (as below).	M
.20				X					X								X		X			X				X	- Dolopackstone - pervasively dolomitized, skeletal in part, thin to medium bedded. Some beds mottled, wispy argillaceous content. Intercrystalline and scattered pinpoint porosity throughout.	K
.40				X					X								X		X			X				X		
.60				X					X								X		X			X				X		
.80				X					X								X		X			X				X		
1742				X							X						X		X			X				X	- Dolorudstone - pervasively dolomitized. Clasts appear to be stromatoporoid fragments (up to 4.5cm diam.), sub-angular to sub-rounded, internal structure rare. Matrix - dolopackstone, skeletal in part, variably argillaceous. Scattered pinpoint porosity, intercrystalline porosity throughout. Rare vugs occluded with anhydrite.	M
.20	Tan/dk. brown			X							X						X		X			X				X		
.40				X							X						X		X			X				X		
.60				X							X						X		X			X				X		
.80				X							X						X		X			X				X		
1743																												

Logged by: Date: Core Interval: 15245-15345 m

Well Location: 100/09-06-002-26W1/00 (Lic.#2610) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	① Lithofacies
1524																												
.20																												
.40																												
.60	↑	⟋ ⊥	—	X		X		X								X		X								X		
.80	Tan/dk.	⟋ ⊥	—	X		X		X								X		X								X	Upper Winnipegosis Member	N
1525	brown	⟋ ⊥	—	X		X		X								X										X	- As below.	

Logged by: Date: Core Interval: 15245-15345 m

Well Location: 100/09-06-002-26W1/00 (Lic.#2610) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	② Lithofacies
.20				X			X		X								X									X		
.40				X			X		X								X									X		
.60				X			X		X								X									X		
.80				X			X		X								X		X							X		
1526				X			X		X								X		X							X	- Very homogeneous, as below with addition of scattered pinpoint porosity and finely disseminated sulphides locally.	
.20				X			X		X								X									X		
.40				X			X		X								X									X		
.60				X			X		X								X									X		
.80				X			X		X								X									X		
1527				X			X		X								X		X							X		
.20	Tan/dk brown			X			X		X								X		X							X		N
.40				X			X		X								X		X							X		
.60				X			X		X								X		X							X		
.80				X			X		X								X									X		
1528				X			X		X								X									X		
.20				X			X		X								X									X		
.40				X			X		X								X									X		
.60				X			X		X								X				X					X		
.80				X			X		X								X		X							X		
1529				X			X		X								X									X		
.20				X			X		X								X									X		
.40				X			X		X								X									X		
.60				X			X		X								X									X		
.80				X			X		X								X									X		
1530				X			X		X								X									X		

Logged by: Date:

Core Interval: 1524.5-1534.5 m

Well Location: 100/09-06-002-26W1/00 (Lic.#2610)

Correction Factor (Log to Core Conversion):

③

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol: Low	% Dol: Moderate	% Dol: High	Comments	Lithofacies
.20			—	X	X		X		X								X									X		
.40			—	X	X		X		X								X									X		
.60			— ~ f	X	X		X		X								X									X	← Small-scale, high-angle fault (3mm displacement).	
.80			— ~	X	X		X		X								X									X		
1531			— ~	X	X		X		X								X				X					X	← Hairline fractures, some occluded with anhydrite.	
.20			—	X	X		X		X								X				X					X		
.40			—	X	X		X		X								X				X	X				X	- Thinly interlaminated to thinly interbedded dolomudstone and dolopackstone (peloidal?- pervasively dolomitized), with wavy/crenulated contacts. Bedding plane alternates between horizontal and very low angle dip. Some laminae contain disseminated organic matter or microstylolites imparting a dark brown color. Good intercrystalline porosity throughout.	
.60			—	X	X		X		X								X				X	X				X		
.80			— ~	X	X		X		X								X				X					X		
1532	Tan/dk. brown		— ~	X	X		X		X								X									X		N
.20			—	X	X		X		X								X									X		
.40			—	X	X		X		X								X									X		
.60			— ~	X	X		X		X								X				X					X		
.80			—	X	X		X		X								X									X		
1533			—	X	X		X		X								X									X		
.20			— ~ f	X	X		X		X								X									X	← Small-scale, high-angle fault (2mm displacement).	
.40			—	X	X		X		X								X									X		
.60			—	X	X		X		X								X									X		
.80			—	X	X		X		X								X									X		
1534			— ~	X	X		X		X								X									X		
.20			— ~	X	X		X		X								X									X		
.40			—	X	X		X		X								X									X		
.60			— ~	X	X		X		X								X									X		
.80																												
1535																												

Logged by: Date: Core Interval: 2223-2238'

Well Location: 100/16-33-004-13W1/100 (Lic# 609) Correction Factor (Log to Core Conversion):

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
2220																												
21																												
22																												
23																											Lower Winnipegosis Member	
24	↑			X			X										X		X							X	- Dolomudstone - (as below).	
2225				X			X					X					X									X	- Intraclastic dolofloatstone interbeds (0.3-7cm), sharp contacts,	
26				X			X					X					X									X	argillaceous. Intraclasts - dolomudstone, sub-angular to rounded (2mm-4cm)	
27				X			X										X		X							X	- Dolomudstone - mottled to nodular, patterned, argillaceous -	
28				X			X										X		X							X	light grey clay. Scattered pinpoint/vuggy porosity. Excellent	
29	Tan/ lt. grey/ purple			X			X										X									X	intercrystalline porosity.	
2230				X			X										X		X							X		
31				X			X										X									X		C
32				X			X		X								X	X								X	- Skeletal dolowackestone interbed, grad. contacts. Bioclasts -	
33				X				X									X	X								X	brachiopod molds, some occluded with anhydrite.	
34				X				X									X	X								X		
2235				X				X									X	X								X		
36				X			X										X	X				X				X	← Anhydrite nodule.	
37	purple/ lt. grey			X			X	X									X	X	X							X	- thin skeletal dolowackestone interbed (as above).	
38	↓			X			X										X		X							X	- Dolomudstone - mottled to nodular, patterned (as above).	
39																												
2240																												

Logged by: Date:

Core Interval: 4413-4506' ADJUSTED TO 4413.4-4506.4'

Well Location: 100/05-03-004-25W1/00 (Lic#1876)

Correction Factor (Log to Core Conversion):

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
11																												
12																												
13																												
14				X									X				X		X	X		X				X	Upper Winnipegosis Member	
4415				X									X				X		X	X						X	- Dolobindstone - thinly laminated, stromatolitic. Single	
16				X									X				X		X	X	X	X				X	rugose coral within stromatolites. Anhydrite occludes	O
17				X									X				X		X	X		X				X	most fenestral porosity. Pinpoint and intercrystalline	
18				X								X			X		X		X	X		X				X	porosity throughout. Sharp lower contact.	
19	Tan/lt. brown			X								X			X		X		X	X		X				X	- Skeletal dolofloatstone. Bioclasts - stromatoporoid	
4420				X								X			X		X		X	X		X				X	fragments (mostly bulbous form), possible minor	
21				X								X			X		X		X	X		X				X	Amphipora. Bioclasts become larger upwards (3mm-	
22				X								X			X		X		X	X						X	7cm). Matrix - dolopackstone, mottled, pervasively	
23				X								X			X		X		X	X						X	dolomitized. Abundant intercrystalline and pinpoint	L
24				X								X			X		X		X	X						X	porosity in matrix. Minor intraskeletal porosity in bioclasts.	
4425				X								X			X		X		X	X	X					X	Minor replacive anhydrite. Sharp contacts.	
26				X								X					X		X	X								
27				X							X						X		X	X								
28				X						X							X		X	X						X	- Dolorudstone - as below.	
29				X						X							X		X	X	X					X		
4430	brown/ Tan			X						X							X		X	X						X		
31				X						X							X		X	X						X		M
32				X						X							X		X	X	X					X		
33				X						X							X		X	X	X					X		
34				X						X							X		X	X	X					X		
4435				X						X							X		X	X	X					X		

B14

Logged by: Date:

Core Interval: 4413-4506' ADJUSTED TO 4413.4-4506.4'

Well Location: 100/05-03-004-25W1/00 (Lic#1876)

Correction Factor (Log to Core Conversion):

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
36				X							X						X	X			X					X	- Dolorudstone - fragments of bulbous/massive corals and encrusting stromatoporoids?, pervasively dolomitized Dolopackstone matrix and anhydrite-occluded interparticle porosity. Locally fractured, scattered pinpoint/vuggy porosity.	M
37				X							X						X	X			X					X		
38				X							X						X	X			X					X		
39				X							X						X	X			X					X		
4440				X					X	X							X	X			X					X	- Dolopackstone - grainstone.	K
41				X							X		X				X	X			X					X	- Dolorudstone - framestone, as above but includes upright syringoporids.	M
42				X							X		X				X	X			X					X		
43				X					X	X							X	X			X					X	- Dolopackstone - grainstone, skeletal in part including Amphipora.	K
44				X					X	X							X	X			X					X		
4445				X							X						X	X			X					X	- Dolorudstone - as above.	M
46	Tan/lt. brown			X					X								X	X			X					X		K
47				X					X								X	X			X					X		
48				X					X								X	X			X					X		
49				X					X								X	X			X					X	- Dolopackstone - skeletal in part, pervasively dolomitized, thin to medium, faintly mottled beds. Macrofossils - very rare tabulate coral fragments. Good intercrystalline and scattered pinpoint porosity throughout. Minor vuggy porosity (up to 1cm). Vertically fractured, some fractures occluded with anhydrite.	
4450				X					X								X	X			X					X		
51				X					X								X	X			X					X		
52				X					X								X	X			X					X		
53				X					X								X	X			X					X		
54				X					X								X	X			X					X		
4455				X					X								X	X			X					X		
56				X					X								X	X			X					X		
57				X					X								X	X			X					X		
58				X					X								X	X			X					X		
59				X					X								X	X			X					X		
4460				X					X								X	X			X					X		

Logged by: Date:

Core Interval: 4413-4506' ADJUSTED TO 4413.4-4506.4'

Well Location: 100/05-03-004-25W1/00 (Lic.#1876)

Correction Factor (Log to Core Conversion): +0.4'

(FEET) Log Depth	Colour	Lithology	Grains, Structures	Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol: Low	% Dol: Moderate	% Dol: High	Comments	Lithofacies
61					X				X								X		X			X				X	- Dolopackstone - generally as below but vugs increase up to 1.5cm, some lined with dolo rhombs. Rare fractures, some occluded with anhydrite. Rare irregular bodies of anhydrite (2mm-2cm), look replacive. ← Stromatoporoid fragments (2mm-2cm).	
62					X				X								X		X							X		
63			⊙		X				X								X		X			X				X		
64	Tan/lt. brown		⊙		X				X								X		X							X		
4465			III		X				X								X		X							X		
66					X				X								X		X							X		
67					X				X								X		X	X		X				X		
68					X				X								X		X							X		
69					X				X								X		X							X		
4470					X				X								X		X							X		
71	Tan				X				X								X		X							X		
72					X				X								X		X							X		K
73			⊙		X				X								X		X		X					X		
74			⊙		X				X								X		X							X		
4475					X				X								X		X							X	- Dolopackstone - skeletal in part, pervasively dolomitized. Thin to thickly bedded, most faintly mottled. Some beds contain macrofossils: crinoids (2-5mm), thamnoporids and rugose corals (5mm-1cm), and Amphipora (2-3mm). Intercrystalline and scattered pinpoint porosity throughout, rare vugs up to 5mm.	
76			⊙		X				X								X		X		X					X		
77			⊙		X				X								X		X							X		
78	Tan/lt. brown		⊙		X				X	X							X		X							X		
79			⊙		X				X	X							X		X		X					X		
4480					X				X								X		X							X		
81			⊙		X				X								X		X		X					X		
82					X				X								X		X							X		
83			⊙		X				X								X		X							X		
84			⊙		X				X								X		X							X		
4485			⊙		X				X								X		X		X					X		

Logged by: Date: Core Interval: 4413-4506' ADJUSTED TO 4413.4-4506.4'

Well Location: 100/05-03-004-25W1/00 (Lic#1876) Correction Factor (Log to Core Conversion): +0.4'

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol: Low	Moderate	High	Comments	Lithofacies
86	Tan/lt. brown			X					X								X		X		X					X		
87				X					X								X		X		X					X		
88				X					X								X		X							X		
89	Tan			X					X								X		X			X				X		
4490				X					X								X		X							X	← Minor disseminated sulphides.	
91				X					X								X		X							X		
92				X					X								X		X							X		
93				X					X								X		X			X				X	- Dolopackstone - skeletal in part, very thick mottled beds, pervasively dolomitized. Bioclasts - sparse crinoids and thamnoporid fragments. Good inter-	
94				X					X								X		X							X	crystalline porosity throughout. Scattered pinpoint	
4495				X					X								X		X							X	and vuggy (up to 5mm) porosity throughout.	K
96				X					X								X		X			X				X		
97				X					X								X		X							X		
98				X					X								X		X							X		
99	Tan/lt. brown			X					X								X		X							X		
4500				X					X								X		X			X				X		
01				X					X								X		X			X				X		
02				X					X								X		X							X		
03				X					X								X		X							X		
04				X					X								X		X							X		
4505				X					X								X		X							X		
06				X					X								X		X							X		
07				X					X								X		X							X		
08																												
09																												
4510																												

Logged by: Date:

Core Interval: 3770-3805' ADJUSTED TO 3774-3809'

Well Location: 100/05-13-005-22W1/00 (Lic.#320)

Correction Factor (Log to Core Conversion): +4'

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
3770																												
71																												
72																												
73																												
74																											Upper Winnipegosis Member	
3775	↑		— S	X					X			X					X		X			X					← Skeletal dolofloatstone, large cylindrical molds (3-6 mm diam.), after thamnoporids? Dolopackstone matrix.	
76			— S	X					X								X		X			X						
77			— ▬	X		X			X			X					X		X			X						
78			— ¶	X					X								X	X	X								- Dolopackstone, mottled-thinly bedded, variably bituminous, burrowed locally with Planolites. Rare thin dolomudstone and skeletal dolofloatstone interbeds. Bioclasts-anhydrite-occluded Amphipora molds. Abundant intercrystalline and pinpoint porosity. Very rare pyrite occluding moldic porosity. Scattered vugs (1-7mm) occluded with anhydrite.	
79	lt./dk. brown		—	X					X								X		X									
3780			—	X					X								X		X									H
81			—	X					X								X		X			X						
82			— θ	X					X								X		X			X						
83			— θ	X					X								X		X			X						
84			—	X					X								X		X									
3785	↓		—	X					X								X		X									

Logged by: Date:

Core Interval: 3770-3805' ADJUSTED TO 3774-3809'

Well Location: 100/05-13-005-22W1/00 (Lic#320)

Correction Factor (Log to Core Conversion): +4'

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
86				X	X				X								X		X							X	← Bituminous laminite, 2mm thick.	D
87				X	X				X								X		X			X				X	- Dolopackstone (as below).	H
88				X	X				X								X		X							X		
89	lt./dk. brown			X	X				X			X					X		X			X				X	- Intraclast dolofloatstone. Intraclasts - dolopackstone, angular to sub-rounded (2mm to >3.5cm diam.). Sharp contacts.	I
3790				X	X				X			X					X		X							X		
91				X	X				X								X					X				X		H
92	tan/lt. brown			X	X				X								X					X				X		
93				X	X				X			X					X					X				X	- Dolopackstone, thin-medium bedded to mottled, variably bituminous (generally as below). Thin to medium skeletal dolofloatstone interbeds, bioclasts remain mostly as Amphipora molds occluded with anhydrite and very rare brach molds.	
94				X	X				X								X		X			X				X		
3795	lt./dk. brown			X	X				X			X					X					X				X		
96				X	X				X			X					X					X				X		
97				X	X				X								X					X				X		
98				X	X				X								X					X				X		
99																												
3800	dk. brown			X	X				X								X		X			X				X	← Bituminous laminite, 5mm thick, fissile.	D
01				X	X				X								X		X			X				X		H
02				X	X				X			X					X		X			X				X	← Bituminous laminite, 3mm thick.	D
03				X	X				X								X		X			X				X	- Dolopackstone, pervasively dolomitized - appears to be dominantly peloidal. Mottled to thin-medium bedded, variably bituminous, some beds burrowed with Planolites. Rare, very thin to thin skeletal dolofloatstone beds, bioclasts remains Amphipora molds occluded with anhydrite. Other bioclasts include rare colonial coral fragments. Good intercrystalline and scattered pinpoint porosity throughout.	
04	lt./dk. brown			X	X				X								X		X			X				X		
3805				X	X				X								X		X			X				X		
06				X	X				X								X		X			X				X		
07				X	X				X			X					X		X			X				X		
08				X	X				X								X		X			X				X		
09				X	X				X								X		X			X				X		
3810																												

Logged by: Date: Core Interval: 3695-3705'

Well Location: 100/07-27-005-24W1 (Lic.#227) Correction Factor (Log to Core Conversion):

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
																											* Hartney Area	
3695																											Upper Winnipegosis Member	
96	↑		–	X					X								X		X		X					X	– Dolopackstone – thin to medium bedded, pervasively dolomitized – appears mostly peloidal. Rare bioclasts include crinoids, most not identifiable. Rare rounded intraclasts of same lithology. Variable disseminated/whispy bituminous content. Rare disseminated sulphides and one nodule (5mm diam.). Many irregular fractures. Good intercrystalline and scattered pinpoint porosity throughout. Rare vugs up to 1cm diam., lined with dolomite rhombs.	H
97			– ⊙	X					X								X		X		X					X		
98			– ~	X					X								X		X		X					X		
99			–	X					X								X		X		X					X		
3700	Tan/lt. brown		–	X					X								X		X		X					X		
01			– ~ ●	X					X								X		X		X					X		
02			– ~	X					X								X		X		X					X		
03			– ~	X					X								X		X		X					X		
04			–	X					X								X		X		X					X		
3705	↓		– ⊙	X					X								X		X		X					X		

Logged by: Date: Core Interval: 3675-3700'

Well Location: 100/16-33-005-24W1/00(Lic.#9) Correction Factor (Log to Core Conversion):

* Hartney Area

Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments: Upper Winnipegosis Member	Lithofacies
76	↑		B	X							X				X		X					X				X	-Skeletal dolorudstone - bioclasts consist mostly of tabulate coral fragments, including syringoporids, and possible minor encrusting stromatoporoids(2mm-7cm). Dolopackstone matrix. Abundant intercrystalline porosity, scattered intraskeletal pinpoint porosity. Interparticle porosity occluded with anhydrite.	M
77			B	X							X				X		X					X				X		
78	lt. brown		B	X							X				X		X					X				X		
79			B	X							X				X		X					X				X		
3680			B	X							X				X		X					X				X		
81			B	X					X		X			X	X		X		X			X				X		
82			—	X					X						X		X		X		X	X			X			
83		⊙	—	X					X						X		X		X			X			X		-Dolopackstone- pervasively dolomitized, appears peloidal. Good intercrystalline porosity and variable pinpoint porosity, rare vugs(3-5mm). Core appears to be brecciated and recrystallized locally. Some fractures partly occluded with anhydrite.	H
84			—	X					X						X		X		X			X			X			
3685		⊙	—	X					X						X		X		X						X			
86			—	X					X						X		X		X						X			
87			—	X					X						X		X		X						X			
88			—	X					X						X		X		X			X			X			
89	Tan/lt. brown		—	X					X						X		X		X			X			X			
3690			—	X					X						X		X		X			X			X		←Core mostly rubble.	
91			—	X					X						X		X		X			X			X			
92		¶ ⌐	B	X							X				X		X		X			X			X		-Skeletal dolorudstone - as above with possible minor replacive anhydrite.	M
93			B	X							X				X		X		X			X			X			
94			B	X					X						X		X		X			X			X			
3695			—	X					X						X		X		X			X			X		-Dolopackstone - as above.	H
96		⌐	—	X					X						X		X		X			X			X			
97		⌐	—	X					X						X		X		X			X			X			
98		⌐	—	X					X						X		X		X			X			X			
99			—	X					X						X		X		X		X	X			X			
3700	↓		—	X					X						X		X		X			X			X		←Core mostly rubble.	

Logged by: Date: Core Interval: 1518.82-1525.4m ADJUSTED TO 1520.15-1526.73m

Well Location: 100/08-13-005-29W1/00 (Lic.#2696) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
1520																												
.20																												
.40	↑		–	X						X																X	-Collapse breccia - angular clasts (1mm - >7cm), various	
.60			–	X						X																X	lithologies and colors, pervasively dolomitized. Very	
.80	lt.-dk.		–	X						X																X	argillaceous dolomudstone matrix.	
1521	grey/ tan/		–	X						X																X		
.20	dk. brown		–	X						X																X		
.40			–	X						X																X		
.60	↓		–	X						X																X		
.80	Tan/ grey		~ III	X							X								X			X				X	Upper Winnipegosis Member	L
1522	↓		~ III	X							X								X			X				X	- Skeletal dolofloatstone (as below).	

Logged by: Date:

Core Interval: 1518.82-1525.4m ADJUSTED TO 1520.15-1526.73m

Well Location: 100/08-13-005-29W1/00 (Lic#2696)

Correction Factor (Log to Core Conversion): +1.33m

②

Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
.20				X	X							X							X			X				X	-Skeletal dolofloatstone - pervasively dolomitized.	
.40	Tan/lt. grey			X	X							X							X			X				X	Bioclasts (2mm->7cm), angular, appear to consist	
.60				X	X							X							X			X				X	mostly of stromatoporoids - internal structures poorly	
.80				X	X							X							X			X				X	preserved. Matrix - dolopackstone to dolograinstone.	L
1523				X	X							X							X			X				X	Trace intraskeletal porosity and pinpoint porosity in matrix.	
.20				X	X							X		X					X			X				X	Most porosity occluded with anhydrite.	
.40	Tan/med. brown			X	X							X							X			X				X		
.60				X	X									X		X			X			X				X		
.80				X	X						X			X		X						X				X		
1524				X	X						X			X		X						X				X	- Skeletal dolorudstone - pervasively dolomitized. Bioclasts -	
.20				X	X						X			X		X						X				X	mostly massive tabulate coral fragments and minor	
.40				X	X						X			X		X						X				X	encrusting stromatoporoids (5mm->7cm). Internal	
.60				X	X						X			X		X						X				X	structures poorly preserved. Very rare thamnoporid	
.80				X	X						X			X		X						X				X	corals and Amphipora. Dolopackstone matrix.	
1525	Tan/lt. brown			X	X						X			X		X						X				X	Intercrystalline porosity poor to good, minor intraskeletal	
.20				X	X						X			X		X						X				X	porosity, scattered pinpoint porosity in matrix, fractures	M
.40				X	X						X			X		X					X	X				X	common but mostly occluded with anhydrite. Interparticle	
.60				X	X						X			X		X					X	X				X	porosity also occluded with anhydrite.	
.80				X	X						X			X		X					X	X				X		
1526				X	X						X			X		X					X	X				X		
.20				X	X						X			X		X					X	X				X		
.40				X	X						X			X		X					X	X				X		
.60				X	X						X			X		X					X	X				X		
.80				X	X						X			X		X					X	X				X		
1527																												

B23

Logged by: Date:

Core Interval: 1193-1211 ADJUSTED TO 1193.08-1211.08m

Well Location: 100/04-12-007-25W1/00 (Lic.#2986)

Correction Factor (Log to Core Conversion): +0.08 m

①

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments
.20																											
.40																											
.60																											
.80																											
1193																											
.20	↑					X																					
.40						X																					
.60						X																					
.80						X																					
1194						X																					
.20						X																					- Prairie Evaporite- massive to thinly bedded anhydrite,
.40						X																					minor enterolithic beds and in-situ brecciated beds.
.60						X																					
.80	Tan/					X																					
1195	brown					X																					
.20						X																					
.40						X																					
.60						X																					
.80						X																					
1196						X																					
.20						X																					
.40						X																					
.60						X																					
.80						X																					
1197	↓					X																					

Logged by: Date:

Core Interval: 1193-1211 ADJUSTED TO 1193.08-1211.08 m

Well Location: 100/04-12-007-25W1/00 (Lic.#2986)

Correction Factor (Log to Core Conversion): +0.08 m

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20						X																						
.40						X																						
.60	Tan/ brown					X																					Prarie Evaporite - massive anhydrite.	
.80						X																						
1198						X																						
.20						X																						
.40						X																						
.60				X	X	X	X		X								X		X								← Thinly interlaminated to very thinly interbedded dolomudstone and anhydrite. Anhydrite content increases upwards. Sharp lower contact (Ratner Formation). Upper Winnipegosis Member (below 1198.55 m).	E
.80	Tan/ black			X	X	X	X		X								X		X									D
1199				X	X	X	X		X								X		X									
.20				X	X	X	X		X								X		X									
.40				X	X	X	X		X								X		X									
.60				X	X	X	X		X								X		X									
.80				X	X	X	X		X								X		X									
1200				X	X	X	X		X								X		X								Bituminous laminite - thinly interlaminated to thinly interbedded bituminous mudstone and non-bituminous dolopackstone. Small-scale normal fault below (6mm displacement).	
.20	Tan/lt. brown			X	X	X	X		X								X		X									
.40				X	X	X	X		X								X		X			X					- Dolopackstone - pervasively dolomitized, appears peloidal, laminated to medium bedded. Rare subrounded dolopackstone intraclasts (2mm-3cm). Rare tabular stromatoporoids. Good intercrystalline porosity throughout, scattered pinpoint porosity.	H
.60				X	X	X	X		X								X		X									
.80				X	X	X	X		X								X		X			X						
1201				X	X	X	X		X								X		X									
.20				X	X	X	X		X								X		X									
.40				X	X	X	X		X								X		X									
.60				X	X	X	X		X								X		X									
.80				X	X	X	X		X								X		X									
1202				X	X	X	X		X								X		X									

Logged by: Date: Core Interval: 1193-1211 m ADJUSTED TO 1193.08-1211.08 m

Well Location: 100/04-12-007-25W1 (Lic #2986) Correction Factor (Log to Core Conversion): +0.08 m

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol: Low	% Dol: Moderate	% Dol: High	Comments	Lithofacies
.20				X	X				X								X		X			X				X		
.40				X	X				X								X		X			X				X		
.60				X	X				X								X		X			X				X		
.80	Tan/Lt. brown			X	X				X	X							X		X			X				X		
1203				X	X				X								X		X			X				X		H
.20				X	X				X								X		X			X				X		
.40				X	X				X								X		X			X				X		
.60				X	X				X								X		X			X				X		
.80				X	X				X								X		X			X				X	← Gradational lithofacies change.	
1204				X	X				X								X		X			X				X		
.20	Tan/dk. brown			X	X				X								X		X			X				X		
.40				X	X				X								X		X			X				X	— Nodular dolopackstone, medium to very thickly bedded. Nodules - consist of fine crystalline, tan dolomite with septarian fractures, smaller (1-4 cm) and not as well defined as below. Some nodules partly replaced with anhydrite. Crinoids and one thamnoporid coral discernable in internodular matrix. Intercrystalline porosity throughout but best in nodules, scattered pinpoint porosity in matrix. Rare vugs (0.5-2 cm) occluded with anhydrite (may be replacive).	
.60				X	X				X								X		X			X				X		
.80				X	X				X								X		X			X				X		
1205				X	X				X								X		X			X				X		
.20				X	X				X								X		X			X				X		
.40				X	X				X								X		X			X				X		G
.60				X	X				X								X		X			X				X		
.80				X	X				X								X		X			X				X		
1206	Tan/M. brown			X	X				X								X		X			X				X		
.20				X	X				X								X		X							X		
.40				X	X				X								X		X							X		
.60				X	X				X								X		X							X		
.80				X	X				X								X		X			X				X		
1207				X	X				X								X		X							X		

Logged by: Date: Core Interval: 1193-1211 m ADJUSTED TO 1193.08-1211.08m

Well Location: 100/04-12-007-25W1 (Lic#2986) Correction Factor (Log to Core Conversion): +0.08m

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
.20				X					X								X		X							X	- Nodular dolopackstone, medium to thickly bedded, generally as below but nodules are better defined and increase up to 5 cm.	G
.40				X					X								X		X							X		
.60				X					X								X		X							X		
.80				X					X								X		X			X				X		
1208				X					X								X		X			X				X	← Bituminous laminite (4mm thick).	D
.20				X					X								X		X			X				X		
.40				X					X								X		X			X				X		G
.60				X					X								X		X			X				X		
.80	Tan/dk. brown			X					X								X		X			X				X		
1209				X					X								X		X			X				X		
.20				X					X								X		X							X	← Bituminous laminite (6mm thick).	D
.40				X					X								X		X			X				X		
.60				X					X								X		X							X	- Nodular dolopackstone, pervasively dolomitized - looks mostly skeletal. Nodules - 5mm - 2cm, gradational to well defined boundaries, consist of tan, very fine crystalline dolomite and have septarian fractures filled with argillaceous /organic matter, and anhydrite. Internodular matrix - variably argillaceous/bituminous. Abundant inter-crystalline porosity in nodules, minor intercrystalline and scattered pinpoint porosity in matrix.	
.80				X					X								X		X			X				X		
1210				X					X								X		X			X				X		
.20				X					X								X		X							X		G
.40				X					X								X		X			X				X		
.60				X					X								X		X							X		
.80	Tan/lt. brown			X					X								X		X			X				X		
1211				X					X								X		X			X				X		
.20				X					X								X		X							X		
.40																												
.60																												
.80																												
1212																												

Logged by: Date: Core Interval: 3848-3858'

Well Location: 100/09-26-007-25W1/00 (Lic#217) Correction Factor (Log to Core Conversion):

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
3845																												
46																												
47																												
48																												
49																											Upper Winnipegosis Member	
3850																												?
51																											Nodular skeletal dolopackstone. Original texture mostly obscured - bioclasts include brachiopods? and crinoids? Nodules are tan, sucrosic in part, irregular shape, increase in size upwards (1 to >10cm), have septarian fractures filled with bituminous matter and anhydrite. Some nodules partly-completely replaced by anhydrite.	
52																												
53																												
54																												
3855																												G
56	Tan/dk. brown																											
57																											← Bituminous laminite (7mm thick), black, undulatory.	D
58																											Internodular matrix - bituminous. Fractures occluded with anhydrite. Minor pinpoint and moldic porosity, fair intercrystalline porosity in matrix - excellent in some nodules.	G
59																												
3860																												

Logged by: Date: Core Interval: 4729-4754' ADJUSTED TO 4727.7-4752.7'

Well Location: 100/02-21-007-28W1/00 (Lic.#91) Correction Factor (Log to Core Conversion): -1.3'

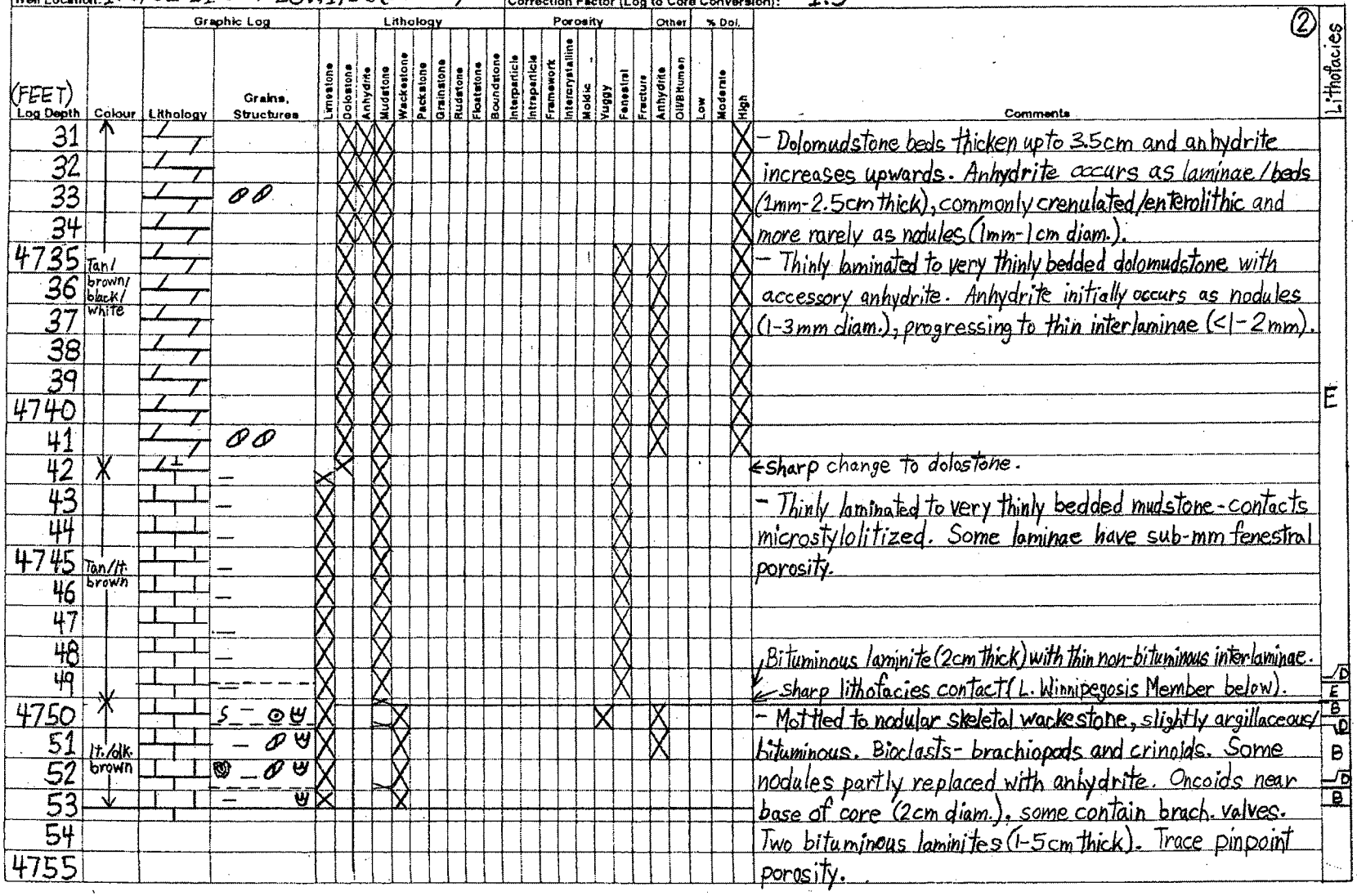
(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments

Logged by: Date:

Core Interval: 4729-4754' ADJUSTED TO 4727.7-4752.7'

Well Location: 100/02-21-007-28W1/00 (Lic.#91)

Correction Factor (Log to Core Conversion): -1.3'



B30

Logged by: Date:

Core Interval: 2568-2578'

Well Location: 100/03-01-008-18W1/00 (Lic#44)

Correction Factor (Log to Core Conversion):

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol: Low	Moderate	High	Comments	Lithofacies
2565																												
66																												
67																											Upper Winnipegosis Member	
68																											Dolopackstone - original texture largely obscured (peloidal?),	
69	↑		~ ⌇ –	X			X		X			X					X	X	X								bituminous, thinly bedded/bioturbated. Rare dolomudstone inter-	
2570	lt./dk. brown		~ ⌇ –	X			X		X			X					X	X	X								beds and common skeletal dolofloatstone interbeds, bioclasts-Amphipora?	H
71			~ ⌇ –	X			X		X			X					X	X	X								molds. Abundant pinpoint/intercrystalline porosity.	
72			⌒	X			\		X			X					X	X	X								- Microbial dolobindstone - thinly laminated, abund. fenestral/vuggy por.	O
73			⌇	X			\		X			X					X	X	X								← Bituminous laminite (4cm).	D
74			~ ⌇	X			\		X			X					X	X	X								← Bituminous laminite (6mm).	H
2575	dark brown		~ ⌇	X			\		X			X					X	X	X			X					← Irregular body of replacive anhydrite (5cm).	D
76			– ⌇	X			\		X			X					X	X	X								- Dolopackstone / skeletal dolofloatstone (as above).	
77			– ⌇	X			\		X			X					X	X	X									H
78	↓		– ⌇	X			\		X			X					X	X	X			X					← Large irregular body of replacive pale blue anhydrite (>14cm).	
79																												
2500																												

Logged by: Date:

Core Interval: 1279-1285m ADJUSTED TO 1280.87-1286.87 m

Well Location: 100/14-13-009-28W1/00 (Lic.#3083)

Correction Factor (Log to Core Conversion): +1.87 m

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
1280																												
.20																												
.40																												
.60																												
.80																												
1281	↑			X					X								X		X							X		
.20				X					X								X		X							X		
.40	Tan/lt. brown			X					X								X		X							X	- Thinly interlaminated to thinly interbedded dolomudstone and dolopackstone (as below).	N
.60				X					X								X		X		X					X		
.80				X					X								X		X							X		
1282	↓			X					X								X		X							X		

B32

Logged by: Date: Core Interval: 1279-1285 m ADJUSTED TO 1280.87-1286.87 m

Well Location: 100/14-13-009-28W1/00 (Lic.#3083) Correction Factor (Log to Core Conversion): +1.87m

②

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20				X			X		X								X		X							X		
.40				X			X		X								X		X							X		
.60			III	X			X		X								X		X							X	- Thinly interlaminated to thinly interbedded dolomudstone and dolopackstone (peloidal), generally as below. Only bioclasts are rare probable tabular stromatoporoids (1-3cm thick), appear white. Scattered pinpoint porosity in dolopackstone beds, abundant locally. Good intercrystalline porosity throughout.	
.80				X			X		X								X		X							X		
1283				X			X		X								X		X							X		
.20				X			X		X								X		X							X		
.40			~	X			X		X								X		X							X		
.60				X			X		X								X		X							X		
.80				X			X		X								X		X							X		
1284			III ~	X			X		X								X		X							X		
.20	Tan / light brown		~	X			X		X								X		X							X		
.40				X			X		X								X		X							X		N
.60				X			X		X								X		X							X		
.80				X			X		X								X		X							X		
1285				X			X		X								X		X							X		
.20				X			X		X								X		X							X		
.40				X			X		X								X		X							X		
.60				X			X		X								X		X							X		
.80				X			X		X								X		X							X		
1286				X			X		X								X		X							X		
.20			~	X			X		X								X		X							X		
.40				X			X		X								X		X							X		
.60			~	X			X		X								X		X							X		
.80	↓			X			X		X								X		X							X		
1287		X																										

B33

Logged by: Date:

Core Interval: 1286.00 - 1304.00m ADJUSTED TO 1287.87 - 1305.87 m

Well Location: 100/14-13-009-28W1/00 (Lic.#3083)

Correction Factor (Log to Core Conversion): +1.87m

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20																												
.40																												
.60																												
.80																												
1288	↑			X		X		X							X	X									X			
.20				X		X		X							X	X									X			
.40			~	X		X		X							X	X									X			
.60				X		X		X							X	X									X	- Thinly interlaminated to thinly interbedded dolomudstone and dolopackstone. Bed contacts typically undulatory and horizontal to gently dipping. Some mottling and less distinctive bedding near base. Dolopackstone beds have a "grainy" appearance and scattered pinpoint porosity. Very good intercrystalline porosity throughout.	
.80				X		X		X							X	X									X			
1289				X		X		X							X	X									X			
.20				X		X		X							X	X									X			
.40				X		X		X							X	X									X			
.60				X		X		X							X	X									X			
.80				X		X		X							X	X									X			N
1290	Tan			X		X		X							X	X									X			
.20				X		X		X							X	X									X			
.40				X		X		X							X	X									X			
.60				X		X		X							X	X									X			
.80			~	X		X		X							X	X									X			
1291				X		X		X							X	X									X			
.20			§	X		X		X							X	X									X			
.40			§	X		X		X							X	X									X			
.60				X		X		X							X	X									X			
.80				X		X		X							X	X									X			
1292	↓			X		X		X							X	X									X	← Lithofacies change	

Logged by: Date:

Core Interval: 1286.00 - 1304.00m ADJUSTED TO 1287.87 - 1305.87 m

Well Location: 100/14-13-009-28W1/00 (Lic.#3083)

Correction Factor (Log to Core Conversion): +1.87m

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
.20				X								X					X		X							X	- Intraclast dolofloatstone - Intraclasts - sub-rounded to rounded, 3mm - 2.5cm diam. Dolopackstone matrix - same as below. Rare crinoids	I
.40				X								X					X		X							X		
.60				X								X					X		X		X					X		
.80				X								X					X		X							X		
1293				X								X					X		X		X					X		
.20				X								X					X				X					X		
.40				X					X								X				X					X		K
.60				X					X								X									X	- Dolopackstone - skeletal in part, pervasively dolomitized, medium to thick mottled beds, rare crinoids and intraclasts. Good intercrystalline and scattered pinpoint porosity throughout, scattered vugs (up To 3cm) some occluded with anhydrite. Total visible porosity 1-15%.	
.80				X					X								X									X		
1294				X					X								X									X		
.20				X					X								X									X		
.40	Tan/lt. brown			X					X								X									X		
.60				X					X								X									X		
.80				X					X								X									X		
1295				X					X								X									X		
.20				X					X								X					X				X	← Pyrite lining fractures and filling vugs. Possible tabular stromatoporoid	
.40				X					X								X					X				X		
.60				X					X								X				X					X	- Soft tan chalky dolomite lines/fills many vugs and fractures between 1295.40 - 1296.60m.	
.80				X					X								X			X						X		
1296				X					X								X				X					X		
.20				X								X					X					X				X	- Intraclast dolofloatstone - (as above).	I
.40				X					X								X									X		
.60				X					X								X									X		K
.80				X					X								X				X					X		
1297				X					X								X									X		

B35

Logged by: Date:

Core Interval: 1286.00 - 1304.00m ADJUSTED TO 1287.87 - 1305.87 m

Well Location: 100/14-13-009-28W1/00 (Lic.#3083)

Correction Factor (Log to Core Conversion): +1.87m

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
.20				X	X				X								X		X							X		
.40				X	X				X								X		X							X		
.60				X	X				X								X		X							X		
.80				X	X				X								X		X							X		
1298				X	X				X								X		X							X		
.20				X	X				X								X		X							X	– Dolopackstone - skeletal in part, pervasively dolomitized, thin to medium mottled beds (as below). Rare horizontal and vertical fractures. Rare replacive anhydrite. Rare large vugs >5cm contain chalky, calcareous dolomite.	
.40				X	X				X								X		X							X		
.60				X	X				X								X		X							X		
.80				X	X				X								X		X			X				X		
1299				X	X				X								X		X							X		
.20				X	X				X								X		X							X		
.40	Tan/Lt. brown			X	X				X								X		X		X					X		K
.60				X	X				X								X		X							X		
.80				X	X				X								X		X							X		
1300				X	X				X								X		X							X		
.20				X	X				X								X		X							X		
.40				X	X				X								X		X			X				X	← Possible tabular stromatoporoid (1cm thick).	
.60				X	X				X								X		X							X		
.80				X	X				X								X		X		X	X				X		
1301				X	X				X								X		X		X					X		
.20				X	X				X								X		X		X	X				X		
.40				X	X				X								X		X			X				X		
.60				X	X				X								X		X							X		
.80				X	X				X								X		X			X				X		
1302				X	X				X								X		X							X		

Logged by: Date: Core Interval: 1286.00 - 1304.00m ADJUSTED TO 1287.87 - 1305.87 m

Well Location: 100/14-13-009-28W1/00 (Lic.#3083) Correction Factor (Log to Core Conversion): +1.87m

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20				X					X								X		X							X		
.40				X					X								X		X							X		
.60				X					X								X		X							X		
.80				X					X								X		X							X		
1303				X					X								X		X							X	- Dolopackstone - skeletal in part, pervasively dolomitized.	
.20				X					X								X		X							X	Only identifiable bioclasts are rare crinoids. Thin to	
.40				X					X								X		X							X	thick mottled beds. Rare hairline fractures. Scattered	
.60				X					X								X		X							X	pinpoint/vuggy (1-5mm) porosity. Very good intercrystalline	
.80				X					X								X		X		X					X	porosity.	
1304	Tan/lt. brown			X					X								X		X							X		K
.20				X					X								X		X							X		
.40				X					X								X		X		X					X		
.60				X					X								X		X							X		
.80				X					X								X		X							X		
1305				X					X								X		X							X		
.20				X					X								X		X							X		
.40				X					X								X		X							X		
.60				X					X								X		X							X		
.80				X					X								X		X							X		
1306				X					X								X		X							X		
.20																												
.40																												
.60																												
.80																												
1307	Tan			X					X								X		X							X		K

B37

Logged by: Date: Core Interval: 1305-1323.23m ADJUSTED TO 1306.87-1325.10m

Well Location: 100/14-13-009-28W1/00 (Lic #3083) Correction Factor (Log to Core Conversion): +1.87m

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20				X					X								X		X							X		
.40				X					X								X		X							X		
.60				X					X								X		X		X					X	- Dolopackstone - skeletal in part, pervasively dolomitized, thin to medium beds - faintly mottled. Rare intraclasts - sub-rounded, up to 1cm. Rare vertical fractures. Common pinpoint porosity and vuggy porosity (up to 3cm). Larger vugs occluded with anhydrite - may be replacive in part. Good intercrystalline porosity. Visible porosity ~3%.	
.80				X					X								X		X							X		
1308				X					X								X	X	X			X				X		
.20				X					X								X		X							X		
.40	Tan/lt. brown			X					X								X		X							X		K
.60				X					X								X		X							X		
.80				X					X								X		X							X		
1309				X					X								X		X			X				X		
.20				X					X								X		X			X				X		
.40				X					X								X		X			X				X		
.60				X					X								X		X			X				X		
.80				X					X								X		X			X				X		
1310				X					X								X		X							X	← Gradational lithofacies change.	
.20				X		X											X		X							X	Lower Winnipegosis Member	
.40				X		X											X		X							X	- Dolomudstone - mottled to nodular, argillaceous.	
.60				X		X											X		X							X	Nodules have septarian fractures filled with grey clay	
.80				X		X											X		X							X	and are more sucrosic than the internodular matrix	
1311	Tan/lt. brown			X		X											X	X	X							X	(as below).	B
.20				X		X											X		X							X		
.40				X		X											X		X							X		
.60				X		X											X		X							X		
.80				X		X											X		X							X		
1312	Tan/ Maroon			X		X											X		X							X	- Dolomudstone - mottled to nodular, patterned (as below).	C

Logged by: Date:

Core Interval: 1305-1323.23m ADJUSTED TO 1306.87-1325.10m

Well Location: 100/14-13-009-28W1/00 (Lic#3083)

Correction Factor (Log to Core Conversion): +1.87m

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20				X		X											X		X							X	- Dolomudstone - mottled to nodular, patterned, argillaceous. Thin, anastomosing argillaceous/silty laminae at top. Rare pinpoint porosity.	C
.40	Tan/ maroon			X		X											X		X		X					X		
.60				X		X											X		X							X		
.80				X		X											X		X		X					X		
1313				X		X											X		X							X		B
.20				X		X											X		X		X					X		
.40				X		X											X		X							X	- Dolomudstone - mottled to nodular, argillaceous. Similar to below but some nodules have septarian fractures with triple junctions and filled with grey clay. Rare replacive anhydrite in nodules. Pinpoint porosity scattered throughout, intercrystalline and vuggy porosity mostly in sucrosic nodules. Total porosity <3%.	
.60				X		X											X		X		X					X		
.80				X		X											X		X		X					X		
1314				X		X											X		X		X					X		
.20				X		X											X		X							X		
.40				X		X											X		X							X		
.60				X		X											X		X							X		
.80	Tan/lt. brown			X		X											X		X							X		
1315				X		X											X		X							X		
.20				X		X											X		X							X		
.40				X		X											X		X							X		
.60				X		X											X	X	X							X		
.80				X		X											X		X							X		
1316				X		X											X		X							X		
.20				X		X											X		X							X		
.40				X		X											X		X							X		
.60				X		X											X	X	X							X		
.80				X		X											X		X			X				X		
1317				X		X											X		X							X		

B39

Logged by: Date: Core Interval: 1305-1323.23m ADJUSTED TO 1306.87-1325.10m

Well Location: 100/14-13-009-28W1/00 (Lic#3083) Correction Factor (Log to Core Conversion): +1.87m

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
.20					X		X										X	X	X			X				X	- Dolomudstone - mottled to nodular, slightly argillaceous. Nodules - tan, fine crystalline dolomite. Internodular matrix - light brown, microcrystalline. Some nodules partly-completely replaced by anhydrite. Scattered pinpoint/moldic porosity. Nodules have abundant intercrystalline porosity	
.40					X		X										X	X	X			X				X		
.60					X		X										X	X	X							X		
.80	Tan/lt. brown				X		X										X	X	X							X		
1318					X		X										X		X			X				X		
.20					X		X										X		X			X				X		
.40					X		X										X	X	X			X				X		
.60					X		X										X		X	X	X	X				X		
.80					X		X											X	X							X		
1319					X			X										X	X							X	- Skeletal dolowackestone - mottled, bioclasts-remain as molds (mostly brachiopods), argillaceous. Porosity 5-10%.	B
.20					X			X										X	X			X				X		
.40					X		X	X										X	X			X				X		
.60	Tan/orange				X		X											X	X			X				X	- Dolomudstone - mottled to locally nodular, argillaceous, scattered brachiopod molds. Rare replacive anhydrite (1-7cm diam.). Scattered pinpoint porosity. Porosity < 2%.	
.80					X		X											X	X			X				X		
1320					X		X											X	X			X				X		
.20					X		X											X	X							X		
.40					X		X											X	X			X				X		
.60					X		X											X	X							X		
.80					X		X											X	X							X		
1321	grey/purple				X		X																			X	- Dolomudstone - thin to med. bedded, some beds mottled or massive, uppermost bed is burrowed (Skolithos-like).	A
.20					X		X														X					X		
.40					X						X															X	- Intraclastic dolorudstone - Intraclasts are sub-rounded to rounded, 1mm-3cm diameter. Argillaceous dolomudstone matrix. Sharp lower contact, gradational upper contact.	
.60		ASHERN	FM.		X						X															X		
.80					X						X															X		
1322					X						X															X		

Logged by: Date: Core Interval: 4175-4192'

Well Location: 100/15-18-010-27W1/00 (Lic#15) Correction Factor (Log to Core Conversion):

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
4175																											Lower Winnipegosis Member	
76	↑		⊙ Ψ Ø _ S	X			X	X											X			X				X	- Dolomudstone-wackestone, mottled to nodular, bituminous.	B
77	Tan/lt. brown		Ø S	X			X												X		X	X				X	Bioclasts - crinoids and brachiopods. Fractured and disjointed hardground (12mm thick) at base. Very fine disseminated pyrite in hardground. Trace pinpoint and fracture porosity, partly occluded with anhydrite.	
78		Ashern ↓																										
79																												
4180																												
81																												
82																												
83																												
84																												
4185																												
86																												
87																												
88																												
89																												
4190																												
91																												
92																												

Logged by: Date: Core Interval: 2788-2838'

Well Location: 100/04-27-011-22W1/00 (Lic#1228) Correction Factor (Log to Core Conversion):

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	① Lithofacies
2785																												
86																												
87																												
88																											Upper Winnipegosis Member	
89	↑	⊥	~	X				X								X	X		X							- Dolapackstone - mottled to thinly bedded (as below).	
2790	lt./dk. brown	⊥	~	X				X								X	X		X									H

Logged by: Date: Core Interval: 2788-2838'

Well Location: 100/04-27-011-22W1/00 (Lic#1228) Correction Factor (Log to Core Conversion):

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
91				X					X								X		X							X	- Dolopackstone - original texture largely obscured (peloidal?), slightly bituminous. Faintly mottled to thinly bedded, Planolites visible locally. Bioclasts - wafter stromatoporoids, rugose corals, tabulate corals?, brachiopods. Hairline fractures common and mostly occluded with anhydrite.	H
92				X					X								X		X			X				X		
93				X					X								X		X			X				X		
94				X					X								X		X			X				X		
2795				X					X								X		X			X				X		
96				X					X								X		X							X	← Brecciated with replacive anhydrite.	
97				X					X								X	X	X			X				X	- Irregular bodies of replacive anhydrite (0.5-3cm) common throughout. Pinpoint porosity common throughout, vugs (up to >2cm) scattered throughout - some suggest moldic porosity. Some vugs lined with dolo rhombs. Good inter-crystalline porosity throughout.	
98				X					X								X		X			X				X		
99				X		X			X								X		X			X				X		
2800				X					X								X		X			X				X		
01	Lt./dk. brown			X					X								X		X			X				X		
02				X					X								X		X			X				X	← Brecciated (13cm) with replacive anhydrite.	
03				X					X								X	X	X			X				X	← Cylindrical moldic porosity (Amphipora?).	
04				X					X								X		X			X				X		
2805				X					X								X		X			X				X		
06				X					X								X		X			X				X		
07				X					X								X		X			X				X		
08				X					X								X		X			X				X		
09				X					X								X		X			X				X		
2810				X					X								X		X							X	← Stringocephalid (4cm diam.).	
11				X					X								X		X							X		
12				X					X								X		X			X				X		
13				X					X								X		X			X				X		
14				X		X			X								X		X							X		
2815				X					X								X		X							X		

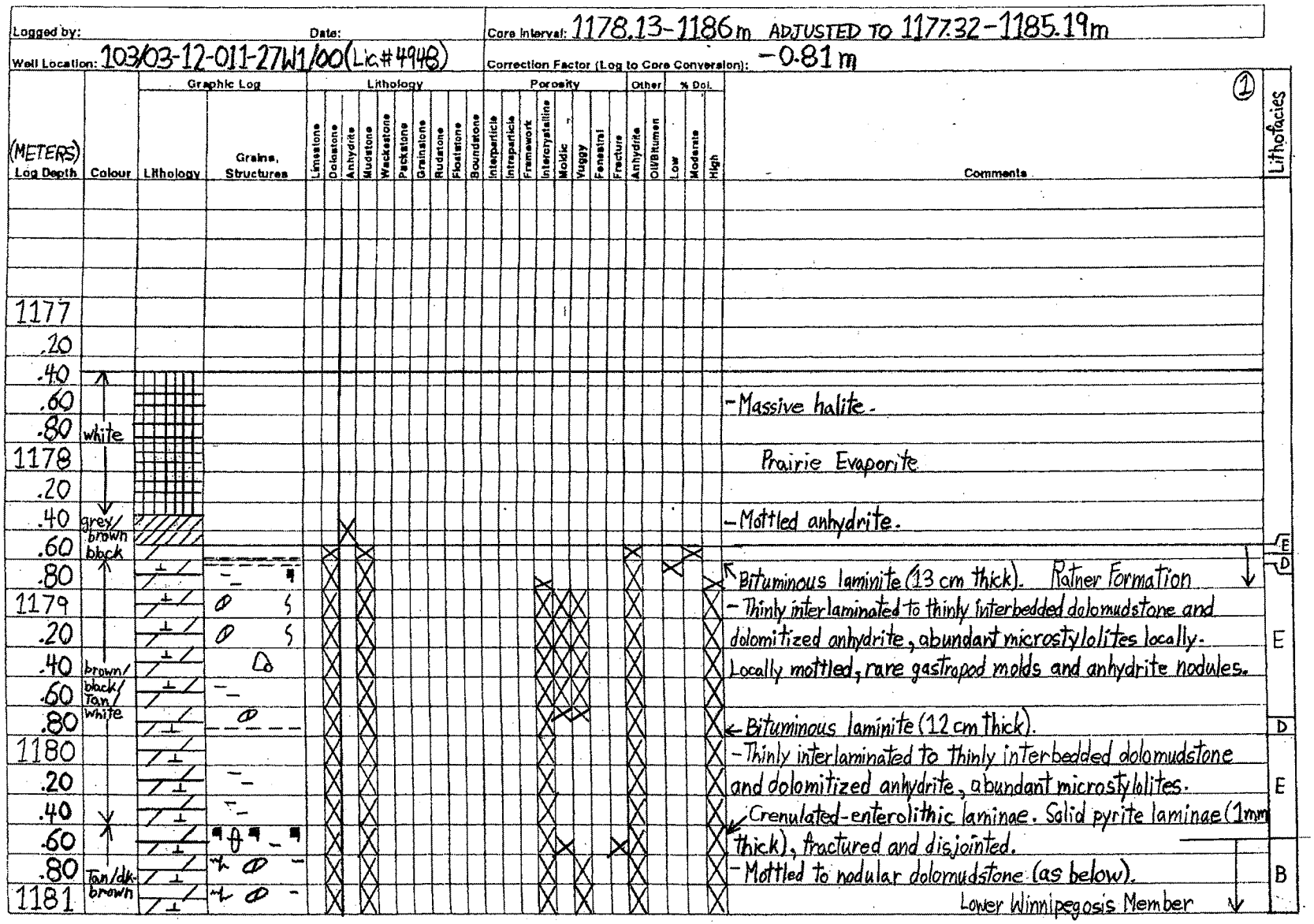
Logged by: Date: Core Interval: 2788-2838'

Well Location: 100/04-27-011-22W1/00 (Lic#1228) Correction Factor (Log to Core Conversion):

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
16					X				X								X									X	- Dolopackstone - mottled and slightly bituminous.	
17	lt./dk. brown				X				X								X									X		H
18					X				X								X		X			X				X		
19			Ø		X				X								X		X		X	X				X	← Gradational facies change.	
2820			Ø		X				X								X		X							X		
21			Ø		X				X								X		X							X	- Dolopackstone, skeletal - most bioclasts not identifiable,	
22	Tan/lt. brown		Ø		X				X								X		X							X	some resemble brachiopod and crinoid fragments. Thin to	
23			Ø		X				X								X		X			X				X	medium bedded (5-30 cm thick). Nodular - nodules are 1-5cm	
24			Ø		X				X								X		X							X	in diam., round-irregular, consist of fine, tan, sucrosic	
2825			Ø		X				X								X		X			X				X	dolomite. Nodules have septarian fractures filled with dark	
26			Ø		X				X								X		X			X				X	bituminous/argillaceous matterial. Some nodules are partly/	
27			Ø		X				X								X		X		X	X				X	completely replaced by anhydrite. Bituminous content in	
28			Ø		X				X								X		X							X	internodular matrix decreases upwards.	G
29	Tan/dk. brown		Ø		X				X								X		X							X		
2830			Ø III		X				X								X		X							X	← Tabular stromatoporoid?	
31			Ø		X				X								X		X							X		
32	Tan/lt. brown		Ø		X				X								X		X							X	- Scattered pinpoint and vuggy/moldic porosity (1mm-6cm	
33			Ø		X				X								X		X							X	diam.) throughout. Very good intercrystalline porosity in	
34			Ø		X				X								X		X							X	nodules.	
35			Ø		X				X								X		X							X		
36	Tan/dk. brown		Ø ⊙		X				X								X		X							X		
37			Ø		X				X								X		X							X		
38			Ø		X				X								X		X							X		
39																												
2840																												

Logged by: Date: Core Interval: 1178.13-1186m ADJUSTED TO 1177.32-1185.19m

Well Location: 103/03-12-011-27W1/00 (Lic#4948) Correction Factor (Log to Core Conversion): -0.81m



Logged by: Date:

Core Interval: 1178.13-1186 m ADJUSTED TO 1177.32-1185.19m

Well Location: 103/03-12-011-27W1/00 (Lic.# 4948)

Correction Factor (Log to Core Conversion): -0.81m

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
.20				X			X										X		X			X				X		
.40				X			X										X		X			X				X		
.60				X			X										X		X			X				X	- Mottled to nodular dolomudstone. Sparsely	
.80				X			X										X		X			X				X	fossiliferous, bioclasts- crinoids and rare possible	
1182	Tan/med brown			X			X										X		X			X				X	brachiopods. Variably bituminous/argillaceous, locally	
.20				X			X										X		X			X				X	burrowed with Planolites. Nodules- nearly round to irregular	
.40				X			X										X		X		X					X	form, 1-8cm diameter, tan sucrosic dolomite with	
.60				X			X										X		X							X	septarian fractures filled with unconsolidated bituminous/	
.80				X			X										X		X							X	argillaceous matter. Some nodules partly-completely	
1183				X			X										X		X							X	replaced with anhydrite. Minor intercrystalline, pinpoint,	B
.20				X			X										X		X							X	and moldic/vuggy (2-8mm) porosity in internodular	
.40	Tan/dk brown			X			X										X	X	X							X	matrix. Excellent intercrystalline porosity in nodules.	
.60				X			X										X	X	X			X				X		
.80				X			X										X		X			X				X		
1184	Tan/med brown			X			X										X		X			X				X		
.20				X			X										X		X							X		
.40				X			X										X		X							X		
.60				X			X										X		X							X		
.80				X			X										X		X							X		
1185	Tan/dk. brown			X			X										X		X							X		
.20				X			X										X		X			X				X		
.40																												
.60																												
.80																												
1186																												

Logged by: Date: Core Interval: 4517-4537'

Well Location: 100/07-08-011-29W1/00 (Lic.# 134) Correction Factor (Log to Core Conversion):

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
16																												
17																											Upper Winnipegosis Member (above 4525')	
18	↑			X								X					X		X			X				X	-Intraclastic dolofloatstone. Intraclasts- angular to sub-rounded, original lithology packstone? (2mm-5cm). Some intraclasts partly replaced by anhydrite. Matrix- slightly bituminous/ argillaceous dolopackstone (skeletal in part). Bioclasts coral? and crinoid fragments. Abundant pinpoint and good intercrystalline porosity.	I
19				X								X					X		X			X				X		
4520	tan/lt. brown			X								X					X		X			X				X		
21				X								X					X		X			X				X		
22				X								X					X		X			X				X		
23				X					X								X		X			X				X		
24				X					X								X		X			X				X	- Dolopackstone, skeletal in part. Thin to medium bedded, locally mottled. Slightly bituminous/argillaceous. Oncoid (1.5cm). Minor replacive anhydrite. Gradational lower contact. Abundant pinpoint porosity and good intercrystalline.	K
4525	↑			X					X								X		X			X				X		
26	tan/lt. brown			X				X									X		X			X				X		
27	↓			X				X									X		X			X				X		
28				X				X									X		X			X				X		
29																											Lower Winnipegosis Member (below 4525')	
4530	↑			X				X									X		X			X				X	- Skeletal dolowackestone, mottled to nodular. Bioclasts- mostly crinoids, rare brachiopod and tabulate coral fragments. Some nodules are sucrosic and variably replaced by anhydrite. Some larger nodules consist of coalesced smaller nodules. Sulphide rim on some nodules. Slightly argillaceous/ bituminous matrix. Scattered pinpoint porosity, intercrystalline porosity fair in internodular matrix, good in sucrosic nodules.	B
31				X				X									X		X			X				X		
32	light brown			X				X									X		X			X				X		
33				X				X									X		X			X				X		
34				X				X									X		X			X				X		
4535				X				X									X		X			X				X		
36	↑			X				X									X		X							X		
37	light brown			X				X	X								X		X							X	-Thin dolopackstone interbed - skeletal/intraclastic?, gradational lower contact, sharp upper contact. Rare scattered sulphides, oxidized red.	
38																												
39																												
4540																												

Logged by: Date: Core Interval: 3104-3107'

Well Location: 100/01-27-017-26W1/00 (Lic#17) Correction Factor (Log to Core Conversion):

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol: Low	Moderate	High	Comments	Lithofacies
3100																												
01																												
02																												
03																												
04																											*Core very fragmented. Upper Winnipegosis Member	
3105	medium brown			X					X								X		X		X	X				X	- Dolopackstone - pervasively dolomitized, peloidal? Slightly	H
06				X					X								X		X		X					X	bituminous, some thin bedding visible. Rare disseminated	
07																											sulphides. Fractured - some fractures occluded with anhydrite.	
08																											Rare vugs - lined with dolo rhombs. Abundant pinpoint and good	
09																											intercrystalline porosity.	
3110																												

Logged by: Date: Core Interval: 3147-3157', 3295-3299'

Well Location: 100/16-18-018-29W1/00(Lic#19) Correction Factor (Log to Core Conversion):

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
46																											Upper Winnipegosis Member	
47																											*Core very fragmented - much missing.	
48	Tan/lt. brown			X							X			X			X					X				X	-Skeletal doloradstone - Bioclasts - fragments of massive	M
49																											tabulate corals and encrusting stromatoporoids. Inter-	?
3150				X							X			X			X					X				X	particle porosity occluded with anhydrite. Minor intraskeletal	
51	Tan/lt. brown			X							X			X			X					X				X	porosity and excellent intercrystalline porosity.	M
52																												?
53				X							X			X			X					X				X		
54	Tan/lt. brown			X							X			X			X					X				X	-Skeletal doloradstone - (as above).	M
3155																												?
56				X							X						X					X				X		M
57				X					X		X						X					X				X	- Dolopackstone with sharp upper contact, skeletal in part,	K
																											irregular body of replacive anhydrite. Overlain by skeletal	
																											doloradstone bed, with grain size increasing upwards.	
3295																												
96		?																										
97				X			X	X	X										X							X	Lower Winnipegosis Member	
98	Tan/lt-zdk. brown		⊙ ↓ S	X			X	X	X										X							X	- Dolomudstone - wackestone, mottled-nodular, slightly	B
99		?																									bituminous. Bioclasts - crinoids. Dolopackstone lens at	
3200																											top (5mm thick). Scattered pinpoint and poor intercrystalline por.	

Logged by: Date: Core Interval: 3133-3193' ADJUSTED TO 3132.08-3192.08'

Well Location: 100/04-17-019-29W1/00 (Lic.#2162) Correction Factor (Log to Core Conversion): -0.92'

Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vugsy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	① Lithofacies
3130																												
31																												
32	↑		–	X					X					X		X		X							X		Upper Winnipegosis Member	
33			–	X					X					X		X	X	X							X		-Dolopackstone- pervasively dolomitized, skeletal in part.	
34			–	X					X					X		X		X							X		Minor bituminous content decreases upwards, thin-medium	
3135			–	X					X					X		X		X							X		bedded. Macro bioclasts are dominantly thamnoporids	
36			–	X					X					X		X		X							X		with rare tabular tabulate and halysitoid corals. Corals	
37	tan		–	X					X					X		X		X							X		are rarely abundant enough to constitute floatstone	
38			–	X					X					X		X		X							X		beds. Intercrystalline and scattered pinpoint porosity	K
39			–	X					X					X		X		X							X		throughout, rare larger vugs (up to 5mm), minor intraskeletal	
3140			–	X					X			X		X		X		X				X			X		and moldic porosity associated with bioclasts.	
41			–	X					X					X		X		X							X			
42			–	X					X					X		X		X							X			
43			–	X					X					X		X		X							X			
44	↓		–	X					X					X		X		X							X			
3145	Tan/lt. brown		–	X					X			X		X		X		X				X			X		↙ Gradational lithofacies change	

Logged by: Date: Core Interval: 3133-3193' ADJUSTED TO 3132.08-3192.08'

Well Location: 100/04-17-019-29W1/00(Lic.#2162) Correction Factor (Log to Core Conversion): -0.92'

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
46	↑		~ ∂ –	X				X	X			X					X					X			X			J
47	tan/lt. brown		~ ∂ –	X				X									X								X			
48	↑		~ ∂	X				X	X								X				X	X			X			
49			~ –	X				X				X					X									X		K
3150	lt./dk. brown		~ ∎ –	X				X				X					X					X				X	~Bituminous, skeletal dolowackestone-floatstone	
51			~ –	X				X									X									X	with thin-medium non-bituminous skeletal dolopackstone	
52			~ ∂ –	X				X									X									X	/grainstone interbeds with sharp, horizontal lower	J
53			~ ∂ –	X				X				X					X					X				X	contacts and irregular upper contacts (as below).	
54			~ –	X				X									X					X				X		
3155	↓		Ψ ~ – ∂	X				X				X					X									X		
56	tan/dk. brown		~ ▬ – ∂	X				X				X					X				X	X				X		K
57	↑		~ ∂ –	X				X	X			X					X				X	X				X		
58			~ ∂ –	X				X				X					X					X				X		
59			~ –	X				X									X		X			X				X		
3160	dark brown		~ –	X				X									X									X		
61			~ –	X				X									X									X		
62			~ –	X				X									X		X		X					X		
63			~ –	X				X									X					X				X		
64			~ Ψ –	X				X									X		X			X				X		J
3165	↓		~ –	X				X				X					X					X				X		
66	tan/dk. brown		~ ∂ –	X				X									X					X				X		
67	↑ dark brown	⊙	~ ∂ –	X				X	X								X					X				X		K
68		⊙	~ ∂ –	X				X									X									X		J
69	↓		~ ∂ –	X				X	X			X					X		X							X		K
3170	tan/dk. brown		~ Ψ –	X				X									X		X			X				X		J

B51

Logged by: Date:

Core Interval: 3133-3193' ADJUSTED TO 3132.08-3192.08'

Well Location: 100/04-17-019-29W1/00 (Lic.#2162)

Correction Factor (Log to Core Conversion): -0.92'

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
71	↑		~ Ψ –	X				X									X		X							X		J
72	dk. brown		⊙ ~ Ψ =	X				X									X					X				X		
73			~ =	X				X									X									X		
74			⊙ ~ Ψ =	X				X	X	X		X		X			X		X							X		J/K
3175			⊙ Ψ ~ =	X				X	X					X			X		X							X		J
76	tan/dk brown		⊙ β ~	X				X	X	X				X			X					X				X		J/K
77			⊙ ~ Ψ –	X				X	X	X		X		X			X									X		K
78			⊙ β ~ =	X				X	X	X		X					X					X				X		J/K
79			⊙ β ~ –	X				X				X			X		X					X				X		J
3180			⊙ β ~ Ψ –	X				X							X		X					X				X	←Gradational lithofacies change.	
81	dk. brown		Ø ~ –	X			X										X									X	Lower Winnipegosis Member	
82			Ø ~ –	X			X										X					X				X	- Mottled to nodular dolomudstone, moderately argillaceous/	
83			Ø ~ –	X			X										X									X	bituminous. Sparsely fossiliferous, only identifiable	
84			Ø ~ ▪ –	X			X										X					X				X	bioclasts are crinoids. Nodules - consist of tan, fine	
3185	lt. brown		Ø ~ –	X			X										X					X				X	crystalline dolomite, 2mm-7cm diam., and have septarian	
86			Ø ~ –	X			X										X					X				X	fractures/internal voids filled with argillaceous/organic	B
87	lt. brown/tan		Ø ~ ⊙ –	X			X										X									X	matter. Some nodules are partly-completely	
88			Ø ~ –	X			X										X					X				X	replaced with anhydrite. Intercrystalline porosity poor	
89			S ~ –	X			X										X					X				X	in internodular matrix, good in nodules.	
3190	lt. brown		S ~ ▪ –	X			X										X					X				X		
91			S ~ ⊙ –	X			X										X					X				X		
92	↓		S ~ ⊙ –	X			X										X					X				X		
93																												
94																												
8195																												

Logged by: Date: Core Interval: 678-721' ADJUSTED TO 674-717'

Well Location: 100/04-33-023-16W1/00 (Lic.#2474) Correction Factor (Log to Core Conversion): -4'

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments ①	Lithofacies
71																												
72																												
73																												
74																											Upper Winnipegosis Member	
675	black			X						X														X			- Bituminous laminite - very thinly laminated, very dense, organic content increases upwards.	D
76	↑			X						X														X				
77	lt./dk. brown		~ S -	X					X	X						X					X	X	X			- Packstone - peloidal, laminated - very thinly bedded and mottled, microstylolites common locally. Rare ovoid nodules (1-3cm), rare possible bioclasts. Hairline fractures and small vugs occluded with anhydrite. Core very fragmented.	H
78	↑ lt. grey/ brown		~ S -	X					X							X					X	X					
79	↑		~ S -	X					X							X					X	X					
680	↑		~	X					X							X							X				
81	lt./dk. brown		∅ - S	X					X							X					X		X				
82	↓		~	X					X							X					X		X				
83	↑		S	X	X							X				X		X								X	- Intraclast dolofloatstone. Intraclasts - mudstone, 1mm - 3cm, subrounded to rounded. Matrix - mudstone, mottled (looks diagenetic). Pervasively dolomitized, core rubble in places. Very good porosity (intercrystalline, pinpoint/vuggy).	I
84			S	X	X							X				X		X				X				X		
685	lt. grey/ brown		S	X	X							X				X		X				X				X		
86	↓		S	X	X							X				X		X				X				X		
87	↑			X	X					X						X		X				X				X	- Dolopackstone (as below).	H
88			S	X	X							X				X		X				X				X	- Intraclast dolofloatstone - as above.	I
89				X	X		X									X		X				X				X	- Dolomudstone - massive, faintly laminated locally, gradational lower contact, sharp upper.	F
690	↓			X	X		X			X						X		X				X	X			X		
91	↑			X	X					X						X		X				X	X			X	- Dolopackstone - packstone, peloidal, medium bedded, rare skeletal floatstone interbeds (crinoids and brachiopods). Spotty oil staining. Excellent intercrystalline porosity in dolostone, abundant pinpoint/vuggy porosity in some beds.	H
92	lt. brown		⊙ ψ	X	X					X		X				X		X				X	X			X		
93			⊙ ψ		X					X		X				X						X				X		
94					X					X						X		X				X				X		
695	↓				X					X						X		X				X				X		

Logged by: Date: Core Interval: 678-721' ADJUSTED TO 674-717'

Well Location: 100/04-33-023-16W1/00 (Lic#2474) Correction Factor (Log to Core Conversion): -4'

(FEET) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
96				X					X								X		X				X			X	rubble in box.	
97				X					X								X		X				X			X		
98			⊙	X					X								X		X				X			X	- Dolopackstone - peloidal, pervasively dolomitized.	
99			⊙ Ψ	X					X			X					X		X				X			X	Rare skeletal floatstone interbeds (bioclasts- brachiopods,	
700	lt. brown			X					X								X		X			X	X			X	crinoids, and rare rugose coral fragments), dolopackstone	
01				X					X								X		X							X	matrix, gradational contacts. Rare fractures occluded	H
02			⊙ Ψ	X					X			X					X		X							X	with anhydrite. Spotty oil staining above 700'. Abundant	
03				X					X								X		X							X	intercrystalline and pinpoint porosity, rare larger vugs	
04				X					X								X		X			X				X	(up to 2cm).	
705				X					X								X	X	X							X		
06	↓			X					X								X	X	X							X		
07	tan		⊙ Ψ	X			X																			X	- Mudstone - as below.	F
08	↑		⊙ Ψ	X					X																	X	- Packstone / dolopackstone - peloidal with sparse	
09	Tan/lt. grey		⊙ Ψ	X					X																	X	bioclasts including brachiopods, crinoids, and very rare	
710			⊙ Ψ		X				X								X		X							X	thamnoporid fragments (2mm-2cm). Rare ovoid nodules (1-3cm)	H
11			⊙ Ψ		X				X			X					X		X							X	some with septarian fractures. Good intercrystalline and	
12			Ø		X				X								X		X							X	scattered pinpoint-vuggy (up to 1cm) porosity in dolostone.	
13			Ø	X	X				X								X		X						X	X		
14	Tan/lt. brown		Ψ ≶	X			X												X						X		- Mudstone - faintly mottled and locally laminated, minor	
715			Ø Ψ ≶	X			X					X						X	X						X		bituminous content locally. Sparsely fossiliferous with	F
16			⊙ Ψ ≶	X			X												X						X		brachiopods and crinoids, grading locally to floatstone.	
17	↓		Ψ ≶	X			X											X	X						X		Rare ovoid nodules (1.5-3cm). Thin packstone inter-	
18																											beds at base. Trace moldic/vuggy porosity.	
19																												
720																												

Logged by: Date: Core Interval: 0.60-25.80 m

Well Location: 16-26-024-10W1 (M-01-72) Correction Factor (Log to Core Conversion):

Log Depth (METERS)	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol: Low	Moderate	High	Comments	Lithofacies
0.00																												
.20																												
.40																												
.60																												
.80	↑		S	X					X								X		X							X	Upper Winnipegosis Member	
1.00			⊙ S	X					X								X		X							X	- Dolopackstone - faintly mottled, pervasively dolomitized,	
.20			S	X					X								X		X							X	looks peloidal. Sparsely fossiliferous with crinoids and	
.40			S	X					X								X		X							X	rugose corals. Excellent intercrystalline and scattered	
.60			S	X					X								X		X							X	pinpoint porosity throughout.	
.80	Tan		S	X					X								X		X									H
2.00			S	X					X								X		X							X		
.20			S	X					X								X		X							X		
.40			S	X					X								X		X							X		
.60			D S	X					X								X		X							X		
.80			S	X					X								X		X							X	← Large vug (>4cm), lined with tan, chalky dolomite.	
3.00	↓		S	X					X								X		X							X		

Logged by: Date: Core interval: 0.60 - 25.80 m

Well Location: 16-26-024-10W1 (M-01-72) Correction Factor (Log to Core Conversion):

② Lithofacies

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol: Low	Moderate	High	Comments
.20			S	X					X								X		X							X	– Dolopackstone – pervasively dolomitized, looks
.40			S	X					X								X		X							X	peloidal. Crude thin-medium bedding / mottled,
.60			S	X					X								X		X							X	very homogeneous. Core very fragmented.
.80			S	X					X								X		X							X	Excellent intercrystalline porosity; pinpoint porosity
4.00	Tan		S	X					X								X		X							X	variable and decreases upwards.
.20			S	X					X								X		X							X	
.40			S	X					X								X		X							X	
.60			S	X					X								X		X							X	
.80			S	X					X								X		X							X	
5.00			S	X					X								X		X							X	← Stromatoporoid fragment (2cm).
.20			S	X					X								X		X							X	
.40			S	X					X								X		X							X	
.60			S	X					X								X		X							X	
.80			S	X					X								X		X							X	
6.00			S	X					X								X		X							X	
.20			S	X					X								X		X							X	
.40	Tan/lt.		S	X					X								X		X							X	
.60	brown		S	X					X								X		X							X	
.80			S	X					X								X		X							X	
7.00			S	X					X								X		X							X	
.20			S	X					X								X		X		X					X	
.40			S	X					X								X		X							X	
.60			S	X					X								X		X							X	
.80			S	X					X								X		X							X	
8.00			S	X					X								X		X							X	

H

Logged by: Date: Core Interval: 0.60 - 25.80 m

Well Location: 16-26-024-10W1 (M-01-72) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20				X					X								X		X							X	← Large vug (3cm), lined with sucrosic tan dolomite.	
.40				X					X								X		X							X		
.60				X					X								X		X							X		
.80				X					X								X		X							X		
9.00				X					X	X							X		X							X	← Large vug (2cm), lined with sucrosic tan dolomite.	
.20				X					X	X							X		X							X		
.40				X					X	X							X		X							X		
.60			III	X					X	X							X		X							X	← Tabular stromatoporoid fragments (7mm - 1.5cm).	
.80				X					X	X							X		X							X		
10.00	Tan/lt brown			X					X	X							X		X							X	- Dolopackstone grading locally to dolograinstone - pervasively dolomitized, looks peloidal. Thin-medium crude bedding/mottled. Core very fragmented. Sparse bioclasts. Excellent intercrystalline porosity, variable pinpoint porosity - abundant in dolograinstone beds.	H
.20				X					X								X		X							X		
.40				X					X								X		X							X		
.60				X					X								X		X							X		
.80				X					X								X		X							X		
11.00				X					X								X		X							X		
.20				X					X								X		X							X		
.40				X					X								X		X							X		
.60				X					X								X		X							X		
.80			B ⊙	X					X								X		X							X	← Rugose coral (5mm) and crinoid ossicles (2mm).	
12.00				X					X								X		X							X		
.20				X					X								X		X							X		
.40				X					X								X		X							X		
.60				X					X								X		X		X					X		
.80				X					X								X		X							X		
13.00	↓			X					X								X		X							X		

Logged by: Date:

Core Interval: 0.60 - 25.80 m

Well Location: 16-26-024-10W1 (M-01-72)

Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol: Low	Moderate	High	Comments	Lithofacies
.20			S		X				X								X		X							X		
.40			S		X				X								X		X							X	- Dolopackstone - pervasively dolomitized, looks peloidal. Thin to medium bedded/mottled, very homogeneous. Core very fragmented. No visible bioclasts. Excellent intercrystalline porosity and variable pinpoint porosity, locally abundant.	
.60			S		X				X								X		X							X		
.80			S		X				X								X		X							X		
14.00			S		X				X								X		X							X		
.20			S		X				X								X		X							X		
.40			S		X				X								X		X							X		
.60			S		X				X								X		X							X		
.80			S		X				X								X		X							X		
15.00	Tan/lt. brown		S		X				X								X		X							X		
.20			S		X				X								X		X							X		
.40			S		X				X								X		X							X		
.60			S		X				X								X		X							X		
.80			S		X				X								X		X							X		
16.00			S		X				X								X		X							X		
.20			S		X				X								X		X							X		
.40			S		X				X								X		X							X		
.60			S		X				X								X		X							X		
.80			S		X				X								X		X							X		
17.00			S		X				X								X		X							X		
.20			S		X				X								X		X							X		
.40			S		X				X								X		X							X		
.60			S		X				X								X		X		X					X		
.80			S		X				X								X		X							X		
18.00			S		X				X								X		X							X		

B58

Logged by: Date: Core Interval: 0.60 - 25.80 m

Well Location: 16-26-024-10W1 (M-01-72) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol: Low	% Dol: Moderate	% Dol: High	Comments ⑤	Lithofacies
.20	↑		S	X					X	X							X		X							X		
.40			S	X					X								X		X							X	- Dolopackstone grading locally to dolograinstone.	
.60			S	X					X								X		X							X	Pervasively dolomitized, looks peloidal. Thin to	
.80			S	X					X								X		X							X	medium crude bedding. Sparsely fossiliferous -	
19.00			S	X					X								X		X							X	bioclasts include rugose corals, crinoid ossicles,	
.20			S	X					X								X		X							X	and Amphipora. Very homogeneous lithology.	
.40			S	X					X								X		X							X	Core very fragmented - from drilling? Intercrystalline	
.60			S	X					X								X		X		X					X	porosity fair to good below 20m, excellent above.	
.80			S	X					X								X		X							X	Pinpoint porosity variable - abundant in dolograinstone.	
20.00	Tan/lt. brown		S	X					X								X		X		X					X		
.20			S	X					X								X		X							X		
.40			S	X					X								X		X							X		
.60			D S	X					X								X	X	X							X		
.80			⊙ S	X					X								X		X							X		
21.00			⊙ S	X					X								X		X							X		
.20			S	X					X								X		X							X		
.40			S	X					X								X		X							X		
.60			D S	X					X								X		X							X		
.80			S	X					X								X		X							X		
22.00			S	X					X								X		X							X		
.20			S	X					X								X	X	X							X		
.40			S	X					X								X		X							X		
.60			S	X					X								X		X							X		
.80			S	X					X								X	X	X							X		
23.00	↓		S	X					X								X		X							X		

H

B59

Logged by: Date: Core Interval: 0.60 - 25.80 m

Well Location: 16-26-024-10W1 (M-01-72) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20			S	X					X								X		X							X		
.40			S	X					X								X		X							X	- Mottled dolopackstone- pervasively dolomitized, looks peloidal, original texture obscured locally by tan sucrosic dolomite. Good intecrystalline porosity, variable pinpoint porosity, locally abundant.	
.60			S	X					X								X		X							X		
.80	Tan/lt. brown		S	X					X								X		X							X		
24.00			S	X					X								X		X							X		H
.20			S	X					X								X		X							X		
.40			D S	X					X								X	X	X							X	- Minor moldic porosity after bioclasts- possibly brachiopods and crinoids. One rugose coral.	
.60			S	X					X								X	X	X							X		
.80			S	X					X								X	X	X							X		
25.00																												
.20																											Core lost below 25.80 m	
.40																												
.60																												
.80																												
26.00																												
.20																												
.40																												
.60																												
.80																												
27.00																												
.20																												
.40																												
.60																												
.80																												
28.00																												

Logged by: Date: Core Interval: 4.40 - 43.78 m

Well Location: 03-35-024-10W1 (M-03-90) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments ①	Lithofacies
.20																												
.40																												
.60																												
.80																												
1.00																		1										
.20																												
.40																												
.60																												
.80																												
2.00																												
.20																												
.40																												
.60																												
.80																												
3.00																												
.20																												
.40																												
.60																												
.80																												
4.00																												
.20																												
.40																												
.60	↑				X				X	X							X		X							X	Upper Winnipegosis Member	H
.80	light yellow				X				X	X							X		X							X	- Dolopackstone/grainstone (as below).	
5.00					X				X	X							X		X							X		

Logged by: Date:

Core Interval: 4.40 - 43.78 m

Well Location: 03-35-024-10W1 (M-03-90)

Correction Factor (Log to Core Conversion):

②

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20				X					X	X							X		X							X		
.40				X					X	X							X		X							X		
.60				X					X	X							X		X							X		
.80	light yellow		S	X					X	X							X		X							X		
6.00				X					X	X							X		X							X	- Dolopackstone - dolograinstone, pervasively dolomitized looks peloidal, non-fossiliferous. Thin-medium crudely bedded, some beds mottled. Very good intercrystalline porosity throughout. Very good pinpoint porosity, especially in dolograinstone beds.	
.20				X					X	X							X		X							X		
.40			S	X					X	X							X		X							X		
.60				X					X	X							X		X							X		
.80				X					X	X							X		X							X		
7.00	Tan/lt. brown		S	X					X	X							X		X							X		H
.20				X					X	X							X		X							X		
.40				X					X	X							X		X							X		
.60				X					X	X							X		X							X		
.80	Tan			X					X	X							X		X							X		
8.00				X					X	X							X		X							X		
.20			S	X					X	X							X		X							X		
.40	Tan/lt. brown		S	X					X	X							X		X							X		
.60			S	X					X	X							X		X							X		
.80			S	X					X	X							X		X		X					X		
9.00			S	X					X	X							X		X							X		
.20	yellow/ lt-brown		S	X					X	X							X		X							X		
.40			S	X					X	X							X		X		X					X		
.60	tan/lt. brown		S	X					X	X							X		X							X		
.80			S	X					X	X							X		X							X		
10.00			S	X					X	X							X		X							X		

Logged by: Date:

Core Interval: 4.40 - 43.78 m

Well Location: 03-35-024-10W1 (M-03-90)

Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
.20			S	X	X				X	X							X		X							X	- Dolopackstone - dolograinstone, pervasively dolomitized looks peloidal, non-fossiliferous. Dolopackstone dominant lithology. Very good intercrystalline porosity throughout. Very good pinpoint porosity, especially in dolograinstone. Rare vugs up to 2cm.	
.40			S	X	X				X	X							X		X							X		
.60	Tan/lt. brown		S	X	X				X	X							X		X							X		
.80				X	X				X	X							X		X							X		
11.00				X	X				X	X							X		X							X		
.20				X	X				X								X		X							X		
.40				X	X				X								X		X							X		
.60				X	X				X								X		X							X		
.80				X	X				X								X		X							X		
12.00	Tan			X	X				X								X		X							X		
.20				X	X				X								X		X							X	- Dolopackstone - pervasively dolomitized, looks peloidal. Very thin to medium bedded, some beds mottled. Rare crinoid bioclasts. Very good intercrystalline and pinpoint porosity.	H
.40				X	X				X								X		X							X		
.60				X	X				X								X		X							X		
.80				X	X				X								X		X							X		
13.00				X	X				X								X		X							X		
.20	tan/lt. brown			X	X				X								X		X							X		
.40				X	X				X								X		X							X		
.60				X	X				X								X		X							X		
.80	Tan			X	X				X								X		X							X		
14.00				X	X				X								X		X							X		
.20			⊙	X	X				X								X		X							X		
.40			S	X	X				X								X		X							X		
.60			S	X	X				X								X		X							X		
.80	Tan/lt. brown		S	X	X				X								X		X							X		
15.00			S	X	X				X								X		X							X		

Logged by: Date:

Core Interval: 4.40 - 43.78 m

Well Location: 03-35-024-10W1 (M-03-90)

Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol: Low	Moderate	High	Comments	Lithofacies
.20	↑		S		X				X								X		X							X	– Dolopackstone – pervasively dolomitized – looks peloidal. Thin–medium bedded, some beds mottled. Rare bioclasts including crinoids and thamnoporid corals. Very good intercrystalline and pinpoint porosity.	H
.40		⊙	S		X				X								X		X							X		
.60	Tan				X				X								X		X							X		
.80					X				X								X		X							X		
16.00	↓	⊙			X				X								X		X							X		
.20	↑				X				X								X		X							X		
.40	Tan/lt. brown	⊙	●		X						X						X		X							X	– Intraclastic dolofloatstone. Intraclasts – various lithologies, angular to subrounded, 2mm–2cm. Matrix – dolopackstone. Very good intercrystalline and pinpoint porosity, minor vuggy/moldic porosity.	I
.60			●		X						X						X		X							X		
.80	↓	⊙	●		X						X						X	X	X							X		
17.00	↑		S		X				X								X	X	X							X		
.20		⊙	S		X				X								X	X	X							X	– Dolopackstone – pervasively dolomitized, looks peloidal, faintly mottled. Very good intercrystalline porosity, abundant pinpoint porosity, minor moldic porosity.	H
.40	light Yellow		S		X				X								X	X	X							X		
.60			S		X				X								X	X	X							X		
.80	↓		S		X				X								X	X	X							X		
18.00	↑	⋓		X			X										X							X			– Dolomitic mudstone – massive, locally mottled, rare thin beds with trace bituminous content. Rare bioclasts – brachiopods and oncoids. Scattered fractures with various orientations – most occluded with sparry calcite. Trace intercrystalline and pinpoint – vuggy (up to 2cm) porosity	F
.20				X			X										X							X			
.40	Tan/lt. brown	⋓	–	X			X										X							X			
.60		⋓	–	X			X										X		X		X			X			
.80				X			X										X		X					X			
19.00	↓	◎		X			X										X		X					X			
.20	↑ Tan		–	X			X										X							X			
.40				X			X										X							X			← Gradational lithofacies change. Lower Winnipegosis Member
.60	↓		– S	X			X										X							X			
.80	Tan/lt. brown		– S	X			X										X							X			– Nodules dissipate, skeletal wackestone grades to mudstone.	B
20.00	↓		– S	X			X										X							X			

Logged by: Date: Core Interval: 4.40 - 43.78 m

Well Location: 03-35-024-10W1 (M-03-90) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments ⑤	Lithofacies
.20	Tan/lt. brown		⊙ ∅ — ⌇	X			X	X									X							X				
.40			⊙ — ⌇	X			X	X									X				X			X				
.60			⊙ — ⌇	X			X	X									X							X				
.80			⊙ — ⌇	X			X	X									X							X				
21.00			⊙ ∅ — ⌇	X			X	X									X							X			- Mottled to nodular, dolomitic skeletal wackestone.	
.20			⊙ ∅ — ⌇	X			X	X									X							X			Very homogeneous - as below.	
.40			⊙ ∅ — ⌇	X				X									X							X				
.60			⊙ ∅ — ⌇	X				X									X							X				
.80			⊙ ∅ — ⌇	X				X									X							X				
22.00			⊙ ∅ — ⌇	X				X									X							X				
.20			⊙ ∅ — ⌇	X				X									X							X				
.40	lt./dk. brown		⊙ ∅ — ⌇	X				X									X							X				B
.60			⊙ ∅ — ⌇	X				X									X							X				
.80			⊙ ∅ — ⌇	X				X									X							X				
23.00			⊙ ∅ — ⌇	X				X									X							X				
.20			⊙ ∅ — ⌇	X				X									X							X				
.40			⊙ ∅ — ⌇	X				X									X							X				
.60			⊙ ∅ — ⌇	X				X									X							X				
.80			⊙ ∅ — ⌇	X				X									X							X				
24.00			⊙ ∅ — ⌇	X				X									X							X				
.20			⊙ ∅ — ⌇	X				X									X							X				
.40			⊙ ∅ — ⌇	X				X									X							X				
.60			⊙ ∅ — ⌇	X				X									X							X				
.80			⊙ ∅ — ⌇	X				X									X							X				
25.00	↓		⊙ ∅ — ⌇	X				X									X							X				

Logged by: Date: Core Interval: 4.40 - 43.78 m

Well Location: 03-35-024-10W1 (M-03-90) Correction Factor (Log to Core Conversion):

(6)

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol: Low	Moderate	High	Comments	Lithofacies
.20				X				X									X							X			- Mottled to nodular, dolomitic skeletal wackestone.	
.40				X				X									X							X			Nodules - dark brown, micritic, sharp boundaries.	
.60				X				X									X							X			Internodular matrix - argillaceous/bituminous.	
.80				X				X									X							X			Bioclasts - mostly crinoids, minor brachiopods and	
26.00				X				X									X							X			unidentifiable skeletal fragments. Bioclasts	
.20	lt./dk. brown			X				X									X							X			occur in both nodules and matrix. Some nodules	
.40				X				X									X							X			fractured and occluded with sparry calcite.	
.60				X				X									X							X			Poor intercrystalline porosity in internodular	
.80				X				X									X							X			matrix.	
27.00				X				X																X				
.20				X				X																X				
.40				X				X									X							X			← Increase in argillaceous/bituminous content upwards.	B
.60				X				X									X							X				
.80	tan/lt. brown			X				X									X							X				
28.00				X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X																X			← Decrease in argillaceous/bituminous content upwards.	
.80				X				X																X				
29.00	light brown			X				X																X				
.20				X				X																X				
.40				X				X																X				
.60				X				X																X				
.80				X				X																X				
30.00				X				X																X				

Logged by: Date:

Core Interval: 4.40 - 43.78 m

Well Location: 03-35-024-10W1 (M-03-90)

Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
.20	↑			X				X									X							X			- Mottled to nodular skeletal wackestone. Crinoids gradually become dominant bioclasts. Argillaceous/ bituminous content increases ~31 m resulting in less contrast between nodules and internodular matrix. Rare vugs occluded with sparry calcite. Fair-poor intercrystalline porosity in internodular matrix.	
.40	lt brown			X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
31.00				X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
32.00				X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				B
.60	Tan/lt. brown			X				X									X							X				
.80				X				X									X							X				
33.00				X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
34.00				X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
35.00	↓			X				X									X							X				

Logged by: Date:

Core Interval: 4.40 - 43.78 m

Well Location: 03-35-024-10W1 (M-03-90)

Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol: Low	Moderate	High	Comments	Lithofacies
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X			- Mottled-nodular, dolomitic skeletal wackestone. Very homogeneous (as below). Stylolites very common.	
36.00				X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
37.00	Tan/H. brown			X				X									X							X				
.20				X				X									X							X				B
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
38.00				X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
39.00				X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X	X								X							X			← Thin, irregular packstone lamina (0.5-1.5 cm), sharp contacts.	
.80				X				X									X							X				
40.00				X				X									X							X				

Logged by: Date: Core Interval: 4.40 - 43.78 m

Well Location: 03-35-024-10W1 (M-03-90) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20				X				X									X							X				
.40				X				X									X							X			- Mottled to nodular, dolomitic skeletal wackestone.	
.60				X				X									X							X			Nodules - brown, dense micritic. Internodular matrix -	
.80				X				X									X							X			tan, very fine crystalline. Bioclasts - brachiopods	
41.00				X				X									X							X			and crinoids. Scattered wispy microstylolites.	
.20				X				X									X							X			Poor to fair intercrystalline porosity in internodular	
.40	Tan/lt. brown			X				X									X							X			matrix.	B
.60				X				X																X				
.80				X				X																X				
42.00				X				X																X				
.20				X				X																X				
.40				X				X																X				
.60				X				X											X					X			← Rare vugs (3-4mm diam.)	
.80				X			X	X																X				
43.00				X			X	X																X				
.20				X	X		X																			X	← Gradational lithofacies change.	
.40					X		X																			X	- Dolomudstone - faintly mottled, sparse rounded	A
.60	Tan				X		X																			X	intraclasts (1-3mm diameter). Tight.	
.80	grey				X		X																			X		
44.00																											Ashern Formation ↓	
.20																												
.40																												
.60																												
.80																												
45.00																												

Logged by: Date: Core Interval: 2.60-42.40 m

Well Location: 05-35-024-10W1 (M-02-87) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
0.00																												
.20																												
.40																												
.60																												
.80																												
1.00																												
.20																												
.40																												
.60																												
.80																												
2.00																												
.20																												
.40																												
.60																												
.80	Tan/			X					X								X	X	X						X			H
3.00	Orange			X					X								X	X	X						X		~as below	

Upper Winnipegosis Member

B70

Logged by: Date: Core Interval: 2.60-42.40 m

Well Location: 05-35-024-10W1 (M-02-87) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments ②	Lithofacies
.20				X					X	X							X		X							X		
.40				X					X	X							X		X							X		
.60	Tan/ orange			X					X	X							X		X							X	- Dolopackstone-dolograinstone - pervasively	
.80				X					X	X							X		X							X	dolomitized, looks peloidal. Thin to thickly bedded,	
4.00				X					X	X							X		X							X	contacts sharp to gradational and horizontal to	
.20				X					X	X							X		X							X	irregular. Dolopackstone dominant lithology. Excellent	
.40	Tan/lt. brown			X					X	X							X		X							X	intercrystalline porosity throughout, scattered	
.60				X					X	X							X		X							X	pinpoint porosity - abundant in dolograinstone beds. Minor	
.80				X					X	X							X		X							X	small vuggy porosity (up to 2mm). Weathered from	
5.00				X					X	X							X		X							X	3.80m upwards - orange staining.	
.20				X					X	X							X		X							X		
.40				X					X	X							X		X							X		H
.60	Tan			X					X	X							X									X		
.80				X					X	X							X									X		
6.00				X					X	X							X		X							X		
.20				X					X	X							X		X							X		
.40				X					X	X							X									X		
.60				X					X	X							X		X							X		
.80	Tan/lt. brown			X					X	X							X		X							X		
7.00				X					X	X							X									X		
.20				X					X	X							X									X		
.40				X					X	X							X									X		
.60				X					X	X							X									X		
.80				X					X	X							X		X							X		
8.00				X					X	X							X		X							X		

B71

Logged by: Date:

Core Interval: 2.60 - 42.40 m

Well Location: 05-35-024-10W1 (M-02-87)

Correction Factor (Log to Core Conversion):

③

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20				X					X								X		X							X	- Dolopackstone - as below	
.40				X					X								X									X		
.60			S	X					X								X		X							X		H
.80				X					X								X		X							X		
9.00				X					X								X									X		
.20				X			X										X		X							X		
.40				X			X										X							X				
.60				X			X										X							X				
.80			W	X			X										X							X				F
10.00			W	X			X					X					X							X				
.20	Tan		W ⊙ S	X			X										X			X				X				
.40			W S	X			X					X					X							X				
.60			W	X			X										X							X				
.80			W	X			X										X							X				
11.00			W		X				X								X								X		- Dolopackstone - pervasively ddomitized, looks peleidal.	
.20			S		X				X								X								X		Thin-medium bedded/mottled. Core very fragmented.	
.40			S		X				X								X								X		Good intercrystalline porosity, scattered pinpoint	
.60			S		X				X								X								X		porosity, rare vugs (up to 1cm).	
.80			S		X				X								X								X			H
12.00			S		X				X								X								X			
.20					X				X								X								X			
.40					X				X								X		X						X			
.60					X				X								X		X						X			
.80					X				X								X		X						X			
13.00					X				X								X		X							X		

B72

Logged by: Date: Core Interval: 2.60 - 42.40 m

Well Location: 05-35-024-10W1 (M-02-87) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol: Low	Moderate	High	Comments	Lithofacies
.20	Tan/lt. brown			X					X								X									X	– Dolopackstone - pervasively dolomitized, looks peloidal, massive to mottled. Good intercrystalline porosity.	H
.40				X					X								X									X		
.60				X					X								X									X		
.80			⊙	X					X								X									X		
14.00				X					X								X									X		
.20	Tan		Ψ	X			X										X								X		– Mudstone - massive, locally faintly mottled and laminated. Sparsely fossiliferous, bioclasts mostly brachiopods, rare crinoids and thamnoporid corals. Rare vugs (1-2cm) occluded with sparry calcite. Poor intercrystalline porosity.	F
.40			⊙	X			X										X							X			
.60			Ψ⊙ B	X			X										X							X			
.80			Ψ	X			X										X							X			
15.00			Ψ	X			X										X							X			
.20				X			X										X							X			
.40			⊙ S	X			X										X							X			
.60	Tan/lt. brown		S	X			X										X							X			
.80			S	X			X										X							X			
16.00				X			X										X							X			
.20	Tan			X			X										X							X			
.40			Ψ	X			X										X							X			
.60			Ψ	X			X										X		X					X			
.80	Tan/lt. brown			X			X										X							X			
17.00				X			X										X							X			
.20	black/ Tan		– – – – –	X			X										X		X					X			– Bituminous laminite - thinly interbedded non-bituminous mudstone and laminated bituminous mudstone.	D
.40			– – – – –	X			X										X				X			X			
.60			– – – – –	X			X										X		X					X			
.80	Tan/lt. brown		Ψ	X			X		X			X					X	X	X					X			– Mudstone - locally mottled / faintly laminated. Rare thin packstone and skeletal floatstone interbeds.	F
18.00			= Ψ △	X			X										X							X			

B73

Logged by: Date:

Core Interval: 2.60 - 42.40 m

Well Location: 05-35-024-10W1 (M-02-87)

Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol: Low	Moderate	High	Comments	Lithofacies
.20	Tan/lt. brown			X			X										X		X					X				F
.40				X			X		X															X			- Bituminous laminite - thinly interbedded non-bituminous mudstone/packstone and bituminous laminated mudstone/	D
.60	black/ Tan			X			X		X															X				
.80				X			X										X		X							X	packstone. Bituminous beds contain white, lenticular	
19.00	Tan/lt. brown		⊙	X			X										X		X					X			bioclasts (cricoconarids).	B
.20			⊙	X			X	X									X		X					X			- Mottled skeletal wackestone (as below).	
.40			⊙	X			X	X									X							X			Lower Winnipegosis Member (below 18.60m).	
.60	black/ Tan			X			X	X									X							X			- Bituminous laminite - thinly interbedded non-bituminous	D
.80			⊙	X			X	X									X							X			mudstone and bituminous laminated mudstone	
20.00			⊙	X			X	X									X	X	X					X				
.20			⊙	X			X	X									X	X	X					X				
.40			⊙	X			X	X									X	X	X					X			- Skeletal wackestone - mottled to nodular, generally	
.60			⊙	X			X	X									X	X	X					X			as below. Bioclasts - mostly crinoids and minor small	
.80	Tan/lt. brown		⊙	X			X	X									X	X	X					X			unidentifiable fragments. Bituminous/argillaceous	
21.00			⊙	X			X	X									X	X	X					X			content decreases upwards. Scattered pinpoint and	
.20			⊙	X			X	X										X	X					X			moldic/vuggy porosity (up to 1 cm) 3-5%.	B
.40			⊙	X			X	X										X	X					X				
.60			⊙	X			X	X											X					X				
.80			⊙	X			X	X												X				X				
22.00			⊙	X			X	X											X					X				
.20			⊙	X			X	X												X				X				
.40	Tan/dk. brown		⊙	X			X	X											X	X				X				
.60			⊙	X			X	X												X				X				
.80			⊙	X			X	X												X				X				
23.00			⊙	X			X	X												X				X				

Logged by: Date:

Core Interval: 2.60 - 42.40 m

Well Location: 05-35-024-10W1 (M-02-87)

Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20	dark brown		⊙ Ø = S	X				X																X				
.40	↓		⊙ Ø = S	X				X																X				
.60	tan/lt. brown ↑		⊙ Ø = S	X				X																X			- Dolomitic skeletal wackestone - mottled to nodular. Bioclasts - dominantly crinoids, rare brachiopods and rugose corals. Bituminous/argillaceous content generally increases upwards and contrast between nodules and internodular matrix decreases. No porosity where argillaceous/bituminous. Rare halite hoppers (1-2 cm) replaced with sparry calcite.	
.80			⊙ Ø S	X				X																X				
24.00	↓		⊙ Ø Ø S	X				X																X				
.20	dark brown ↑		⊙ Ø =	X				X																X				
.40	↓		⊙ =	X				X																X				
.60	tan/ brown ↑		⊙ Ø = S	X				X																X				
.80			⊙ =	X				X																X				
25.00			⊙ =	X				X																X				
.20			⊙ = S	X				X																X				B
.40	dark brown		⊙ =	X				X																X				
.60			⊙ =	X				X																X				
.80			⊙ Ø =	X				X																X				
26.00			⊙	X				X																X				
.20			⊙ Ø = S	X				X																X				
.40			⊙ Ø = ≡	X				X	X															X			← Packstone bed (4 cm), intraclastic with rare crinoids.	
.60	tan/dk. brown ↓		⊙ Ø S ~	X				X									X							X			↖ Tabular stromatoporoid (1 cm thick).	
.80	↑		⊙ Ø S ~	X				X									X							X				
27.00			⊙ Ø S ~	X				X		X	X						X							X			← Grainstone - rudstone bed (12 cm), intraclastic/skeletal.	
.20	tan/lt. brown		⊙ Ø S ~	X				X									X							X				
.40			⊙ Ø S ~	X				X									X							X				
.60			⊙ Ø S ~	X				X									X							X				
.80			⊙ Ø S ~	X				X									X							X				
28.00	↓		⊙ S	X				X									X							X				

Logged by: Date: Core Interval: 2.60 - 42.40 m

Well Location: 05-35-024-10W1 (M-02-87) Correction Factor (Log to Core Conversion):

(7)

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20				X				X									X							X				
.40				X				X									X				X			X				
.60				X				X									X				X			X				
.80				X				X	X	X	X						X							X			← Packstone-rudstone bed, 18 cm thick; skeletal/intraclastic, sharp lower contact, bounded at top by stylolite.	
29.00				X				X									X							X				
.20				X				X									X				X			X				
.40				X				X									X				X			X			- Dolomitic skeletal wackestone - mottled to nodular. As below but bioclasts exclusively crinoids. Scattered sub-vertical fractures lined with sparry calcite and/or red clay. Minor intercrystalline porosity.	
.60				X				X									X				X			X				
.80				X				X									X				X			X				
30.00				X				X									X				X			X				
.20	Tan/lt brown			X				X									X							X				
.40				X				X									X				X			X				B
.60				X				X									X				X			X				
.80				X				X									X				X			X				
31.00				X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
32.00				X				X									X							X				
.20				X				X		X	X						X							X			← Rudstone bed - 4 cm thick, skeletal/intraclastic, sharp contacts.	
.40				X				X									X				X			X				
.60				X				X									X				X			X				
.80				X				X									X							X				
33.00	↓			X				X									X				X			X				

Logged by: Date: Core Interval: 2.60 - 42.40 m

Well Location: 05-35-024-10W1 (M-02-87) Correction Factor (Log to Core Conversion):

(B)

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X			- Dolomitic skeletal wackestone- mottled to nodular. Nodules: brown, micritic, rarely fractured- fractures occluded with sparry calcite. Internodular matrix- tan, fine crystalline. Bioclasts- mostly crinoids (up to 3mm), minor brachiopods (up to 6mm), smaller bioclasts not identifiable. Rare vugs occluded with sparry calcite, some are angular- likely replaced halite hoppers. Rare fractures cut both nodules and matrix and occluded with anhydrite. Minor intercrystalline porosity.	
.80				X				X									X							X				
34.00				X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
35.00				X				X									X							X				
.20	Tan/lt. brown			X				X									X							X				B
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
36.00				X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
37.00				X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
38.00				X				X									X							X				

Logged by: Date:

Core interval: 2.60 – 42.40 m

Well Location: 05-35-024-10W1 (M-02-87)

Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	OWB Rumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20				X				X									X							X			– Dolomitic skeletal wackestone – mottled to nodular. Nodules – brown, micritic, sharp to gradational boundaries. Internodular matrix – tan, very fine crystalline. Bioclasts – mostly brachiopods – present in nodules and matrix. Minor intercrystalline porosity.	
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
39.00	Tan/lt. brown			X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
40.00				X				X									X							X				B
.20				X				X									X							X				
.40				X				X									X							X			– Dolomitic skeletal wackestone, mottled. Bioclasts – brachiopods and rare crinoids, others unidentifiable. Rare vugs occluded with sparry calcite. Minor intercrystalline porosity.	
.60				X				X									X							X				
.80				X				X									X							X				
41.00	Tan			X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
42.00				X				X									X							X			← Gradational lithofacies contact.	
.20	white/ Tan				X		X																			X	– Dolomudstone – massive, patterned bottom 8cm.	A
.40					X		X																			X	Sparse maroon dolomudstone intraclasts (<1mm – 2cm). Tight.	
.60																												
.80																											Ashern Formation ↓	
43.00																												

Logged by: Date: Core Interval: 1.60-45.00 m

Well Location: 06-35-024-10W1(M-02-90) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20																												
.40																												
.60																											Upper Winnipegosis Member	
.80	↑			X									X				X			X						X	- Dolobindstone - stromatolitic, thinly laminated, sharp	O
2.00				X									X				X			X						X	lower contact. Pervasively dolomitized. Abundant	
.20				X					X								X		X							X	intercrystalline and fenestral porosity.	
.40				X					X								X		X							X		
.60				X					X								X		X							X		
.80				X					X								X		X							X		
3.00				X					X								X		X							X	- Dolopackstone - dolograinstone, thin to medium	
.20				X					X								X		X							X	crudely bedded/mottled. Generally as below with	
.40				X					X								X		X							X	scattered, subrounded intraclasts (0.5-1.5cm diam.)	
.60	Tan/			X					X								X		X							X	of same lithology locally.	
.80	Yellow		S	X					X								X		X							X		H
4.00			S	X					X								X		X							X		
.20			S	X					X								X		X							X		
.40			S	X					X								X		X							X		
.60			S	X					X								X		X							X		
.80			S	X					X								X		X							X		
5.00			S	X					X								X		X							X		
.20			S	X					X								X		X							X		
.40			S	X					X								X		X							X		
.60			S	X					X								X		X							X		
.80			S	X					X								X		X							X		
6.00	↓		S	X					X								X		X							X		

Logged by: Date: Core Interval: 1.60-45.00 m

Well Location: 06-35-024-10W1(M-02-90) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	② Lithofacies
.20			S	X					X	X							X		X							X		
.40			S	X					X								X									X		
.60			S	X					X								X									X		
.80			S	X					X	X							X		X							X		
7.00	tan/ yellow		S	X					X	X							X		X							X	- Dolopackstone - dolograinstone - thin-medium crude bedding. Very homogeneous - as below.	
.20			S	X					X								X									X		
.40			S	X					X	X							X		X							X		
.60			S	X					X								X									X		
.80			S	X					X								X									X		
8.00			S	X					X								X									X		
.20			S	X					X	X							X		X							X		H
.40			S	X					X								X									X		
.60			S	X					X								X									X		
.80			S	X					X	X							X		X							X		
9.00			S	X					X	X							X		X							X		
.20			S	X					X	X							X		X							X		
.40	tan/lt. brown		S	X					X	X							X		X							X		
.60			S	X					X	X							X		X							X		
.80			S	X					X	X							X		X							X		
10.00			S	X					X	X							X		X							X		
.20				X					X	X							X		X							X		
.40			S	X					X	X							X		X							X		
.60				X					X	X							X		X							X		
.80			S	X					X	X							X		X							X		
11.00			S	X					X	X							X		X							X		

B80

Logged by: Date: Core Interval: 1.60-45.00 m

Well Location: 06-35-024-10W1(M-02-90) Correction Factor (Log to Core Conversion):

③

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol: Low	% Dol: Moderate	% Dol: High	Comments	Lithofacies
.20	tan		∿	X	X				X	X							X		X							X		
.40	↑		∿	X	X				X	X							X		X							X		
.60	tan/lt. grey/lt. brown		∿	X	X				X	X							X		X							X	- Dolopackstone-dolograinstone, pervasively dolomitized-looks peloidal. Thin-medium crude bedding/mottled. Dolopackstone dominant lithology. Rare nodules (1-2cm diam.). Good intercrystalline porosity throughout, scattered pinpoint porosity in dolopackstone, abundant pinpoint porosity in dolograinstone. Rare vugs (up to 2cm).	
.80	↓		∿	X	X				X	X							X		X							X		
12.00			∿	X	X				X								X		X							X		
.20			∿	X	X				X	X							X		X							X		
.40			∿	X	X				X								X									X		
.60			∿	X	X				X	X							X		X							X		
.80			∿	X	X				X								X									X		
13.00			∿	X	X				X								X									X		
.20			∿	X	X				X								X		X							X		
.40			∿	X	X				X								X									X		
.60			∿	X	X				X								X									X		
.80			∿	X	X				X								X									X		
14.00	tan		∿	X	X				X								X		X							X		
.20				X	X				X								X		X							X		
.40			⌀	X	X				X								X									X		
.60				X	X				X								X									X		
.80				X	X				X								X		X							X		
15.00				X	X				X								X									X		
.20				X	X				X								X		X							X		
.40				X	X				X								X		X							X		
.60				X	X				X								X		X							X		
.80			⌀	X	X				X								X		X							X		
16.00	↓			X	X				X								X		X							X		

H

Logged by: Date: Core Interval: 1.60-45.00 m

Well Location: 06-35-024-10W1(M-02-90) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Lithology	Grains, Structures	Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Anhydrite	Oil/Bitumen	Low	Moderate	High	Comments	Lithofacies
.20				X					X								X		X						X		- Dolopackstone - pervasively dolomitized, looks peloidal. Thickly bedded/mottled. Very good intercrystalline porosity, scattered pinpoint porosity.	
.40				X					X								X		X						X			
.60	tan/lt. brown			X					X								X		X						X			
.80				X					X								X								X			H
17.00			S	X					X								X								X			
.20				X					X								X								X			
.40				X					X								X								X			
.60			W	X					X								X		X						X			
.80				X							X						X		X						X		- Intraclastic dolofloatstone - subrounded to rounded clasts (0.5-1.5 cm diam.). Dolopackstone matrix.	I
18.00				X							X						X		X						X			
.20	tan			X					X								X		X						X		- Dolopackstone (as above).	H
.40				X		X											X								X		- Mudstone - dolomudstone. Faintly laminated/mottled. Sparsely fossiliferous, bioclasts - brachiopods. Rare cylindrical moldic porosity. Poor-fair intercrystalline porosity (better in dolostone).	F
.60				X		X											X								X			
.80				X		X											X								X			
19.00				X		X											X								X			
.20			—	X		X																		X				
.40			— W	X		X											X								X			
.60			Ø	X		X											X		X						X			
.80			—	X		X											X								X		← Gradational lithofacies change.	
20.00	tan/lt. brown		Ø W	X		X		X									X								X		Lower Winnipegosis Member	
.20			S Ø	X		X		X									X								X		- Mottled-nodular dolomitic skeletal wackestone (as below).	B
.40			Ø W	X		X		X									X		X						X		- Bituminous laminite - thinly interbedded non-bituminous mudstone and bituminous, laminated mudstone.	D
.60			—	X		X											X								X			
.80			— Ø W	X		X											X								X		- Mottled-nodular dolomitic skeletal wackestone (as below).	B
21.00			S W	X		X		X									X								X			

B82

Logged by: Date: Core Interval: 1.60-45.00 m

Well Location: 06-35-024-10W1(M-02-90) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
.20				X			X										X							X				
.40				X			X	X									X							X				
.60				X			X										X							X				
.80				X			X										X							X			- Mottled-nodular dolomitic skeletal wackestone.	
22.00				X			X										X							X			Nodules-micritic, brown. Internodular matrix-tan,	
.20				X			X										X							X			fine crystalline. Bioclasts- dominantly crinoids, rare	
.40				X			X	X									X							X			brachiopods, unidentifiable skeletal fragments throughout.	
.60				X			X	X									X							X			Nodules decrease in abundance above 22.30 m. Some	
.80				X				X									X							X			nodules fractured-occluded with sparry calcite. Rare	
23.00	Tan/med. brown			X				X									X							X			vugs occluded with sparry calcite (~1cm). Rare	
.20				X				X									X							X			halite hoppers replaced with sparry calcite. Poor	
.40				X				X									X							X			intercrystalline porosity in internodular matrix.	B
.60				X				X									X							X				
.80				X				X									X							X				
24.00				X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
25.00				X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X			← Bituminous/argillaceous content gradually decreases	
.60				X				X									X		X					X			upwards.	
.80	lt.-dk. brown			X				X									X		X					X			Horizontal fracture occluded with sparry calcite	
26.00				X				X									X							X			and black sulphides with Fe staining.	

B83

Logged by: Date: Core Interval: 1.60 - 45.00 m

Well Location: 06-35-024-10W1 (M-02-90) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20				X				X									X							X				
.40				X				X									X							X			– Mottled-nodular dolomitic skeletal wackestone, generally as below. Nodules - micritic, dark brown. Internodular matrix - light brown. Rare irregular vugs (~1cm) occluded with sparry calcite. Rare halite hoppers replaced with sparry calcite. Poor intercrystalline porosity in internodular matrix. Trace scattered pinpoint porosity.	
.60				X				X									X							X				
.80				X				X									X							X				
27.00	lt.-dk. brown			X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
28.00				X				X									X							X				
.20				X				X									X							X			← Bituminous/argillaceous content increases upwards.	
.40				X				X									X		X					X				B
.60				X				X									X		X					X				
.80				X				X									X		X					X				
29.00	tan/med brown			X				X	X								X							X			← Thin intraclastic/skeletal bed, sharp irregular contacts.	
.20				X				X									X		X					X				
.40				X				X									X		X					X				
.60				X				X									X		X					X			← Bituminous/argillaceous content decreases upwards.	
.80				X				X									X							X				
30.00				X				X									X							X				
.20	lt.-med brown			X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
31.00				X				X									X							X				

B84

Logged by: Date: Core Interval: 1.60-45.00 m

Well Location: 06-35-024-10W1(M-02-90) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
32.00	lt./med.			X				X									X							X				
.20	brown			X				X	X	X	X						X							X			← Thin intraclastic packstone-rudstone bed, sharp contacts.	
.40				X				X									X							X				
.60				X				X									X							X			- Mottled-nodular dolomitic skeletal wackestone.	
.80				X				X									X							X			Generally as below but crinoids become dominant	
33.00				X				X									X							X			bioclasts and bituminous/argillaceous content	
.20				X				X									X							X			increases upwards (nodules and internodular	
.40				X				X									X							X			matrix become darker). Fair-poor intercrystalline	B
.60				X				X									X							X			porosity.	
.80				X				X									X							X				
34.00				X				X									X							X				
.20				X				X									X							X				
.40	Tan/med.			X				X									X							X				
.60	brown			X				X									X							X				
.80				X				X									X							X				
35.00				X				X	X	X							X							X			← Thin intraclastic/skeletal packstone bed, irregular	
.20				X				X									X							X			gradational contacts.	
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
36.00				X				X									X							X				

Logged by: Date: Core Interval: 1.60-45.00 m

Well Location: 06-35-024-10W1(M-02-90) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments
.20				X				X									X							X			
.40				X				X									X							X			
.60				X				X									X							X			Mottled to nodular skeletal wackestone. Bioclasts- crinoids and brachiopods, rarely intact, occur in both nodules and matrix. Abundant stylolites. Fair intercrystalline porosity in internodular matrix.
.80				X				X									X							X			
37.00				X				X									X							X			
.20				X				X									X							X			
.40				X				X									X							X			
.60				X				X									X							X			
.80				X				X									X							X			
38.00				X				X									X							X			
.20	Tan/			X				X									X							X			
.40	brown			X				X									X							X			
.60				X				X									X							X			
.80				X				X									X							X			
39.00				X				X									X							X			
.20				X				X									X							X			
.40				X				X									X							X			
.60				X				X									X							X			
.80				X				X									X							X			
40.00				X				X									X							X			← Stringocephalid (2.5cm).
.20				X				X									X							X			
.40				X				X									X							X			
.60				X				X									X							X			
.80				X				X									X							X			
41.00	↓			X				X									X							X			

Lithofacies: B

Logged by: Date:

Core Interval: 1.60-45.00 m

Well Location: 06-35-024-10W1(M-02-90)

Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Lithology	Grains, Structures	Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Anhydrite	Oil/Bitumen	Low	Moderate	High	Comments	Lithofacies
.20								X									X							X				
.40								X									X							X			- Mottled-nodular skeletal wackestone. Nodules- micritic and brown. Internodular matrix- tan, fine crystalline, dolomitic. Bioclasts- brachiopods and minor crinoids. Scattered wispy microstylolites. Fair intercrystalline porosity in matrix.	
.60								X									X							X				
.80								X									X							X				
42.00								X									X							X				
.20								X									X							X				
.40								X									X							X				
.60	tan/ brown							X									X							X				
.80								X									X							X			← Stringocephalid (>3cm diam.).	B
43.00								X									X							X				
.20								X									X							X				
.40								X									X							X				
.60								X									X							X				
.80								X									X							X				
44.00								X									X							X				
.20								X									X							X				
.40								X									X							X				
.60	X				X	X																				X	- Dolomudstone - thickly laminated to medium bedded.	
.80	grey/ purple		S		X	X																				X	Beds- massive to faintly laminated and patterned.	A
45.00	↓				X	X			X																	X	Intraclastic at base.	
.20																												
.40																											Ashern Formation ↓	
.60																												
.80																												
46.00																												

Logged by: Date: Core Interval: 3-42.18 m

Well Location: 12-35-024-10W1 (M-04-90) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	① Upper Winnipegosis Member Comments	Lithofacies
.20	↑			X									X				X			X						X	- Microbial bindstone (63cm thick), thinly laminated with crenulated contacts. Fenestral porosity 10-15%, very good intercrystalline porosity.	O
.40	lt. brown yellow/ tan			X									X				X			X						X		
.60				X									X				X			X						X		
.80				X						X			X				X		X	X						X		
4.00				X						X							X		X							X		H
.20				X						X							X		X							X		
.40			S	X						X							X		X							X	- Dolopackstone - original texture largely obscured (peloidal?). Thin to medium bedded, locally mottled. Rare thin dolograinstone interbeds. Horizontal to irregular bed contacts. Pinpoint porosity common throughout. Vugs scattered, rarely up to 1cm. Excellent intercrystalline porosity. Total porosity ~10-15%.	
.60			S	X						X							X		X							X		
.80			S	X						X							X		X							X		
5.00			S	X						X							X		X							X		
.20				X						X							X		X							X		
.40	tan / lt. brown			X						X							X		X							X		
.60				X						X							X		X							X		
.80			S	X						X							X		X							X		
6.00			S	X						X							X		X							X		
.20				X						X							X		X							X		
.40				X						X							X		X							X		
.60				X						X							X		X							X		
.80				X						X							X		X							X		
7.00				X						X							X		X							X		
.20			S	X						X							X		X							X		
.40			S	X						X							X		X							X		
.60			S	X						X							X		X							X		
.80				X						X							X		X							X		
8.00				X						X							X		X							X		

B88

Logged by: Date: Core Interval: 3-42.18 m

Well Location: 12-35-024-10W1 (M-04-90) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
.20	↑			X					X								X		X							X	- Dolopackstone - faintly mottled to thinly bedded. Original texture largely obscured (peloidal?). Very good intercrystalline porosity.	H
.40	tan / lt. brown		⊙	X					X								X		X							X		
.60				X					X								X		X							X		
.80	↓		⊙	X					X								X		X							X		
9.00				X			X										X							X			- Dolomitic mudstone - massive to mottled, very rare thin beds. Sparse bioclasts - brachiopods and very rare crinoids. Sparse vuggy porosity and poor intercrystalline porosity.	F
.20				X			X		X								X							X			
.40			⊎⊙	X			X										X		X					X			
.60			⊎	X			X										X		X					X			
.80	tan		⊎⊙	X			X										X		X					X			
10.00			⊎	X			X										X		X					X			
.20			⊎	X			X										X		X					X			
.40			⊎	X			X										X		X					X			
.60	↓		-	X	X		X		X	X							X		X							X	
.80			- ⌀		X				X								X		X							X		
11.00			-		X				X								X		X							X	- Dolopackstone - mottled, pervasively dolomitized - original texture largely obscured (peloidal?). No visible bioclasts. Sparse nodules and bituminous wisps. Scattered pinpoint porosity and good intercrystalline porosity.	H
.20			-		X				X								X		X							X	
.40	tan / lt. brown / lt. grey		-		X				X								X		X							X	
.60			-		X				X								X		X							X	
.80			-		X				X								X		X							X	
12.00	↓		- ⌀	X			X		X								X		X					X			
.20			⊎	X			X										X		X					X			- Dolomitic mudstone (as below).	F
.40			⊎	X			X										X		X					X			
.60	tan		⊎	X			X										X		X					X			
.80			⊎⊙	X			X										X		X					X			
13.00	↓		⊎	X			X										X		X					X			

Logged by: Date:

Well Location: 12-35-024-10W1 (M-04-90)

Core Interval: 3-42.18 m

Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Lithology	Grains, Structures	Comments	Lithofacies
.20				- Dolomitic mudstone, faintly mottled, sparsely fossiliferous, bioclasts (2mm-2cm) - brachiopods and crinoids. Vuggy/moldic porosity (1-3%). Vugs locally up to 2cm. Poor intercrystalline porosity.	F
.40					
.60					
.80					
14.00					
.20					
.40					
.60					
.80				- Dolomitic mudstone, mostly massive. Rare faint mottles and thin laminae. Rare bioclasts - brachiopods and crinoids. Trace vuggy porosity.	
15.00	tan				
.20					
.40					
.60					
.80					
16.00				- Thinly interbedded bituminous mudstone laminites and non-bituminous dolomitic mudstone to packstone beds (peloidal?). Variable vuggy porosity (1-5%)	D
.20					
.40					
.60					
.80				- Dolomitic mudstone, as above with thin packstone (peloidal?) interbeds. Scattered pinpoint/vuggy porosity.	F
17.00					
.20	dk. brown/tan			- Thin to med. interbedded bituminous mudstone laminites and non-bituminous mudstone. Bituminous laminites - fissile, bioclasts - scattered cricoconarids.	D
.40	black				
.60	black				
.80	↑			Lower Winnipegosis Member ↓	
18.00	brown/tan			- Dolomitic mudstone-wackestone (as below).	B

Graphic Log

Lithology: Limestone, Dolostone, Anhydrite, Mudstone, Wackestone, Packstone, Grainstone, Rudstone, Floatstone, Boundstone

Porosity: Interparticle, Intraparticle, Framework, Intercrystalline, Moldic, Vuggy, Fenestral, Fracture

Other: Anhydrite, Oil/Bitumen

% Dol.: Low, Moderate, High

Logged by: Date: Core Interval: 3-42.18m

Well Location: 12-35-024-10W1(M-04-90) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
.20				X			X	X										X	X					X			- Dolomitic skeletal wackestone-mudstone, mottled-nodular. Vuggy/moldic porosity ~10%, some vugs lined with sparry calcite.	B
.40	brown/ Tan			X			X	X										X	X					X				
.60				X			X	X														X	X	X				
.80	black/ brown			X			X	X														X	X	X			- Interbedded bituminous mudstone laminites (~1cm thick) and nodular skeletal wackestone-mudstone (4-8cm)	D
19.00	brown/ Tan			X			X	X										X						X				
.20				X			X	X									X		X					X				B
.40				X			X	X									X		X					X				
.60				X			X	X									X		X					X			- Dolomitic skeletal wackestone, mottled-nodular, generally as below but darker with less contrast between nodules and internodular matrix. Some nodules and bioclasts have a dark, sulphide? rim. Rare pinpoint and vuggy porosity (up to 1cm), poor intercrystalline porosity in internodular matrix.	
.80				X			X	X									X		X					X				
20.00				X			X	X									X		X					X				
.20				X			X	X									X		X					X				
.40				X			X	X									X		X					X				
.60				X			X	X									X		X					X				
.80				X			X	X									X		X					X				
21.00	tan/dk. brown			X			X	X									X		X					X				
.20				X			X	X									X		X					X				
.40				X			X	X									X		X					X				
.60				X			X	X									X		X					X				
.80				X			X	X									X		X					X				
22.00				X			X	X									X		X					X			← Tabular stromatoporoid (6mm thick)	
.20				X			X	X									X		X					X				
.40				X			X	X									X		X					X				
.60				X			X	X									X		X					X				
.80				X			X	X									X		X					X				
23.00				X			X	X									X		X					X			← Disseminated sulphides with Fe staining.	

Logged by: Date: Core Interval: 3-42.18m

Well Location: 12-35-024-10W1 (M-04-90) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20	↑		∅∅	X				X									X		X					X			- Dolomitic skeletal wackestone. Mottled-nodular (as below). Bioclast-crinoids. Variably bituminous/argillaceous internodular matrix. Scattered pinpoint/vuggy porosity (up to 2cm). Vugs lined/occluded with sparry calcite. Visible porosity 1-5%.	
.40			∅∅	X				X									X		X					X				
.60			∅∅	X				X									X		X					X				
.80	Tan/ dk. brown		∅∅	X				X									X		X					X				
24.00			∅	X				X									X		X					X				
.20			⊙∅S	X				X									X	X	X					X			↖ Tabular stromatoporoid.	
.40			⊙∅S	X				X									X	X	X					X				
.60			⊙∅S	X				X									X	X	X					X				
.80			⊙S∅	X				X									X	X	X					X				
25.00			⊙S=∅	X				X									X	X	X					X				B
.20			⊙SS=∅	X				X									X	X	X					X				
.40			⊙SS∅∅	X				X									X	X	X					X			← large, articulated crinoids.	
.60			⊙SS=∅	X				X									X	X	X					X				
.80	Tan/ brown		⊙SS∅	X				X									X	X	X					X			- Poor to fair intercrystalline porosity in internodular matrix.	
26.00			⊙SS=∅	X				X									X	X	X					X				
.20			⊙SS∅∅	X				X									X	X	X					X				
.40			⊙∅∅SS	X				X									X	X	X					X				
.60			⊙∅∅=SS	X				X									X	X	X					X				
.80			⊙∅∅=SS	X				X									X	X	X					X				
27.00			⊙∅∅SS	X				X									X	X	X					X				
.20			⊙∅∅SS	X				X									X	X	X					X				
.40			⊙∅∅SS	X				X									X	X	X					X				
.60			⊙∅∅SS	X				X									X	X	X					X				
.80			⊙∅∅SS	X				X									X	X	X					X				
28.00	↓		⊙∅∅SS	X				X									X	X	X					X				

Logged by: Date: Core Interval: 3-42.18m

Well Location: 12-35-024-10W1 (M-04-90) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20				X				X									X	X	X					X			- Dolomitic skeletal wackestone, mottled-nodular (as below). Scattered pinpoint, vuggy/moldic porosity (<1-5%). Calcite cement occludes some vugs.	
.40				X				X									X	X	X					X				
.60				X				X									X	X	X					X				
.80				X				X									X	X	X					X				
29.00	Tan/ brown			X				X									X	X	X					X			← Oncoid — 3cm diameter, brachiopod valve nucleous.	
.20				X				X									X		X					X				
.40				X				X									X		X					X				
.60				X				X									X		X					X				
.80				X				X									X	X	X					X				
30.00	Tan/ brown			X				X									X	X	X					X				
.20				X				X									X		X					X				
.40				X				X									X		X					X				
.60				X				X									X		X					X				
.80				X				X									X		X					X				
31.00	Tan/ brown			X				X									X		X					X				
.20				X						X							X		X					X			← Skeletal grainstone-rudstone interbed (9cm), sharp lower contact, grad. upper contact. Vuggy/moldic porosity 10-15%.	
.40				X				X									X		X					X				
.60				X				X									X		X					X				
.80				X				X									X	X	X					X				
32.00	Tan/ brown			X				X									X	X	X					X				
.20				X				X									X		X					X				
.40				X				X									X		X					X				
.60				X				X									X	X	X					X			- Vugs up to 15cm.	
.80				X				X									X		X					X				
33.00	Tan/ brown			X				X									X	X	X					X				

Lithofacies: B

Logged by: Date: Core Interval: 3-42.18m

Well Location: 12-35-024-10W1 (M-04-90) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Lithology: Dolostone	Lithology: Anhydrite	Lithology: Mudstone	Lithology: Wackestone	Lithology: Packstone	Lithology: Grainstone	Lithology: Rudstone	Lithology: Floatstone	Lithology: Boundstone	Porosity: Interparticle	Porosity: Intraparticle	Porosity: Framework	Porosity: Intercrystalline	Porosity: Moldic	Porosity: Vuggy	Porosity: Fenestral	Porosity: Fracture	Other: Anhydrite	Other: Oil/Bitumen	% Dol.: Low	% Dol.: Moderate	% Dol.: High	Comments	Lithofacies
.20				X				X									X		X					X			← Pinpoint porosity <1%	
.40				X				X									X		X					X				
.60				X				X									X							X				
.80				X				X									X							X				
34.00	Tan/ brown			X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X			- Dolomitic skeletal wackestone. Mottled to nodular (as below). Bioclasts (<1-3mm) - mostly crinoids,	
.60				X				X									X							X			rare brachs. Stylolites and argillaceous/bituminous	
.80				X				X									X							X			wisps scattered throughout. Poor to fair intercrystalline	
35.00	Tan/ brown			X				X									X							X			porosity in internodular matrix.	B
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
36.00	Tan/ brown			X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
37.00	Tan/ brown			X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
38.00	Tan/ brown			X				X									X							X				

Logged by: Date: Core Interval: 3-42.18 m

Well Location: 12-35-024-10W1 (M-04-90) Correction Factor (Log to Core Conversion):

(METERS) Log Depth	Colour	Graphic Log: Lithology	Graphic Log: Grains, Structures	Lithology: Limestone	Dolostone	Anhydrite	Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Porosity: Interparticle	Intraparticle	Framework	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	Other: Anhydrite	Oil/Bitumen	% Dol.: Low	Moderate	High	Comments	Lithofacies
.20				X				X									X							X			- Dolomitic skeletal wackestone. Bioclasts (<1-3mm) - brachs, crinoids, rare gastropods. Mottled - nodular. Nodules - brown, micritic, contain bioclasts, sharp - gradational boundaries, 1-6 cm diameter. Internodular matrix - tan, very fine sucrosic texture - dolomitic. Poor to fair inter-crystalline porosity in internodular matrix.	
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
39.00	tan/brown			X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				B
40.00				X				X									X							X				
.20				X				X									X							X			- Dolomitic skeletal wackestone. Bioclasts - brachiopods (up to 13mm diam.). Faintly mottled.	
.40				X				X									X							X				
.60				X				X									X							X				
.80				X				X									X							X				
41.00	tan			X				X									X							X				
.20				X				X									X							X				
.40				X				X									X							X				
.60				X				X									X							X				
.80	↓				X		X											X								X	- Calcareous dolomudstone, massive, sparse intraclasts up to 1.5 mm diam. Pinpoint porosity <1%.	A
42.00	lt. brown				X		X											X								X		
.20	↓				X		X	X	X									X								X	- Basal 8cm - intraclast dolopackstone, sharp lower contact, gradational upper contact. Intraclasts - dolomudstone, ~~tan/grey~~/purple, sub-angular to rounded.	
.40																												
.60																												
.80																												
43.00																											Ashern Formation	

APPENDIX C: CORE PHOTOGRAPHS

This appendix consists of a CD-ROM containing digital photographs in JPEG format of all cores logged for this study. Core numbers are denoted by the prefix "C" and box numbers are denoted by the prefix "B"; stratigraphic test cores only have box numbers as they do not have multiple cores. The depths of detailed core photographs are in original units except for stratigraphic test cores, which were all measured in metric units.

APPENDIX C: CORE PHOTOGRAPHS

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APPENDIX D: THIN SECTION DESCRIPTIONS

This appendix contains a spreadsheet of thin section descriptions for all the samples examined petrographically in this study. Core samples were assigned a sample number corresponding to the well license number for the well from which the core was retrieved and the order in which they were collected. The lone outcrop sample was assigned a sample label based on its geographic location. The sample descriptions are arranged by well location in ascending order followed by depth in descending order.

Sample #	Location	Depth	Lithofacies	Lithology								Allochems																		Matrix	Dolomite										
				Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Anhydrite	% Allochems	Peloids	Ostracods	Crinoids	Brachiopods	Styliolinids	Tentaculitids	Bryozoans	Corals	Gastropods	Calcareous Algae	Amphipora	Stromatoporoids	Calcispheres	Intraclasts	Unidentifiable	% Matrix	Non-Dolomitized	Partly Dolomitized	Fully Dolomitized	Aphanocrystalline	Very Fine	Fine	Medium	Coarse	Non-Planar	Planar-S	Planar-E
L2543#11	11-29-001-25W1	1520.21 m (4987.55')	N	*																												*									
L2543#10	11-29-001-25W1	1522.35 m (4994.6')	M							*		?																?			*	*		*	*		*		*	
L2543#9	11-29-001-25W1	1522.54 m (4995.2')	G			*						?		?	?	*			?												*	*		*	*		*	*	*	
L2543#8	11-29-001-25W1	1524.55 m (5001.8')	G																												*			*				*		
L2543#7	11-29-001-25W1	1525.62 m (5005.3')	G		?	?						?			*												*	?			*			*	*			*	*	
L2543#6	11-29-001-25W1	1528.34 m (5014.25')	G			*						?		?	?	?												?			*			*	*			*	*	
L2543#5	11-29-001-25W1	1530.02 m (5019.75')	G			*						?			?	?											*	?			*			*	*			*	*	
L2543#12	11-29-001-25W1	1530.63 m (5021.75')	G		?	?						?		?	?	?											*	?			*			*	*			*	*	
L2543#4	11-29-001-25W1	1531.64 m (5025.05')	B		*							10			?	?												85			*			*	*	*		*	*	
L2543#3	11-29-001-25W1	1531.85 m (5025.75')	B		?							?				?												?			*			*	*			*	*	
L2543#3	11-29-001-25W1	1531.85 m (5025.75')	D	*																											*	*								
L2543#2	11-29-001-25W1	1532.61 m (5028.25')	B		*							10			?	?											*	85			*			*	*		*		*	
L2543#1	11-29-001-25W1	1532.98 m (5029.45')	B	*								3			*												*	93			*			*	*		*	*	*	
L184#1	09-13-001-26W1	1545.45 m (5070.5')	K			?						?																?			*		*		*		*	*		
L4115#4	10-09-001-28W1	1729.90 m (5675.5')	N	*		*																									*			*	*			*	*	
L4115#2	10-09-001-28W1	1740.30 m (5709.6')	M					*				?	?															?			*	*		*	*			*	*	
L4115#1	10-09-001-28W1	1742.55 m (5717')	M					*				?	?															?			*	*		*	*	*	*	*	*	
L2610#2	09-06-002-26W1	1531.8 m (5025.6')	N	?		?						?																?			*			*	*			*	*	
L609#1	16-33-004-13W1	681.12 m (2234.63')	C	*																											*							*	*	
L1876#11	05-03-004-25W1	1353.01 m (4439.01')	K			*	*					?																?			*	*		*	*	*		*	*	
L1876#10	05-03-004-25W1	1354.14 m (4442.71')	K				*					60											30				70	0			*	*		*	*			*	*	
L320#12	05-13-005-22W1	1151.12 m (3776.6')	H	*		*						?																?			*			*	*			*	*	
L320#9	05-13-005-22W1	1153.76 m (3785.3')	H			?						?																?			*			*	*			*	*	
L320#9	05-13-005-22W1	1153.76 m (3785.3')	D	*																											*	*		*						
L320#7	05-13-005-22W1	1154.83 m (3788.8')	I						*			?														?		?			*	*		*	*		*		*	
L320#4	05-13-005-22W1	1158.18 m (3799.8')	H			?						?																?			*			*	*			*	*	
L2696#7	08-13-005-29W1	1521.57 m (4992')	L						*			10												100							*	*		*	*			*	*	
L2986#12	04-12-007-25W1	1198.52 m (3932.2')	E	*																											*		*	*				*		

D2

Sample # (Cont.)	Structures						Accessories												Porosity								Comments
	Laminated	Bedding	Nodular Texture	Boudinage	Stylolites	Microstylolites	Opaque Minerals	Hematite	Sphalerite	Quartz Silt	Feldspar Silt	Quartz Cement	Chalcedony	Anhydrite	Halite	Organic Matter	Argillaceous Material	% Porosity	Interparticle	Intraskeletal	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	
L2543#11	*					*	*							*				3			*		*		*	Thinly laminated mudstone with undulating contacts. Microstylolites common, rare anhydrite cement.
L2543#10					*	*	*							*				3			*		*		*	Highly dolomitized and stylolitized, no original texture remaining.
L2543#9														*		*		15			*	*	*		*	Skeletal packstone - most allochems not identifiable.
L2543#8							*							*		*		5			*				*	No original texture remaining.
L2543#7			*				*							*		*		5			*	*			*	Allochems unidentifiable. Nodular with septarian structure. Matrix slightly bituminous. Rare opaques and anhydrite cement.
L2543#6			*			*	*							*		*		10			*	*	*			Allochems unidentifiable. Nodular with septarian structure. Microstylolites common throughout. Rare anhydrite cement.
L2543#5							*							*		*		7			*	*	*			Original texture largely destroyed, appears to be skeletal packstone.
L2543#12														*		*		2			*	*	*		*	Wackestone/packstone? Allochems unidentifiable. Trace bituminous content, rare anhydrite cement.
L2543#4			*				*									*		5			*	*	*		*	Nodules contain coarser dolomite and more porosity than the matrix. Matrix variably bituminous, disseminated and in microstylolites, some with horsetails. Fractures partly occluded byplanar-e dolomite - cement?
L2543#3							*									*		7			*	*	*		*	Allochems not identifiable. Variable disseminated organic matter. Scattered clusters of opaques.
L2543#3		*				*										*										Bituminous laminite, 1 cm thick. Organic matter occurs as an anastomosing network of microstylolites. Large burrow through laminite.
L2543#2						*	*							*		*		5			*		*		*	Original texture destroyed, allochems unidentifiable. Variably bituminous, disseminated and in microstylolites, horsetails common. Fractured - fractures accentuated by coarser dolomite and increased bituminous content. Blocky calcite and anhydrite cement.
L2543#1			*			*								*		*		5			*	*	*		*	Sparsely fossiliferous mudstone, completely dolomitized, most allochems not identifiable. Variably bituminous, microstylolites drape nodules. Anhydrite cement common.
L184#1						*	*							*				4			*		*			No original texture remaining - likely packstone.
L4115#4	*					*								*				8			*					Interlaminated mudstone and peloidal packstone (based on porosity pattern). Laminae contacts microstylolitized, some laminae bituminous. Minor anhydrite cement.
L4115#2														*		*		15			*		*			Rudstone based on core, microtexture destroyed. Trace scattered organic matter, minor anhydrite cement.
L4115#1						*								*				15			*	?	*			Rudstone based on core, microtexture destroyed. Microstylolites and anhydrite cement common.
L2610#2						*								*				4			*		*			No original texture remaining, core show laminae. Likely mudstone/packstone.
L609#1					*	*	*	*						*	*		*	1			*		*		*	Patterned mudstone - scattered and patchy concentrations of translucent, purple, round hematite crystals (~2µm diam.) and opaque minerals. Two halite hoppers, one with anhydrite inclusions, the other with dolomite inclusions. Patchy argillaceous content.
L1876#11														*				3			*		*		*	Pervasively dolomitized, allochems not identifiable. Minor anhydrite cement.
L1876#10																		8		*	*		*			Many allochems not identifiable. Abundant anhydrite cement.
L320#12	*					*	*							*				4			*	*	*			Mudstone to packstone? - no allochems remaining. Faint laminae in mudstone. Anhydrite cement occluding some porosity. Scattered reddish-brown staining.
L320#9						*	*									*		5			*	?	*			No original texture remaining - likely packstone.
L320#9	*									*				*		*										Bituminous laminite, very organic rich, reddish-brown to black, rare anhydrite laths, common quartz silt.
L320#7																		10			*	?	*			Original texture largely destroyed, aphanocrystalline patches appear to be intraclasts.
L320#4																*		8			*	*	*			Allochems not identifiable. Abundant organic matter, disseminated & in microstylolites.
L2696#7						*	*							*				0								Original texture largely destroyed. Stromatoporoid fragments in probable packstone/grainstone matrix. All porosity occluded by anhydrite cement.
L2986#12	*					*				*				*		*	*	1					*			Thin to thickly interlaminated mudstone and argillaceous/bituminous mudstone. Mudstone laminae - very finely disseminated opaques and discontinuous scattered microstylolites common. Argillaceous mudstone - disseminated opaques common and layered in places. Scattered reddish brown bituminous matter. Rare quartz silt and anhydrite laths. Rare anhydrite cement.

Sample #	Location	Depth	Lithofacies	Lithology								Allochems																% Matrix	Dolomite									
				Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Anhydrite	% Allochems	Peloids	Ostracods	Crinoids	Brachiopods	Stylioliniids	Tentaculitids	Bryozoans	Corals	Gastropods	Calcareous Algae	Amphipora	Stromatoporoids	Calcispheres	Intraclasts	Unidentifiable		Non-Dolomitized	Partly Dolomitized	Fully Dolomitized	Aphanocrystalline	Very Fine	Fine	Medium	Coarse	Non-Planar	Planar-S	Planar-E
L2986#11	04-12-007-25W1	1198.60 m (3932.4')	D	*		*						?	?	?	?	?														*	*		*			*		*
L2986#7	04-12-007-25W1	1200.30 m (3937.9')	H			*						?																?			*		*	*	*		*	*
L2686#6	04-12-007-25W1	1201.30 m (3941.3')	H			*						?	*		?	?											*	?			*	*		*	*		*	*
L2986#5	04-12-007-25W1	1202.63 m (3945.6')	H			*						?	?		?												*				*	*		*	*		*	*
L2686#4	04-12-007-25W1	1203.15 m (3947.3')	G-H			*						?			?	?						?	?					?			*			*	*		*	*
L2686#3	04-12-007-25W1	1205.44 m (3954.9')	G									?		?	*	?											*	?			*	*		*	*	*	*	*
L2986#2	04-12-007-25W1	1209.48 m (3968.1')	G			*						?				?											*	?			*			*	*		*	*
L2986#1	04-12-007-25W1	1210.68 m (3972')	G			*						?		?	?	?											*	?			*	*		*	*			*
L91#9	02-21-007-28W1	1441.31 m (4728.7')	E	*							*																				*	*		*	*		*	*
L91#8	02-21-007-28W1	1442.41 m (4732.3')	E	*																											*	*		*	*		*	*
L91#5	02-21-007-28W1	1447.50 m (4749')	E	*																										*				*				*
L91#6	02-21-007-28W1	1445.57 m (4742.7')	E	*																										*				*	*			*
L91#7	02-21-007-28W1	1445.67 m (4743')	E	*																										*				*	*			*
L91#10	02-21-007-28W1	1447.71 m (4749.7')	D	*								1					100											97		*		*		*	*		*	*
L91#4	02-21-007-28W1	1447.80 m (4750.1')	B		*							15	28			2	60										10	75		*			*	*	*		*	*
L91#3	02-21-007-28W1	1448.17 m (4751.2')	B		*							14	10	5	5	56	1				*	1			<1		20	83		*				*	*			*	*
L91#2	02-21-007-28W1	1448.20 m (4751.3')	B		*							20	15		10	58			1		1				<1		15	78		*				*	*				*
L91#1	02-21-007-28W1	1448.26 m (4751.5')	B		*							25	40	5	5	34		1							<1		15	73		*				*				*	*
L44#3	03-01-008-18W1	783.95 m (2572')	D/H	*		?						?																?			*		*	*	*		*	*
L3083#21	14-13-009-28W1	1282 m (4206')	N	*		*						?	*															?			*	*		*	*			*	*
L3083#20	14-13-009-28W1	1282.60 m (4208')	N	*		*						?	*														*	?			*	*		*	*			*	*
L3083#19	14-13-009-28W1	1285.30 m (4216.9')	N	*		*						?	*														*	?			*	*		*	*			*	*

Sample # (Cont.)	Structures						Accessories												Porosity								Comments
	Laminated	Bedding	Nodular Texture	Boudinage	Stylolites	Microstylolites	Opaque Minerals	Hematite	Sphalerite	Quartz Silt	Feldspar Silt	Quartz Cement	Chalcedony	Anhydrite	Halite	Organic Matter	Argillaceous Material	% Porosity	Interparticle	Intraskeletal	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	
L2986#11	*	*					*			*				*		*		5			*	*	*		*	Thinly interlaminated to very thinly interbedded packstone and bituminous mudstone, contacts irregular/undulatory. Original packstone texture largely destroyed - appears to be dominantly peloidal. Discontinuous microstylolites and opaques common in packstone. Minor anhydrite cement in fractures. Bituminous mudstone - organic matter occurs in microstylolites, opaques and angular quartz silt common. Some laminae contain non-bituminous carbonate lenses. Orange bitumen common in porosity.
L2986#7						*								*		*		15			*	*	*		*	Original texture destroyed, porosity pattern suggests peloidal packstone. Minor bituminous content scattered and in small microstylolites. Anhydrite cement common.
L2686#6														*				10			*	*	*			Mostly peloidal - replaced with aphanocrystalline dolomite. Common anhydrite cement.
L2986#5						*								*		*		20			*	*	*			Allochems mostly unidentifiable or remain as molds. Organic matter patchy or in discontinuous microstylolites. Rare anhydrite cement.
L2686#4																		8			*	*	*		*	Allochems mostly unidentifiable or remain as molds. Scattered organic matter and microstylolites. Minor anhydrite cement.
L2686#3			*			*								*		*		10			*	*			*	Allochems mostly unidentifiable or remain as molds. Nodules have septarian structure with bituminous fill and very high intercrystalline porosity. Microstylolites common in matrix. Minor anhydrite cement.
L2986#2			*			*								*		*		13			*	*	*		*	Allochems mostly unidentifiable. Nodules have septarian structure with bituminous fill. Organic matter scattered and in microstylolites in matrix, rare opaques. Minor anhydrite cement.
L2986#1			*				*									*		5			*	*	*		*	Allochems mostly unidentifiable. Nodules have septarian structure with bituminous fill. Scattered organic matter in matrix, rare opaques.
L91#9	*	*					*									*		0								Thinly interlaminated to interbedded mudstone and enterolithic anhydrite. Mudstone completely dolomitized, anhydrite is fibrous. Disseminated bituminous content and scattered patches of opaques.
L91#8			*			*					*			*		*		3			*					Dolomitized mudstone, slightly bituminous, with anhydrite nodules. Nodules - 0.2-1.5 mm diameter, fibrous. Anhydrite cement in intercrystalline porosity.
L91#5	*			*			*									*		2			*				*	Thinly laminated mudstone, micrite mostly recrystallized to microspar and pseudospar, partly dolomitized. Microstylolites occur in wavy and anastomosing sets. Scattered clusters of opaques.
L91#6						*	*									*		5			*				*	Thinly laminated mudstone, micrite mostly recrystallized to microspar, minor dolomite. Microstylolites occur in wavy, irregular sets. Isolated clusters of opaques - framboidal pyrite? Rare anhydrite cement.
L91#7																		5			*		*		*	Thinly laminated mudstone, micrite mostly recrystallized to microspar and minor pseudospar, partly dolomitized. Microstylolites occur in wavy and anastomosing sets. Scattered clusters of opaques. Rare anhydrite cement.
L91#10	*		*			*	*					*		*		*		2		*	*				*	Laminated bituminous mudstone, nodular in part. Micrite mostly dolomitized, some dedolomite. Organic matter occurs as tightly clustered microstylolites, horsetails common. Opaques associated with organic matter. Blocky calcite, anhydrite, and quartz cements.
L91#4			*											*		*		10		*	*	*	*			Nodules remain largely undolomitized. Matrix dolomitized and variably bituminous. Some microstylolites show compactional drape around nodules with horsetails. Minor anhydrite cement.
L91#3			*			*								*		*		2		*	*	*			*	Many allochems recrystallized to pseudospar. Matrix consists of micrite, partly dolomitized. Variably bituminous. Some microstylolites show compactional drape over nodules, some with horsetails. Calcareous algae - udoteacean. Most fractures occluded by blocky calcite and rare anhydrite.
L91#2														*				2		*	*					Matrix consists of micrite, mostly dolomitized. Bituminous content finely disseminated. Fractures occluded by blocky calcite cement and minor anhydrite.
L91#1			*			*										*		2			*	?	*		*	Matrix consists of micrite with minor microspar, partly dolomitized. Nodules and allochems remain undolomitized.
L44#3	*					*	*											25			*	?	*			Interlaminated dolomite and bituminous laminae. Dolomite laminae - 1-3.5 mm thick. Bituminous laminae - 0.08-0.7 mm thick, anastomosing/microstylolitized, no allochems remaining.
L3083#21														*				30			*		*			Mudstone to possible packstone, aphanocrystalline patches appear to be replacing peloids. Minor anhydrite cement.
L3083#20																		5			*		*			Mudstone with scattered peloids? Aphanocrystalline patches appear to be replacing peloids. Minor anhydrite cement.
L3083#19	*																	20			*	*	*			Thickly interlaminated mudstone/packstone with wavy/irregular contacts. Original texture largely destroyed, patchy aphanocrystalline dolomite appears to be replacing peloids.

Sample #	Location	Depth	Lithofacies	Lithology								Allochems																Matrix	Dolomite										
				Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Anhydrite	% Allochems	Peloids	Ostracods	Crinoids	Brachiopods	Stylioliniids	Tentaculitids	Bryozoans	Corals	Gastropods	Calcareous Algae	Amphipora	Stromatoporoids	Calcispheres	Intraclasts	Unidentifiable	% Matrix	Non-Dolomitized	Partly Dolomitized	Fully Dolomitized	Aphanocrystalline	Very Fine	Fine	Medium	Coarse	Non-Planar	Planar-S	Planar-E
L3083#18	14-13-009-28W1	1290.60 m (4234.3')	N			*						?	*														*	?			*	*		*	*		*		*
L3083#17	14-13-009-28W1	1292 m (4238.8')	N	*		*						?	*															?			*	*	*	*			*		
L3083#16	14-13-009-28W1	1292.10 m (4239.2')	I			*						?	*									?					*	?			*	*	*	*	*		*	*	*
L3083#15	14-13-009-28W1	1292.73 m (4241.2')	I			?						?			*	?						?					*	?			*	*	*		*		*	*	*
L3083#14	14-13-009-28W1	1295.50 m (4250.3')	K			*						?	*															?			*	*		*	*		*	*	*
L3083#13	14-13-009-28W1	1303.80 m (4277.6')	K			*						?	*	?	*							?						?			*	*	*		*		*	*	*
L3083#12	14-13-009-28W1	1305.50 m (4283.1')	K			*						?			?		?					?						?			*	*	*	*	*		*	*	*
L3083#11	14-13-009-28W1	1310 m (4297.9')	B		*							?			?	?						?						?			*	*	*	*	*		*	*	*
L3083#10	14-13-009-28W1	1310.20 m (4298.6')	B		*	*						15-80			?	?	?											15-80			*		*	*	*		*	*	*
L3083#9	14-13-009-28W1	1311.80 m (4303.8')	B	*								?			?													?			*		*	*			*	*	*
L3083#8	14-13-009-28W1	1312 m (4304.5')	C	*																											*		*	*			*		
L3083#7	14-13-009-28W1	1312.20 m (4305.1')	C	*																											*			*			*	*	
L3083#6	14-13-009-28W1	1313.60 m (4309.7')	B	*								*																			*			*	*			*	*
L3083#5	14-13-009-28W1	1317.80 m (4323.5')	B	*								0																			*			*	*			*	*
L3083#4	14-13-009-28W1	1319 m (4327.4')	B		*							10			?	100												75			*			*	*			*	
L3083#3	14-13-009-28W1	1320.40 m (4332')	B	*								0																			*			*	*			*	*
L3083#2	14-13-009-28W1	1321.25 m (4334.8')	A	*				*	*			0-90														*		10-100			*	*		*			*		*
L3083#1	14-13-009-28W1	1321.45 m (4335.5')	A					*	*			10-90														*		10-90			*	*		*			*		*
L1228#12	04-27-011-22W1	850.12 m (2789.1')	H	?		?						?																?			*			*	*			*	*
L1228#10	04-27-011-22W1	850.27 m (2789.6')	H	?		?						?																?			*			*	*		*	*	
L1228#9	04-27-011-22W1	852.80 m (2797.9')	H			?						?			?	?											*	?			*			*	*		*	*	*
L1228#8	04-27-011-22W1	854.32 m (2802.9')	H			?						?											?					?			*		*	*	*		*	*	*
L1228#7	04-27-011-22W1	857.65 m (2813.8')	H			?						?																?			*			*				*	
L1228#6	04-27-011-22W1	860.21 m (2822.2')	G			?																									*			*	*			*	*
L1228#5	04-27-011-22W1	860.99 m (2824.8')	G			*						?		?	?	?											*	?			*	*		*	*			*	*
L1228#4	04-27-011-22W1	863.65 m (2833.5')	G			*						?			*												*	?			*			*	*			*	*
L1228#2	04-27-011-22W1	864.14 m (2835.1')	G			*						?															*	?			*			*	*			*	*
L1228#1	04-27-011-22W1	864.92 m (2837.65')	G		*	*						?			*	?												*	?			*		*	*			*	*	*
L4948#4	103/03-12-011-27W1	1180.46 m (3872.9')	E	*																											*	*	*	*	*		*	*	*

Sample # (Cont.)	Structures						Accessories												Porosity								Comments
	Laminated	Bedding	Nodular Texture	Boudinage	Stylolites	Microstylolites	Opaque Minerals	Hematite	Sphalerite	Quartz Silt	Feldspar Silt	Quartz Cement	Chalcedony	Anhydrite	Halite	Organic Matter	Argillaceous Material	% Porosity	Interparticle	Intraskeletal	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	
L3083#18	*													*				10			*	?	*			Subtle laminae visible. Patchy aphanocrystalline dolomite appears to be replacing peloids. Possible rare skeletal fragments. Minor anhydrite cement.
L3083#17	*																	10			*	?	*			Thin to thickly interlaminated mudstone/packstone. Patchy aphanocrystalline dolomite appears to be replacing peloids.
L3083#16																		15			*	?	*			Intraclast floatstone matrix. Original texture largely destroyed - patchy aphanocrystalline dolomite appears to be replacing peloids, remnants of skeletal fragments appear to be udoteacean algae.
L3083#15																		10			*		*			Intraclast floatstone matrix, original texture largely destroyed - likely packstone (skeletal in part).
L3083#14							*											20			*	*	*		*	Original texture largely destroyed - packstone (peloidal in part)
L3083#13																		10			*	*	*			Original texture largely destroyed - appears to be peloidal/algal (udoteacean) packstone.
L3083#12																		15			*	*	*			Original texture largely destroyed - likely packstone.
L3083#11			*															5			*	*	*		*	Original texture largely destroyed. Very high intercrystalline porosity in nodules.
L3083#10			*		*											*	*	5			*		*		*	Nodular - coarser dolomite in nodule. Patchy argillaceous/bituminous content.
L3083#9			*			*										*	*	5			*	*	*		*	Internodular matrix is variably bituminous/argillaceous. Rare remnants of bioclasts appear to have been crinoids. Intranodular fracture fill consists of argillaceous/bituminous matter.
L3083#8	*		*				*	*		*				*			*	2			*		*		*	Nodular, patterned mudstone - patches of finely disseminated opaque minerals and associated hematite. Nodules bounded by fractures. Argillaceous/silty laminae contains scattered anhydrite laths & quartz silt.
L3083#7						*	*	*		*							*	5			*	*	*		*	Patterned mudstone, variably argillaceous, disseminated and patchy concentrations of opaque minerals rarely associated with translucent pink/purple hematite crystals (~2 µm diam.).
L3083#6			*							*				*		*	*	10			*		*		*	Nodular mudstone - disseminated organic matter in internodular matrix. Intranodular fracture fill is argillaceous/silty with rare anhydrite laths and quartz silt.
L3083#5			*													*		15			*	?	*			Nodular mudstone, disseminated organic matter. Possible moldic porosity after bioclasts. Much higher porosity in nodules than in inter-nodular matrix.
L3083#4														*				15			*	*	*			Minor anhydrite cement. Moldic porosity after bioclasts.
L3083#3			*			*										*		3			*	*				Nodular mudstone, horsetail microstylolites drape nodules.
L3083#2										*				*			*	1				*				Intraclast rudstone grading to mudstone. Mudstone intraclasts, subangular to rounded, some broken, some very argillaceous, some contain opaques. Matrix - argillaceous mudstone with rare anhydrite laths and scattered quartz silt. Moldic porosity after laths.
L3083#1							*			*							*	0								Gradational transition from intraclast rudstone to floatstone. Mudstone intraclasts subangular to subrounded, some broken. Minor disseminated opaques in matrix. Trace quartz silt in matrix and intraclasts.
L1228#12							*									*		20			*		*			No original texture remaining, abundant porosity suggests packstone.
L1228#10					*	*	*									*		5			*				*	No original texture remaining. Abundant microstylolites and rare stylolites. Scattered opaques common.
L1228#9							*						*	*		*		10			*	*	*			Bioclasts visible with white card, most not identifiable. Minor scattered organic matter and opaques. Abundant replacive anhydrite, blue chalcedonic cement common.
L1228#8													*	*		*		3			*	*			*	Bioclasts visible with white card - appear to be *Amphipora*. Rare scattered organic matter. Fracture-filling and replacive anhydrite. Minor blue chalcedonic cement.
L1228#7							*											7			*	*	*			No original texture remaining.
L1228#6						*										*		13			*	*	*			No original texture remaining. Minor disseminated organic matter and in microstylolites.
L1228#5						*	*									*		5			*				*	Bioclasts visible with white card. Very common microstylolites containing organic matter and opaques.
L1228#4							*							*		*		10			*	*	*		*	Rare crinoid fragments remain, bioclasts visible with white card but not identifiable. Rare opaques and organic matter. Anhydrite cement common in fractures. Probable replacive anhydrite.
L1228#2			*			*	*									*		10			*	*				Remnants of bioclasts visible with white card. Minor organic matter and opaques in discontinuous microstylolites. Nodules have elevated intercrystalline porosity.
L1228#1			*				*									*		15			*	*			*	Most allochems unidentifiable. Variably bituminous - organic matter scattered and in microstylolites. Opaques common. Nodules contain very porosity (30%).
L4948#4	*		*			*	*		*			*				*		5			*		*		*	Very thinly laminated dolomudstone & dolomitized anhydrite with microstylolitized contacts. Locally nodular, contorted, and enterolithic. Opaques occur disseminated, clustered (framboids?), and in one solid laminae (1 mm thick). Rare vug-filling sphalerite.

Sample #		Depth	Lithofacies	Lithology								Allochems																Matrix	Dolomite									
				Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Anhydrite	% Allochems	Peloids	Ostracods	Crinoids	Brachiopods	Styliolinids	Tentaculitids	Bryozoans	Corals	Gastropods	Calcareous Algae	Amphipora	Stromatoporoids	Calcispheres	Intraclasts	Unidentifiable	% Matrix	Non-Dolomitized	Partly Dolomitized	Fully Dolomitized	Aphanocrystalline	Very Fine	Fine	Medium	Coarse	Non-Planar	Planar-S	Planar-E
L4948#10	103/03-12-011-27W1	1178.57 m (3866.67')	D	*		*						87	85	2														13		*	*	*		*	*			*	*
L4948#9	103/03-12-011-27W1	1178.70 m (3867.13')	E	*																											*		*	*			*	*	*
L2162#11	04-17-019-29W1	955.57 m (3135.08')	K			?						?																			*					*			
L2162#8	04-17-019-29W1	961.84 m (3155.63')	J	*								5								100								95			*			*	*		*		
L2162#3	04-17-019-29W1	968.35 m (3177')	K			*						60	5		5							70					20	33			*	*		*				*	
L2162#3	04-17-019-29W1	968.35 m (3177')	J		*							12			40												60	88			*			*	*		*		
L2474#17	04-33-023-16W1	205.53 m (674.3')	D				*					85													100													
L2474#16	04-33-023-16W1	205.95 m (675.7')	D	*			*					85	1												99													
L2474#15	04-33-023-16W1	206.59 m (677.8')	H			*						85	94	2			1									3		14		*				*	*			*	*
L2474#13	04-33-023-16W1	206.75 m (678.3')	H			*						80	100															19		*				*	*			*	*
L2474#12	04-33-023-16W1	207.08 m (679.4')	H	*		*						80	99												<1			20		*				*	*				*
L2474#11	04-33-023-16W1	207.57 m (681')	H			*						80	82			8										10		20		*				*	*			*	*
L2474#9	04-33-023-16W1	209.61 m (687.7')	I						*			15				?										90		80			*	*	*	*				*	*
L2474#8	04-33-023-16W1	210.07 m (689.2')	F	*								1				100												99		*				*	*			*	*
L2474#7	04-33-023-16W1	210.92 m (692')	H			?						?			?	?												?		*		*						*	*
L2474#4	04-33-023-16W1	215.43 m (706.8')	F	*								8			40	58										2		92		*		*		*	*	*		*	*
L2474#1	04-33-023-16W1	218.39 m (716.5')	F	*								3			3	92	1					1?				3		96		*				*	*			*	*
1-72-23	16-26-024-10W1	3.29 m (10.8')	H			*	*					?	?															?			*			*	*		*	*	*
1-72-22	16-26-024-10W1	6.54 m (21.5')	H			*	*					?	?															?			*			*	*			*	*
1-72-20	16-26-024-10W1	13.55 m (44.5')	H			*	*					?	?															?			*			*	*			*	*
1-72-19	16-26-024-10W1	15.00 m (49.2')	H			*						?	?															?			*			*	*			*	*
1-72-18	16-26-024-10W1	20.87 m (68.5')	H			*	*					?	?		*													?			*			*	*	*		*	*
1-72-17	16-26-024-10W1	21.29 m (69.8')	H			*						?	?		*					*								?			*			*	*			*	*
1-72-16	16-26-024-10W1	25.64 m (84.1')	H			*						?	?														?	?			*			*				*	*
1-72-11	16-26-024-10W1	31.54 m (103.5')	B		*							15		5	48	20	<1		*			3			1		20	84		*				*	*	*	*	*	*
1-72-10B	16-26-024-10W1	31.87 m (104.6')	B		*							20		2	50	19	1		2		1	4			1		20	80		*				*	*			*	*

Sample # (Cont.)	Structures						Accessories												Porosity								Comments
	Laminated	Bedding	Nodular Texture	Boudinage	Stylolites	Microstylolites	Opaque Minerals	Hematite	Sphalerite	Quartz Silt	Feldspar Silt	Quartz Cement	Chalcedony	Anhydrite	Halite	Organic Matter	Argillaceous Material	% Porosity	Interparticle	Intraskeletal	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	
L4948#10	*	*	*	*			*			*		*	*	*		*		8			*		*		*	Interlaminated/bedded bituminous dolomudstone, dolomudstone, peloidal dolopackstone, and anhydrite. Anhydrite mostly replaced with calcite/dolomite. Rare calcite nodules, replaced anhydrite nodules, and anhydrite laths. Horizontal and irregular bedding contacts. Some mudstone laminae fractured & disjointed. Minor fracture & vug-filling coarse blocky calcite. Opaques disseminated and framboidal.
L4948#9	*			*		*	*					*				*		3			*		*			Interlaminated bituminous dolo-mudstone (1 mm - 1.7 cm thick) & dolomitized anhydrite (1-5 mm thick). Irregular contacts, some irregular and boudinaged bedding. Framboidal opaques.
L2162#11						*								*				8			*		*			No original texture remaining - likely packstone. Rare anhydrite cement.
L2162#8					*	*								*		*		0								Bioclasts poorly preserved-thamnoporid fragments? Abundant microstylolites. Rare anhydrite cement.
L2162#3																		7					*			Pervasively dolomitized, many allochems not identifiable. Calcareous algae - udoteacean.
L2162#3						*								*		*		0								Bituminous skeletal wackestone at top of thin section, most allochems not identifiable. Organic matter concentrated in abundant microstylolites. Rare anhydrite cement.
L2474#17	*									*		*				*		?	*						*	Very thinly interlaminated light and dark brown bituminous, calcisphere grainstone laminae. Large calcispheres have dark brown cores & clear cortices. Sutured contacts visible locally. Rare possible calcitized anhydrite nodules/lenses. One lamina partly silicified. Organic matter occurs interparticle & in microstylolites. Organic matter/oil staining makes porosity estimation difficult. Some blocky calcite cement.
L2474#16	*					*	*							*		*		3	*						*	Very thinly laminated bituminous & non-bituminous calcisphere grainstone. Calcispheres circular to oval, larger ones have brown cores and clear cortices. Sutured boundaries visible. OM occurs in microstylolites and interparticle. Opaques common, anhydrite laths rare. One bituminous mudstone inter-laminae with abundant calcitized anhydrite laths. Some irregular & lenticular bedding. Interparticle blocky calcite cement locally.
L2474#15																		1				*	*			Mostly dolomitized. Intraclasts sub-rounded to rounded. Blocky calcite occludes bioclast molds.
L2474#13						*												1			*		*		*	Mostly dolomitized. Peloids circular to elongate. Blocky calcite in micro-vugs.
L2474#12	*					*	*										*	0								Thin to thickly interlaminated argillaceous mudstone & packstone, mostly packstone. Peloids - circular, oval, and elongate. Packstone matrix - mostly dolomitized micrite & pseudospar. Abundant framboidal opaques in mudstone. Blocky calcite occludes fractures and vugs.
L2474#11												*						0								Peloids circular and oval. Micrite & microspar matrix, mostly dolomitized. Blocky calcite cement occluding fractures and vugs, rare quartz cement.
L2474#9																		5			*	*	*			Sparse bioclasts unidentifiable.
L2474#8																		7			*		*			Brachiopods are partly re-crystallized and have corroded margins. Micrite matrix mostly dolomitized, dedolomite common.
L2474#7																		5			*	*	*			Mostly dedolomite, no original texture.
L2474#4																		0								Blocky calcite cement in micro-vugs.
L2474#1																		1				*				Matrix consists of partly dolomitized micrite and microspar. Rare dogtooth/blocky calcite cement.
1-72-23																		30			*	*	*			Rare surviving crinoid fragments. Porosity pattern suggests peloidal packstone to grainstone.
1-72-22																		25			*	*	*		*	Porosity pattern suggests peloidal packstone to grainstone.
1-72-20																		35			*	*	*			Porosity pattern suggests peloidal packstone to grainstone.
1-72-19																		20			*	*	*			Porosity pattern suggests peloidal packstone.
1-72-18																		30			*	*	*			Porosity pattern suggests peloidal packstone to grainstone. Rare surviving crinoid fragments.
1-72-17																		25			*	*	*			Original texture mostly destroyed - scattered crinoid fragments and one thamnoporid fragment remain. Moldic porosity pattern suggests dominantly peloidal.
1-72-16																		10				*	*			No original texture remaining. Moldic porosity pattern suggests packstone dominated by peloids with secondary bioclasts.
1-72-11					*											*		1					*		*	Matrix dolomitized. Nodules remain micrite and microspar, allochems remain calcite. Calcareous algae - udoteacean. Variably bituminous. Blocky calcite occludes most porosity.
1-72-10B			*		*											*		0								Matrix consists of micrite and microspar, mostly dolomitized. Nodules and allochems remain undolomitized. Calcareous algae - udoteacean. Some allochems recrystallized to pseudospar. Minor disseminated organic matter. Blocky calcite occludes vugs.

Sample #	Location	Depth	Lithofacies	Lithology								Allochems																Matrix	Dolomite										
				Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Anhydrite	% Allochems	Peloids	Ostracods	Crinoids	Brachiopods	Styliolinids	Tentaculitids	Bryozoans	Corals	Gastropods	Calcareous Algae	Amphipora	Stromatoporoids	Calcispheres	Intraclasts	Unidentifiable	% Matrix	Non-Dolomitized	Partly Dolomitized	Fully Dolomitized	Aphanocrystalline	Very Fine	Fine	Medium	Coarse	Non-Planar	Planar-S	Planar-E
1-72-9	16-26-024-10W1	33.41 m (109.6')	B		*							20		2	50	14			10			3		5	1	5	10	79		*				*	*			*	*
1-72-8	16-26-024-10W1	36.33 m (119.2')	B		*							10			67	20			2						1		10	89		*				*	*			*	*
1-72-6	16-26-024-10W1	44.54 m (146.1')	B		*							10		5	29	45			1		2	2			1		15	90		*				*	*			*	*
1-72-3	16-26-024-10W1	46.4 m (152.2')	B		*							20			29	55						1					15	79		*				*	*			*	*
1-72-2	16-26-024-10W1	47.20 m (154.9')	A	*																											*	*	*				*		
M-3-90-A	03-35-024-10W1	18.33 m (60.14')	F	*								1			50	50												98		*		*		*	*	*			*
3-90-11	03-35-024-10W1	18.40 m (60.4')	F	*								1				100												96			*			*				*	
3-90-6A	03-35-024-10W1	20.90 m (68.6')	B		*							3		5	20	75												96											
3-90-4B	03-35-024-10W1	22.50 m (73.8')	B		*							15		5	20	54	<1		1						<1		20	85		*			*	*		*	*		
3-90-1B	03-35-024-10W1	41.30 m (135.5')	B		*							20			45	45									<1		10	79		*				*				*	*
M-2-87-E	05-35-24-10W1	9.98 m (32.74')	F	*								3			5	95												97		*				*	*				*
M-2-87-C	05-35-24-10W1	15.18 m (49.8')	F	*								1			100													99		*							*		
M-2-87-B	05-35-24-10W1	16.26 m (53.35')	F	*								3				100												97		*				*	*		*		*
M-2-87-A	05-35-24-10W1	18.50 m (60.7')	D		*							45	50		1		45	4										54		*				*	*				*
2-87-12	05-35-024-10W1	21.88 m (71.78')	B		*							10			20	60					1	10			<1		9	89		*				*					*
2-87-9B	05-35-024-10W1	24.03 m (78.8')	B		*							25		5	25	25						20			1		25	73	*										
2-87-9H	05-35-024-10W1	24.03 m (78.8')	B		*							25	5	2	30	25			2			15			1	5	15	74	*										
2-87-6B	05-35-024-10W1	27.07 m (88.8')	B		*							15		5	40	30	<1		1		2	2			<1		20	84	*										
2-87-6H	05-35-024-10W1	27.07 m (88.8')	B		*							15		5	50	25			1			?			1		18	84	*										
2-87-4B	05-35-024-10W1	28.77 m (94.4')	B		*							30	2	5	30	40			2	1					<1		20	70	*										
2-90-14	06-35-024-10W1	22.7 m (74.5')	B		*							10			25	55	<1								<1		20	87		*				*		*	*		*
2-90-15	06-35-024-10W1	22.9 m (75.1')	B		*							10			10	70									<1		20	89		*				*				*	*
2-90-10	06-35-024-10W1	26.7 m (87.6')	B		*							10			56	20					2	2			<1		20	89		*				*			*		
2-90-4	06-35-024-10W1	34.16 m (112.1')	B		*							15			75	15			5			5		*	<1			84	*										
4-90-25	12-35-024-10W1	4.60 m (15.1')	F			*	*					?	?															?			*			*				*
4-90-20B	12-35-024-10W1	10.44 m (34.3')	F	*								3			40	60												96		*				*	*				*

Sample # (Cont.)	Structures						Accessories												Porosity								Comments
	Laminated	Bedding	Nodular Texture	Boudinage	Stylolites	Microstylolites	Opaque Minerals	Hematite	Sphalerite	Quartz Silt	Feldspar Silt	Quartz Cement	Chalcedony	Anhydrite	Halite	Organic Matter	Argillaceous Material	% Porosity	Interparticle	Intraskeletal	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	
1-72-9			*															1		*	*		*		*	Matrix consists of micrite, minor microspar and pseudospar, and patchy dolomite. Nodules and allochems remain mostly undolomitized. Calcareous algae - udoteacean. Tabular stromatoporoid at base of thin section, partly encrusted with *Rothpletzella*.
1-72-8																		1			*		*			Matrix consists of micrite, microspar, and pseudospar, mostly dolomitized. Allochems remain mostly calcite.
1-72-6							*											<1		*						Matrix consists of micrite, microspar, minor pseudospar, and patchy dolomite with minor dedolomite. Some allochems recrystallized to pseudospar, minor dolomitization. Calcareous algae - udoteacean. Fractures occluded by blocky calcite.
1-72-3																		1			*	*				Matrix consists of micrite, microspar, and minor pseudospar, mostly dolomitized. Most allochems remain calcite, some recrystallized to pseudospar, some partly dolomitized. Calcareous algae - udoteacean. Moldic porosity after dolomite rhombs.
1-72-2																		1					*			Massive dolomicrite.
M-3-90-A																		1				*				Mostly dolomitized, pseudospar and dedolomite in part. Coarse, blocky calcite cement occluding porosity.
3-90-11							*											3			*		*		*	Bioclasts poorly preserved. Matrix consists of microspar and minor pseudospar, partly dolomitized with common dedolomite. Trace disseminated opaque minerals. Fractures mostly occluded by blocky calcite.
3-90-6A																*		1			*	*	*			Matrix consists of microspar, pseudospar, partly dolomitized. Dolomite partly dedolomitized. Allochems remain calcite but recrystallized to microspar.
3-90-4B							*									*		<1					*			Matrix and most allochems dolomitized. Minor disseminated bituminous content.
3-90-1B																		1				*				Matrix consists of microspar and pseudospar, partly dolomitized. Allochems partly dolomitized.
M-2-87-E																		0								Matrix-partly dolomitized micrite. Micro-vuggy porosity occluded by blocky calcite cement.
M-2-87-C																		0								Blocky calcite occluding intercrystalline and rare possible moldic porosity.
M-2-87-B																		0								Blocky calcite occluding brachiopod molds and intercrystalline porosity.
M-2-87-A	*					*	*			*						*		1		*					*	Matrix consists of micrite and microspar. Internal & external isopachous radial-prismatic calcite cement on cricoconarids. Organic matter occurs as anastomosing microstylolites in matrix. Opaques common throughout, many framboidal.
2-87-12						*										*		1				*	*			Matrix consists of micrite and microspar, partly dolomitized. Variably bituminous, disseminated and in microstylolites. Calcareous algae - udoteacean. Bladed prismatic and blocky calcite cement.
2-87-9B						*	*									*		2					*			Matrix consists of micrite and microspar. Calcareous algae - udoteacean. Microstylolites show compactional drape over nodules. Opaque mineral occludes one vug.
2-87-9H			*			*										*		1				*	*			Matrix consists of micrite, microspar, and minor pseudospar. Wispy microstylolites show compactional drape over nodules. Calcareous algae - udoteacean. Intraclasts - skeletal wackestone, well rounded.
2-87-6B			*															1				*	*			Matrix consists of micrite, microspar, and rare pseudospar. Calcareous algae - udoteacean. One halite hopper mold occluded by blocky calcite.
2-87-6H			*															1				*	*			Matrix consists of micrite and minor microspar. Nodules have sharp to gradational boundaries. Calcareous algae - udoteacean. Blocky calcite cement occludes some porosity.
2-87-4B					*													0								Matrix consists of micrite and subordinate pseudospar. Corals - halysitids. Porosity occluded by blocky calcite.
2-90-14																		3					*		*	Matrix mostly dolomitized, some pseudospar remaining. Allochems remain calcite. Moldic porosity after dolomite rhombs. Fractures mostly occluded by blocky calcite cement.
2-90-15																		1				*	*			Allochems and matrix mostly dolomitized, some microspar remaining. Moldic porosity after dolomite rhombs. Fracture occluded by blocky calcite cement.
2-90-10			*			*										*		1					*			Matrix dolomitized, allochems remain calcite. Matrix slightly bituminous, disseminated and in microstylolites. Calcareous algae - udoteacean. Nodules partly dolomitized. Fracture in nodule occluded by blocky calcite cement.
2-90-4					*													1					*			Matrix consists of micrite and microspar. Calcareous algae - udoteacean. Tabular stromatoporoid across end of thin section, encrusted by bryozoans. Fracture occluded by blocky calcite cement.
4-90-25																		10			*	*				No original texture remaining. Moldic porosity pattern suggests packstone-grainstone, likely peloidal.
4-90-20B																		1					*			Matrix mostly dolomitized.

Sample #	Location	Depth	Lithofacies	Lithology								Allochems																Matrix	Dolomite											
				Mudstone	Wackestone	Packstone	Grainstone	Rudstone	Floatstone	Boundstone	Anhydrite	% Allochems	Peloids	Ostracods	Crinoids	Brachiopods	Styliolinids	Tentaculitids	Bryozoans	Corals	Gastropods	Calcareous Algae	Amphipora	Stromatoporoids	Calcispheres	Intraclasts	Unidentifiable	% Matrix	Non-Dolomitized	Partly Dolomitized	Fully Dolomitized	Aphanocrystalline	Very Fine	Fine	Medium	Coarse	Non-Planar	Planar-S	Planar-E
4-90-13B	12-35-024-10W1	16.85 m (55.3')	F	*	*							5-15	45	<1	1	20	30											80-89		*				*	*				*
4-90-13A	12-35-024-10W1	17.10 m (56.1')	D		*							10				<1	100											88		*				*					*
M-4-90-C	12-35-24-10W1	17.35 m (56.92')	D			*						70	75	2			20			1		3						28		*				*	*	*		*	
M-4-90-A	12-35-24-10W1	17.57 m (57.64')	D			*						80	62		1		30	5								2		19	*										
4-90-11	12-35-024-10W1	21.17 m (69.5')	B		*							10		2	40	30			1		1	5			1	10	10	89	*										
4-90-10B	12-35-024-10W1	22.27 m (73.1')	B		*							30		10	29	39	1		1		2	2			1	5	10	69		*				*					*
4-90-4	12-35-024-10W1	33.5 m (109.9')	B		*							10				40	50										10	89		*				*					*
R.H.O.P.#1	518030E, 5661405N	0 m (0')	O							*																					*	*		*	*			*	*

Sample # (Cont.)	Structures						Accessories											Porosity								Comments
	Laminated	Bedding	Nodular Texture	Boudinage	Stylolites	Microstylolites	Opaque Minerals	Hematite	Sphalerite	Quartz Silt	Feldspar Silt	Quartz Cement	Chalcedony	Anhydrite	Halite	Organic Matter	Argillaceous Material	% Porosity	Interparticle	Intraskeletal	Intercrystalline	Moldic	Vuggy	Fenestral	Fracture	
4-90-13B		*					*									*		3		*		*	*			Mudstone to wackestone, bedding contact visible. Matrix consists of micrite, microspar, and pseudospar, partly dolomitized. Variable disseminated organic matter. Opaque minerals common in vugs, some iron staining. Dog tooth calcite cement lines some pore spaces.
4-90-13A	*		*			*										*		2		*			*			Laminated bituminous skeletal wackestone. Matrix consists of micrite and microspar, partly dolomitized. Styliolinids oriented parallel to bedding. Bituminous content occurs as anastomosing microstylolites. One non-bituminous displacive nodule consisting of micrite and microspar with diffuse boundaries. Styliolinids are sparse and randomly oriented within the nodule.
M-4-90-C						*	*									*		2		*	*	*			*	Internal & external radial-prismatic calcite cement on cricoconarids. Calcareous algae consists of a tubular network - variety? Organic matter disseminated & in microstylolites. Opaques common, most framboidal.
M-4-90-A	*					*	*									*		1		*						Internal & external radial-prismatic calcite cement on cricoconarids. Opaques common, most framboidal, some euhedral.
4-90-11			*				*											1				*	*			Matrix consists of micrite, microspar, and minor pseudospar. Allochems mostly recrystallized to microspar/pseudospar. Calcareous algae - udoteacean. Nodules remain largely micritic. Finely disseminated opaques. Fractures occluded by blocky calcite cement.
4-90-10B						*	*			*						*		1		*		*	*			Matrix consists of micrite and microspar, partly dolomitized. Calcareous algae - *Girvanella* and possible dasyclads. Intraclasts - skeletal wackestone, subrounded. Organic matter - disseminated and in microstylolites. Finely disseminated opaque minerals. Trace quartz silt. Some moldic porosity after dolomite rhombs - plucked?
4-90-4						*	*									*		1		*			*			Micrite consists of micrite and microspar, partly dolomitized. Variably bituminous - wispy microstylolites. Disseminated opaques, mostly within dolomite rhombs.
R.H.O.P.#1	*																	12			*		*			Bindstone-stromatolitic, laminae are crenulated.

APPENDIX E: ORGANIC PETROLOGY DATA

Table E.1 summarizes the maceral assemblage descriptions for all of the organic-rich samples examined petrographically in this study at the Organic Petrology Laboratory at the Geological Survey of Canada (Calgary). The sample numbers correspond to the core samples from which the pellets were made. The pellet numbers correspond to the archived samples at the Geological Survey of Canada (Calgary). The sample descriptions are arranged by well location in ascending order followed by depth in descending order.

Table E.1: Maceral assemblage descriptions.

Key:	
A	Abundant
C	Common
R	Rare
T	Trace
?	Questionable
N/P	Not Present

								Liptinite											Huminite/ Vitrinite		Zooclasts		Calcareous/Phosphatic Microfossils		
								Alginites				Acritarchs	Sporinite		Cutinite	Resinite	Amorphinite									
						Organic Facies		Prasinophytes		Coccoidal	Filamentous	(spiny)	Microspores	Megaspores			Hebamorphinite	Fluoramorphinite	Vitrinite	Corpohuminite-like	Conchostracan	Chitinozoans	Calcispheres	Cricoconarids	Fish Bones
Well	Licence #	Depth	Sample #	Pellet #	Laminite Type	Primary	Secondary	Large >50µm	Small <50µm											Akinete cells					
11-29-001-25W1	2543	1528.34 m (5014.25')	L2543#6	1168	Platform Slope	BL1	A	R	C	N/P	N/P	N/P	N/P	N/P	N/P	N/P	R	A	N/P	T	N/P	N/P	N/P	N/P	N/P
11-29-001-25W1	2543	1531.85 m (5025.75')	L2543#3	1167	Ramp-to-Platform Transition	BL1	C	C	C	T	N/P	T	T?	N/P	N/P	N/P	C	A	N/P	T	N/P	N/P	N/P	N/P	N/P
05-13-005-22W1	320	1153.76 m (3785.3')	L320#9	1164	Platform Interior	BL2	C?	A	C	N/P	T?	N/P	R	N/P	N/P	N/P	R	A	N/P	C	C	N/P	N/P	N/P	N/P
05-13-005-22W1	320	1157.94 m (3799')	L320#13	1162	Platform Interior	BL2	C?	A	C	N/P	N/P	N/P	T	N/P	N/P	N/P	C	A	N/P	T	N/P	N/P	N/P	N/P	N/P
04-12-007-25W1	2986	1198.68m (3932.68')	L2986#10	1169	Onlapping Platform Slope	BL1	C?	R	A	N/P	N/P	N/P	R	N/P	N/P	N/P	R	A	N/P	R? (pyrite)	A	N/P	N/P	N/P	N/P
09-26-007-25W1	217	1175.46 m (3856.5')	L217#1	1163	Platform Slope	BL1	B	C	A	N/P	N/P	R	R	N/P	N/P	N/P	C	A	N/P	T	N/P	N/P	N/P	N/P	N/P
02-21-007-28W1	91	1447.7 m (4749.7')	L91#10	1173	Ramp-to-Basin Transition	A	N/P	R	C	N/P	N/P	N/P	N/P	N/P	N/P	N/P	C	A	N/P	N/P	N/P	N/P	N/P	N/P	N/P
03-01-008-18W1	44	783.95 m (2572')	L44#3	1159	Platform Interior	E	N/P	T	N/P	N/P	T?	N/P	T	N/P	N/P	N/P	A	N/P	N/P	N/P	N/P	N/P	N/P	N/P	N/P
03-01-008-18W1	44	784.55 m (2574')	L44#6	1161	Platform Interior	E	N/P	R	C	R	N/P	N/P	C	N/P	T?	R	C	A	C	N/P	N/P	N/P	N/P	N/P	N/P
103/03-12-011-27W1	4948	1178.57m (3866.70')	L4948#10	1171	Basinal Salina	BL2	C?	A	C	N/P	N/P	N/P	N/P	R	N/P	N/P	C	A	N/P	C	N/P	N/P	N/P	N/P	N/P
04-33-023-16W1	2474	205.53 m (674.3')	L2474#17	1166	Onlapping Platform Slope	BL3	C?	N/P	N/P	N/P	N/P	T	N/P	N/P	N/P	N/P	A	N/P	N/P	N/P	N/P	N/P	A	N/P	T
04-33-023-16W1	2474	205.95 m (675.7')	L2474#16	1165	Onlapping Platform Slope	BL3	C?	N/P	N/P	T	N/P	N/P	N/P	N/P	N/P	N/P	A	N/P	N/P	N/P	N/P	N/P	A	N/P	N/P
12-35-024-10W1	M-4-90	17.58m (57.68')	M-4-90A	1172	Ramp-to-Platform Transition	BL1	C?	R	C	N/P	N/P	N/P	R	N/P	N/P	N/P	A	N/P	N/P	T	N/P	T	N/P	C	N/P

APPENDIX F: ROCK-EVAL PYROLYSIS METHODOLOGY AND RESULTS

F.1 METHODOLOGY

Rock-Eval pyrolysis is widely used to provide information on the hydrocarbon potential, maturity, and geochemical type of source rocks because it is simple, rapid, and inexpensive (e.g., Hunt, 1996; Lafargue et al., 1998). The Rock-Eval 6 pyrolysis method involves temperature programmed heating of a small, whole-rock ground sample (up to ~100 mg) in an inert atmosphere of helium or nitrogen to determine both the free hydrocarbons in the sample as well as the hydrocarbons that can potentially be released after maturation (Fig. F.1) (e.g., Peters, 1986; Behar et al., 2001). Results for each sample analyzed are recorded in the form of five characteristic curves or pyrograms (e.g., Hunt, 1996; Lafargue et al., 1998).

Hydrocarbons released from the sample are monitored by a flame ionizing detector (FID) and recorded on the FID curve as two surfaces referred to as S1 and S2, both of which are expressed in mg HC/g of initial sample (e.g., Lafargue et al., 1998; Behar et al., 2001). The area under the curve designated as S1 represents the quantity of thermovaporized free hydrocarbons contained in the sample which were either present at the time of deposition or were generated since deposition and are released during the isothermal temperature step at 300°C (e.g., Hunt, 1996; Behar et al., 2001). The area under the curve designated as S2 represents the quantity of hydrocarbons released from thermal cracking of organic matter in the sample between 300° and a maximum of 650° C (e.g., Behar et al., 2001). The Tmax value is a maturity parameter that is calculated from the

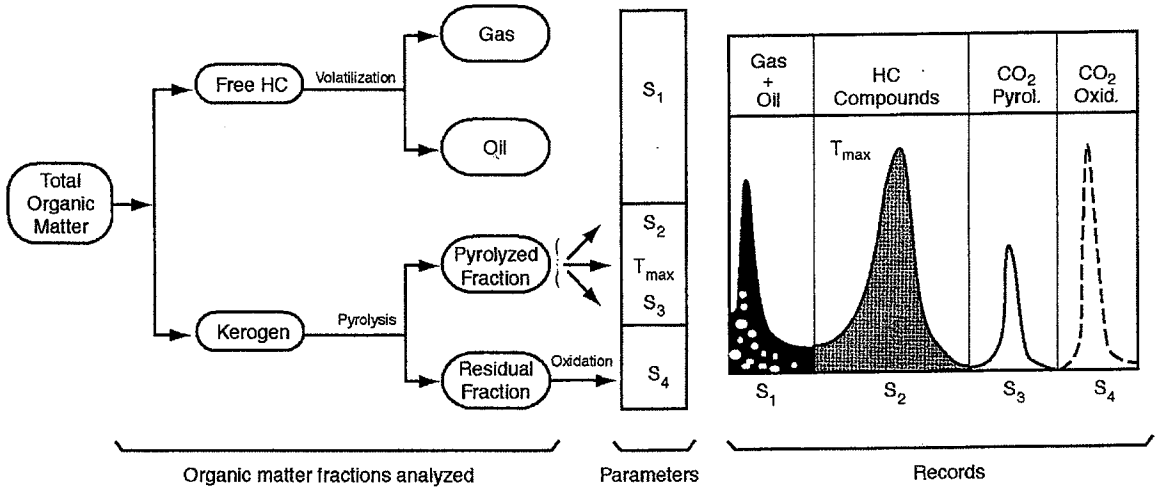


Figure F.1: Generalized schematic diagram representing the different fractions of the total organic matter in powdered rock samples analyzed with the Rock-Eval pyrolysis method and the corresponding parameters and their records (modified from Lafargue et al., 1998).

temperature at which the S2 surface achieves its maximum or peaks (e.g., Peters, 1986).

Both CO_2 and CO released during pyrolysis are monitored by an infra-red cell and are recorded on the CO_2 and CO pyrolysis curves (e.g., Lafargue et al., 1998). The area under the S3 surface on the CO_2 pyrolysis curve represents the sum of CO_2 released from organic matter in the sample at the same time as the S1 surface and that released between 300° and 400° C (e.g., Behar et al., 2001). The area under the S3' surface represents the CO_2 released from a mineral origin between 400° C and the end of the measurement. The area under the S3CO surface on the CO pyrolysis curve represents CO released by organic matter in the sample between 300° C and the temperature where CO production is first observed. The area under the CO pyrolysis curve designated as S3'CO represents CO released by organic and mineral matter in the sample from the upper limit of the S3CO surface to the end of the measurement.

Following pyrolysis, the residual organic carbon in the sample is combusted (oxidized) under artificial air in a second oven up to 850°C (e.g., Lafargue et al., 1998; Behar et al., 2001). CO_2 and CO produced during oxidation are recorded on CO_2 and CO oxidation curves and represented by the area under the $S4CO_2$ and S4CO surfaces respectively (e.g., Behar et al., 2001). The dry weight percent total organic carbon (TOC), which is the sum of extractable organic matter carbon, reactive carbon, and inert carbon content of the sample, is obtained by summing pyrolysis carbon (PC) and residual carbon (RC)

(e.g., Jarvie, 1991; Behar et al., 2001). The following equation can be used to calculate TOC:

(1) $$TOC = PC + RC$$

$$PC = \frac{[(S1 + S2) \times 0.83] + [S3 \times 12/44] + [(S3CO + S3'CO/2) \times 12/28]}{10}$$

$$RC = RC\ CO + RC\ CO_2$$

$$RC\ CO = [S4CO \times (12/28)] / 10$$

$$RC\ CO_2 = [S4CO_2 \times (12/44)] / 10$$

Hydrogen Index (HI) is obtained using the following equation:

(2) $$HI = (S2 \times 100) / TOC$$

Oxygen Index (OI) is obtained using the following equation:

(3) $$OI = (S3 \times 100) / TOC$$

F.2 RESULTS

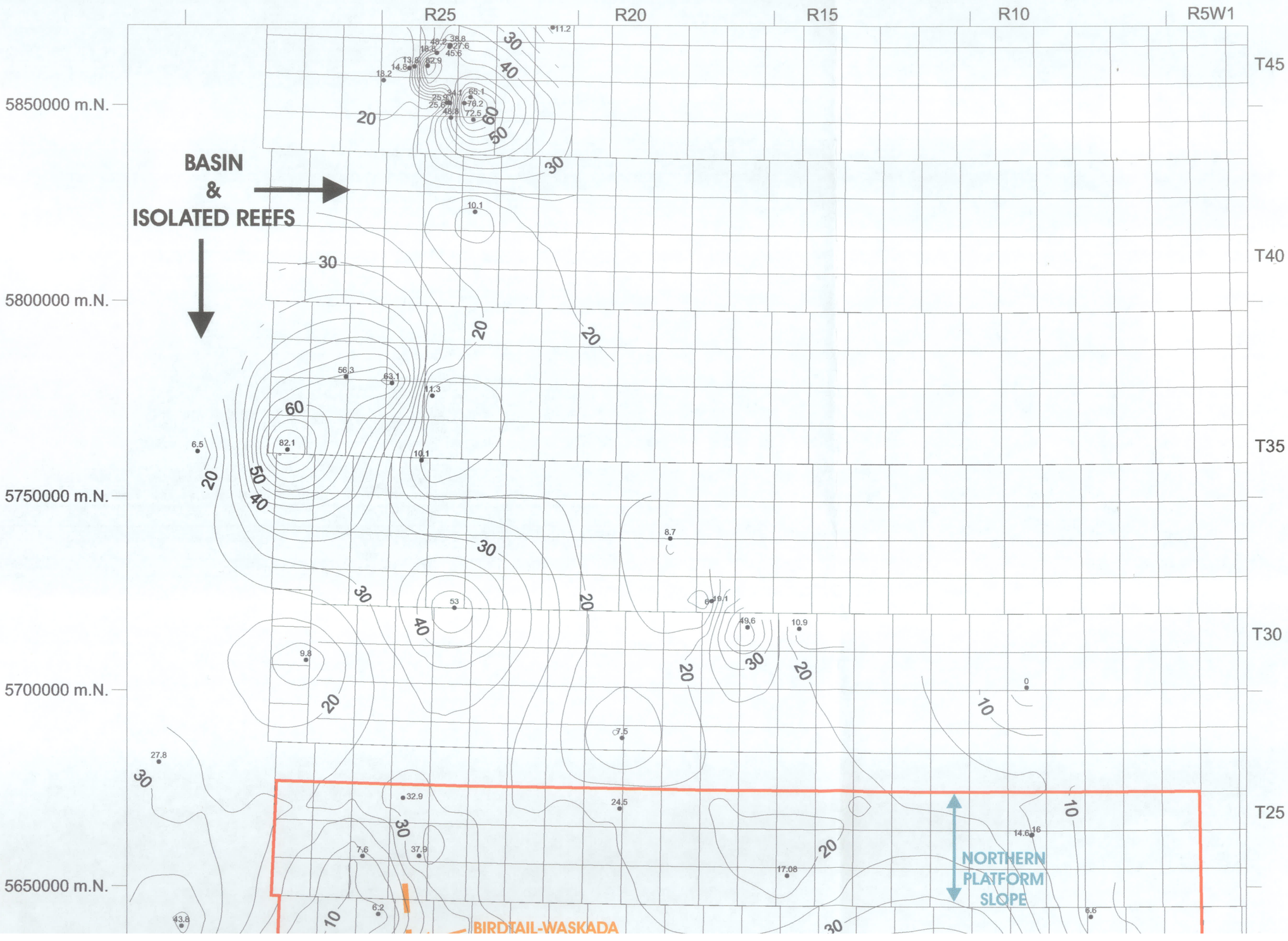
Table F.1 is a compilation of all data determined from Rock-Eval 6 pyrolysis analysis of organic-rich samples undertaken for this study at the Organic Geochemistry Laboratory at the Geological Survey of Canada (Calgary). The samples are arranged by well location in ascending order followed by depth in descending order. The pellet numbers correspond to the archived samples at the Geological Survey of Canada (Calgary).

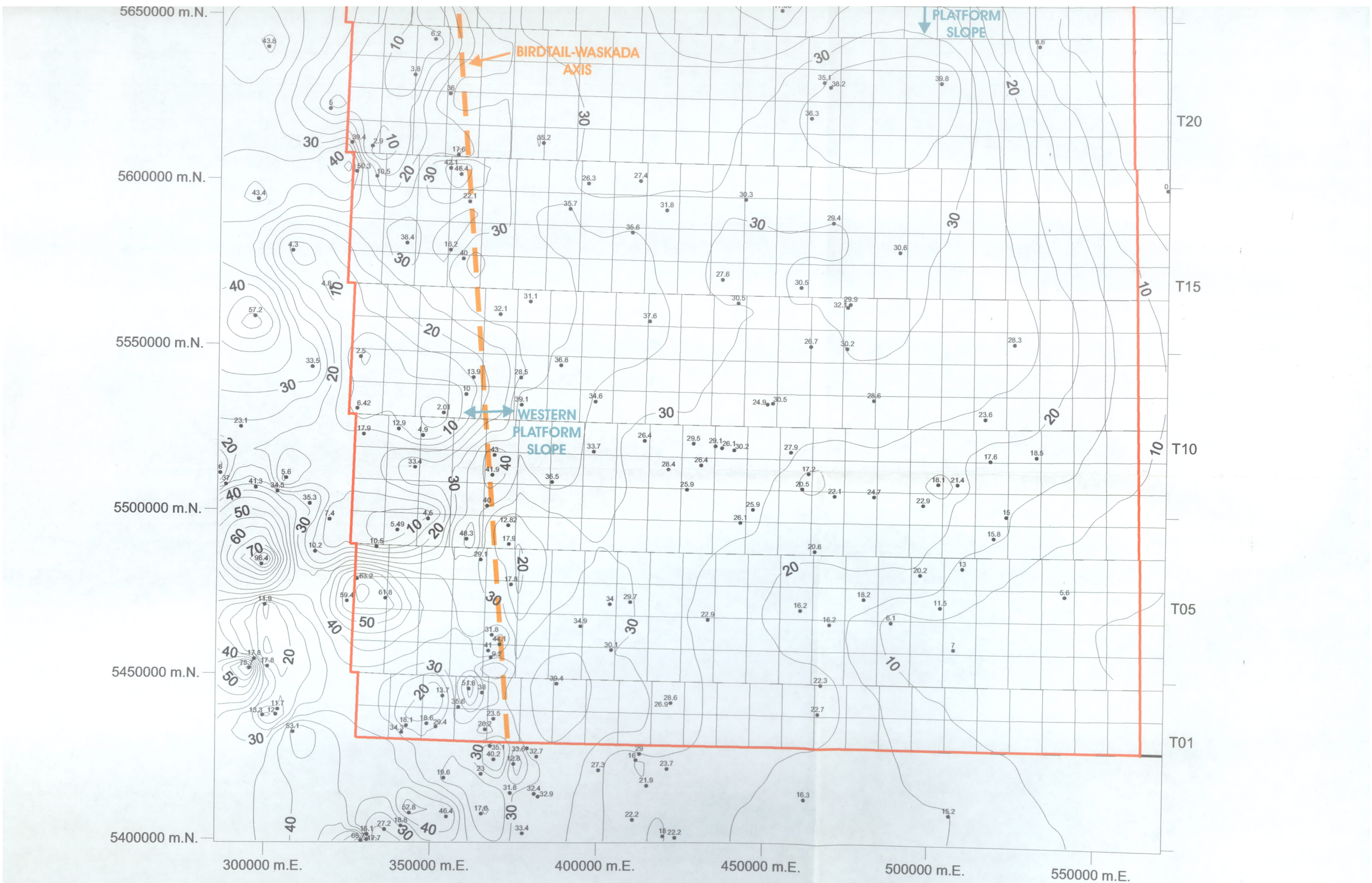
Table F.1: Rock-Eval 6 pyrolysis data.

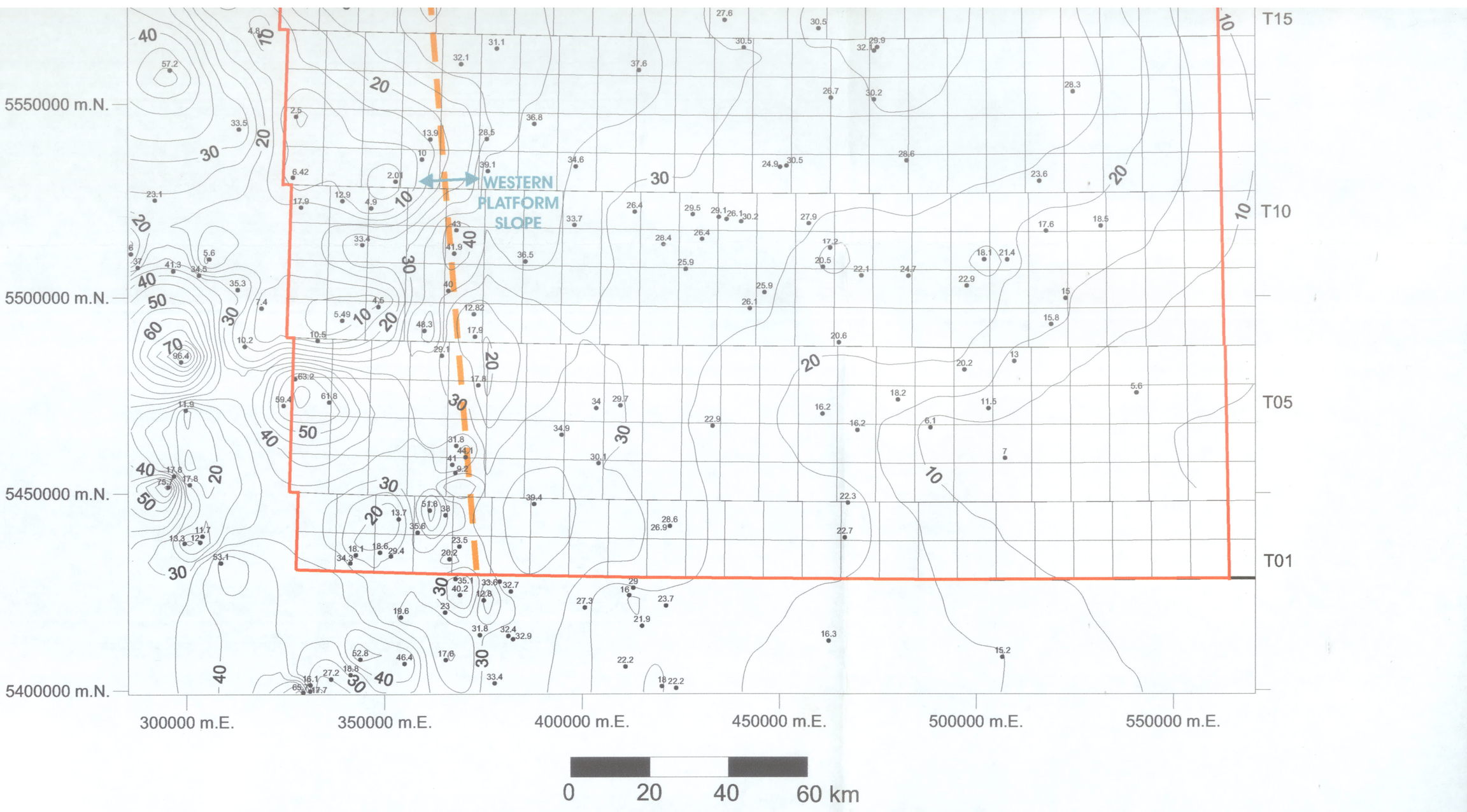
Location	Depth	Sample	Pellet #	Laminite Type	Qty (mg)	S1	S2	S'2	PI	$S3CO_2$	Tmax
11-29-001-25W1	1528.34 m (5014.25')	L2543 #6	1168	Platform Slope	71.0	0.23	5.64	0.01	0.04	0.57	427
11-29-001-25W1	1531.85 m (5025.75')	L2543 #3	1167	Ramp-to-Platform Transition	70.2	0.27	7.92	0.01	0.03	0.55	428
05-13-005-22W1	1153.76 m (3785.3')	L320 #9	1164	Platform Interior	70.7	1.88	62.91	0.07	0.03	1.64	423
05-13-005-22W1	1157.94 m (3799')	L320 #13	1162	Platform Interior	10.5	6.49	166.26	0.25	0.04	7.49	412
04-12-007-25W1	1198.68 m (3932.68')	L2986 #10	1169	Onlapping Platform Slope	70.2	3.78	83.51	0.04	0.04	1.68	416
09-26-007-25W1	1175.46 m (3856.5')	L217 #1	1163	Platform Slope	20.8	5.13	126.10	0.26	0.04	9.32	412
02-21-007-28W1	1447.7 m (4749.7')	L91#10	1173	Ramp-to-Basin Transition	70.2	0.76	15.81	0.02	0.05	0.71	421
03-01-008-18W1	783.95 m (2572')	L44 #3	1159	Platform Interior	70.0	0.11	1.41	0.00	0.07	0.32	425
03-01-008-18W1	784.55 m (2574')	L44 #6	1161	Platform Interior	10.8	6.17	208.42	0.37	0.03	13.75	415
103/03-12-011-27W1	1178.57 m (3866.70')	L4948 #10	1171	Basinal Salina	69.9	1.92	54.52	0.03	0.03	0.37	413
04-33-023-16W1	205.53 m (674.3')	L2474#17	1166	Onlapping Platform Slope	70.5	3.24	79.10	0.06	0.04	0.80	407
04-33-023-16W1	205.95 m (675.7')	L2474#16	1165	Onlapping Platform Slope	70.5	0.21	2.86	0.01	0.07	1.15	430
12-35-024-10W1	17.58 m (57.68')	M-4-90A	1172	Ramp-to-Platform Transition	69.9	1.17	30.26	0.03	0.04	2.20	399

Sample	Tpeak	S3CO	PC(%)	TOC	S1/TOC	RC%	HI	OICO	$OICO_2$	OIRE6	MINC%	S4CO	$S4CO_2$	RCCO(%)	$S4CO_2$	$S5aCO_2$
L2543 #6	467	0.03	0.49	2.09	0.11	1.60	270	1	27	20	12.0	1.9	55.7	0.081	42.6	120.3
L2543 #3	468	0.18	0.69	2.61	0.10	1.92	304	7	21	19	12.0	2.8	66.1	0.120	49.7	128.2
L320 #9	463	1.02	5.43	10.70	0.18	5.27	589	10	15	17	10.3	16.2	167.7	0.694	134.3	48.6
L320 #13	452	6.95	14.66	41.55	0.16	26.89	401	17	18	23	1.7	106.9	817.8	4.581	675.4	24.8
L2986 #10	456	1.25	7.30	12.71	0.30	5.41	657	10	13	15	4.6	20.1	166.6	0.861	128.5	48.4
L217 #1	452	6.81	11.21	36.55	0.14	25.34	346	19	25	29	1.3	107.4	760.2	4.603	648.0	2.6
L91#10	461	0.16	1.38	2.87	0.26	1.49	552	6	25	22	11.1	1.8	52.0	0.077	35.5	46.1
L44 #3	465	0.03	0.13	0.84	0.13	0.71	168	4	38	30	11.9	1.5	23.7	0.064	15.3	43.2
L44 #6	455	11.91	18.35	52.25	0.12	33.90	400	23	26	32	0.8	98.7	1087.9	4.230	944.5	1.1
L4948 #10	453	0.21	4.70	5.98	0.32	1.28	912	4	6	7	9.9	3.1	41.9	0.133	30.5	40.6
L2474#17	447	0.34	6.85	13.09	0.25	6.24	605	3	6	6	9.0	22.1	194.2	0.947	166.9	43.0
L2474#16	470	0.41	0.27	2.20	0.10	1.93	130	19	52	49	11.3	4.5	63.8	0.193	45.4	38.0
M-4-90A	439	1.11	2.66	6.05	0.19	3.39	501	18	36	36	11.0	8.9	110.2	0.381	53.0	24.2

Sample	$S5bCO_2$	KFID	$RCCO_2$(%)
L2543 #6	252.5	1403.447	1.52
L2543 #3	248.9	1403.447	1.80
L320 #9	299.9	1403.447	4.57
L320 #13	0.7	1403.447	22.30
L2986 #10	83.1	1403.447	4.54
L217 #1	0.0	1403.447	20.73
L91#10	328.8	1403.447	1.42
L44 #3	376.6	1403.447	0.65
L44 #6	0.3	1403.447	29.67
L4948 #10	304.4	1403.447	1.14
L2474#17	264.1	1403.447	5.30
L2474#16	365.4	1403.447	1.74
M-4-90A	368.3	1403.447	3.01


R25
R20
R15
R10
R5W1
T45
T40
T35
T30
T25
5850000 m.N.
5800000 m.N.
5750000 m.N.
5700000 m.N.
5650000 m.N.
BASIN
&
ISOLATED REEFS
NORTHERN
PLATFORM
SLOPE
BIRDTAIL-WASKADA


BIRDTAIL-WASKADA AXIS
PLATFORM SLOPE
WESTERN PLATFORM SLOPE
5650000 m.N.
5600000 m.N.
5550000 m.N.
5500000 m.N.
5450000 m.N.
5400000 m.N.
300000 m.E.
350000 m.E.
400000 m.E.
450000 m.E.
500000 m.E.
550000 m.E.
T20
T15
T10
T05
T01



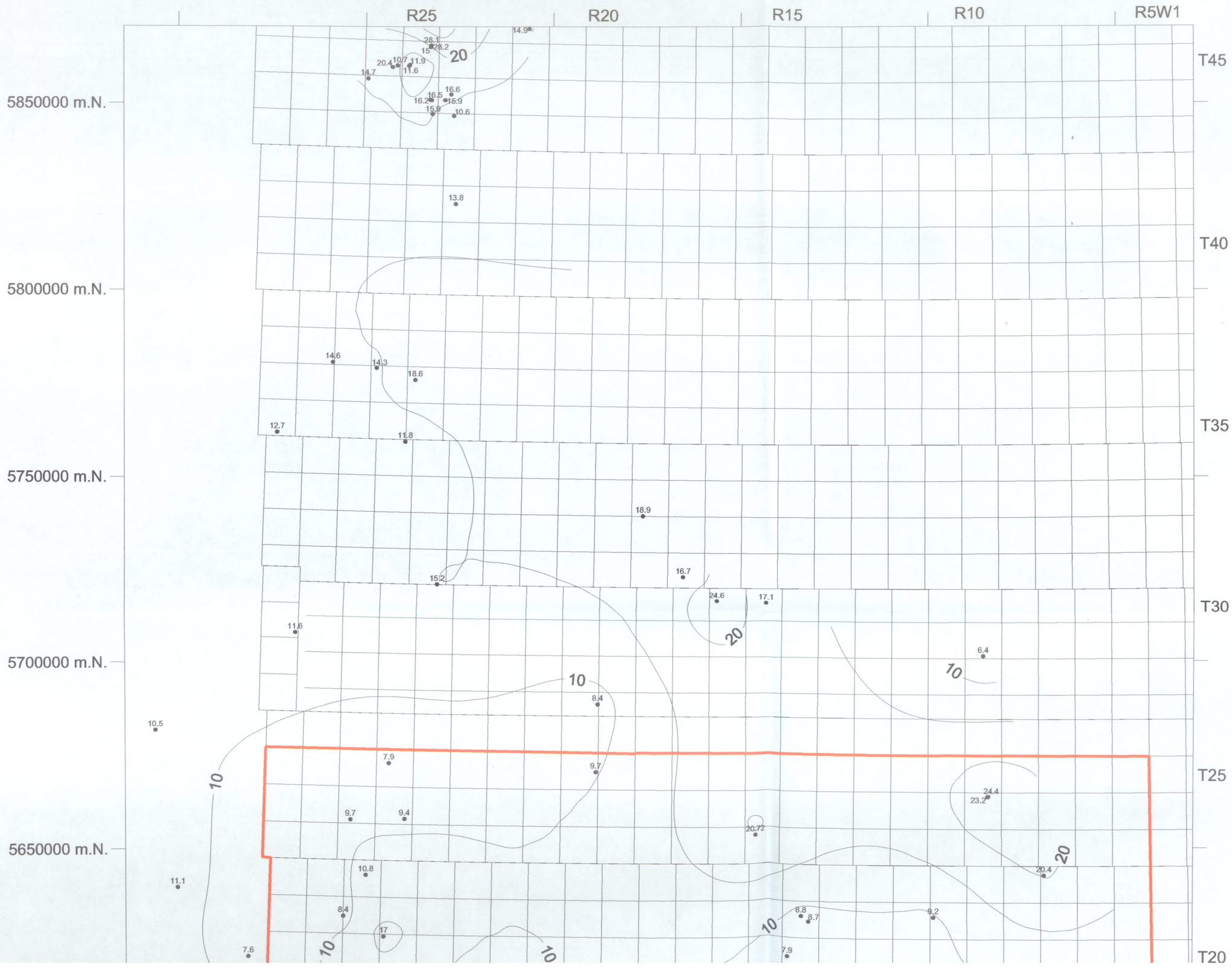
Enclosure 9: Isopach Map of the Upper Winnipegosis Member and Ratner Formation

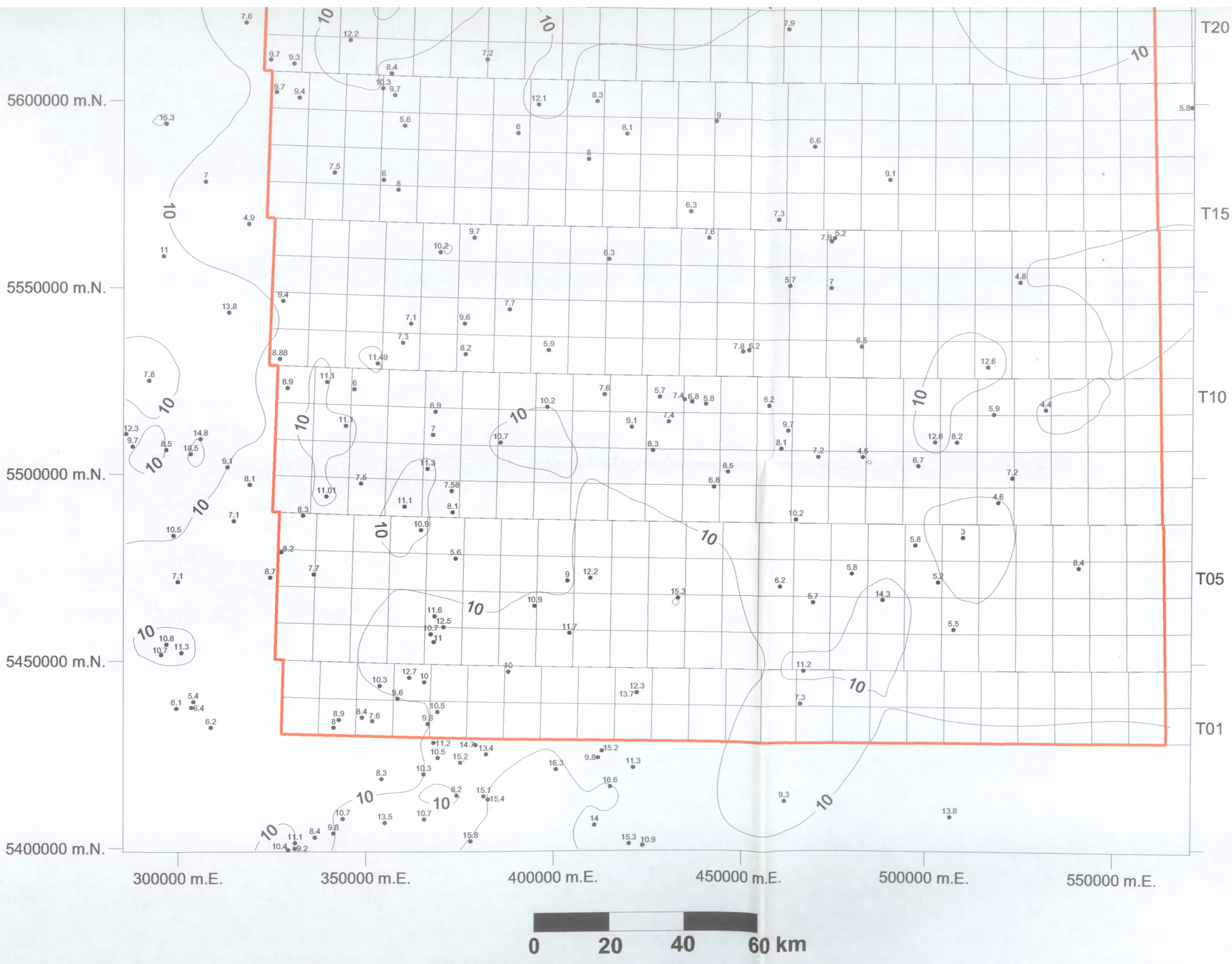
Projection: UTM, Zone 14U, NAD-83.

Isopach values given in meters.

Isopach contour Interval: 5 m.

Study area outlined in red.


R25
R20
R15
R10
R5W1
T45
T40
T35
T30
T25
T20
5850000 m.N.
5800000 m.N.
5750000 m.N.
5700000 m.N.
5650000 m.N.
20
10
14.9
28.1
28.2
15
20.4
10.7
11.9
11.6
14.7
16.6
16.5
16.2
15.9
15.9
10.6
13.8
14.6
14.3
18.6
12.7
11.8
18.9
15.2
16.7
24.6
17.1
11.6
6.4
8.4
10.5
7.9
9.7
9.7
9.4
24.4
23.2
20.72
20.4
10.8
11.1
8.4
17
8.8
8.7
9.2
7.6
7.9



sure 8: Isopach Map of the Lower Winnipegosis Member and Elm Point Formation

5550000 m.N.

5500000 m.N.

5450000 m.N.

5400000 m.N.

300000 m.E.

350000 m.E.

400000 m.E.

450000 m.E.

500000 m.E.

550000 m.E.

T10

T05

T01

0 20 40 60 km

closure 8: Isopach Map of the Lower Winnipegosis Member and Elm Point Formation

Projection: UTM, Zone 14U, NAD-83.

Isopach values given in meters.

Isopach contour Interval: 5 m.

Study area outlined in red.

A

07-08-011-29W1
LIC#: 134

<=24.9 km=>

14-13-009-28W1
LIC#: 3083

<=33.3 km=>

09-26-007-25W1 04-12-007-25W1
<=5.7 km=>
LIC#: 217 LIC#: 2986

GAMMA RAY
SONIC
SPONTANEOUS POTENTIAL
RESISTIVITY
RESISTIVITY
GAMMA RAY

1350
1275
1175
1150
1375
1325
1225

UPPER WINNIPEGOSIS MEMBER
UPPER WINNIPEGOSIS MEMBER
RATNER FORMATION
RATNER FORMATION
LOWER WINNIPEGOSIS MEMBER
TOP OF ASHERN FM.
?

-12-007-25W1

<=35.7 km=>

05-13-005-22W1

=>

LIC#: 2986

LIC#: 320

ITY

1175

RESISTIVITY

GAMMA RAY

RESISTIVITY

50

1175

1225

?

?

?

?

?

?

?

?

TOP OF WINNIPEGOSIS FM.

TOP OF WINNIPEGO

UPPER WINNIPEGOSIS MEMBER

UPPER WIN

LOWER WINNIPEGOSIS MEMBER

LOWER WI

TOP OF ASHERN FM.

<=85 km=>

16-33-004-13W1

A'

LIC#: 609

SPONTANEOUS POTENTIAL

650

675

50 m

40 m

30 m

20 m

10 m

0 m

150'

100'

50'

0'

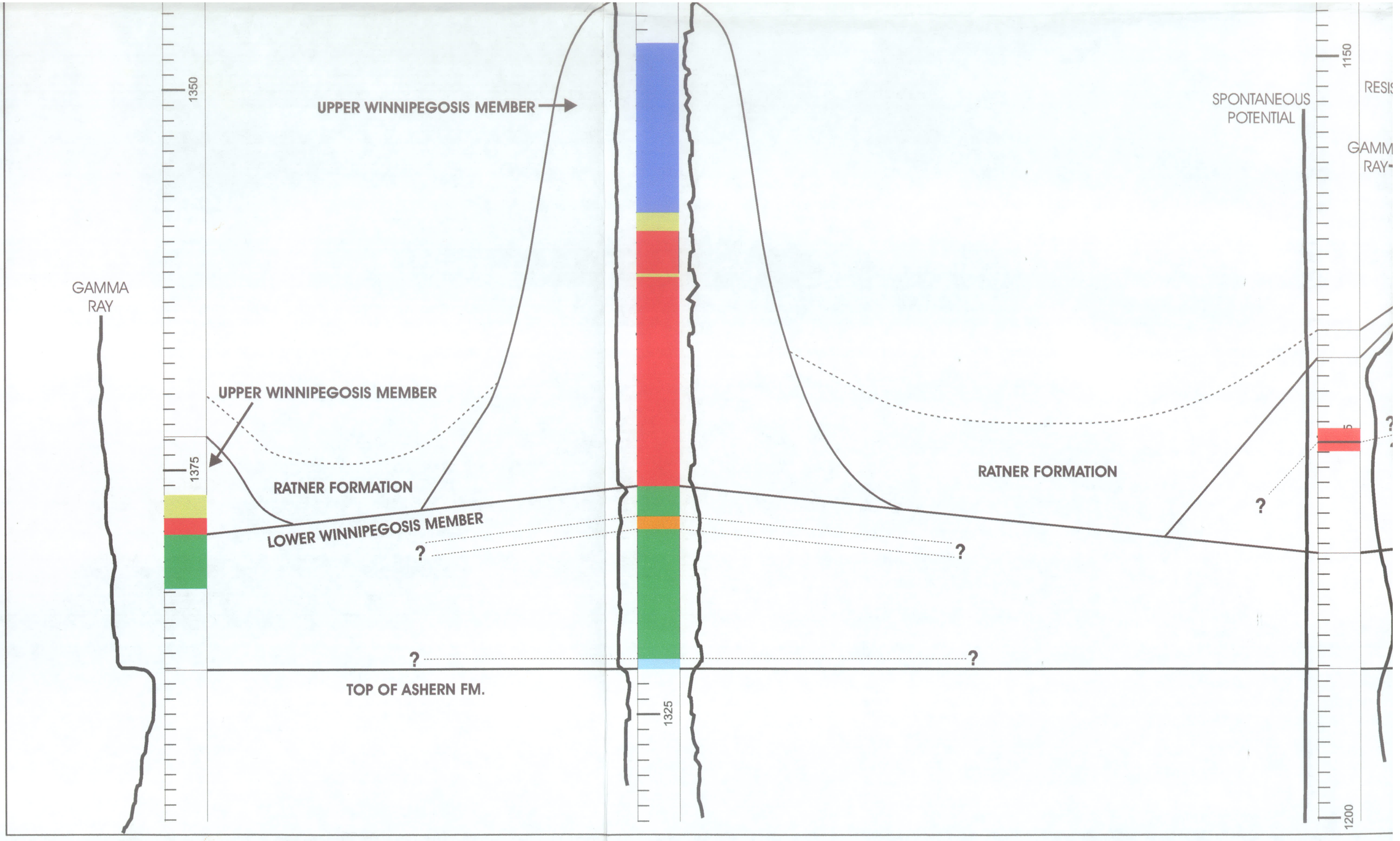
TOP OF WINNIPEGOSIS FM.

UPPER WINNIPEGOSIS MEMBER

LOWER WINNIPEGOSIS MEMBER

?

TOP OF ASHERN FM.



ENCLOSURE 1: CROSS SECTION A-A'

OUS
AL

1150

RESISTIVITY

GAMMA
RAY

RESISTIVITY

?

TOP OF WINNIPEGOSIS FM.

?

?

?

TOP OF WINNIPEGOSIS FM.

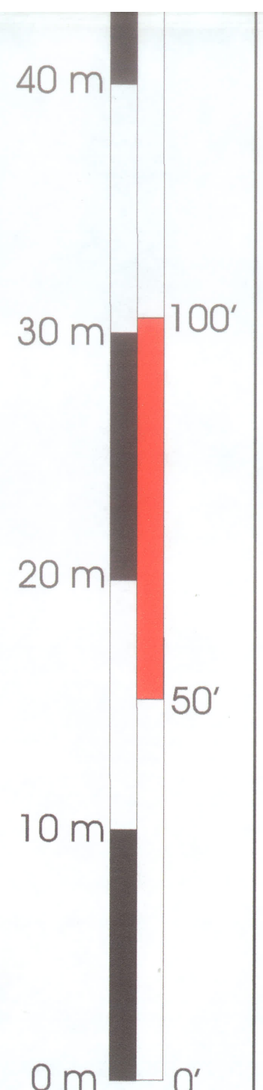
UPPER WINNIPEGOSIS MEMBER

LOWER WINNIPEGOSIS MEMBER

?

TOP OF ASHERN FM.





B

16-18-018-29W1

<=35.2 km=>

LIC#: 19

GAMMA RAY

RESISTIVITY

950

975

1000

UPPER WINNIPEGOSIS MEMBER

01-27-017-26W1

<=71.2 km=>

LIC#: 17

925

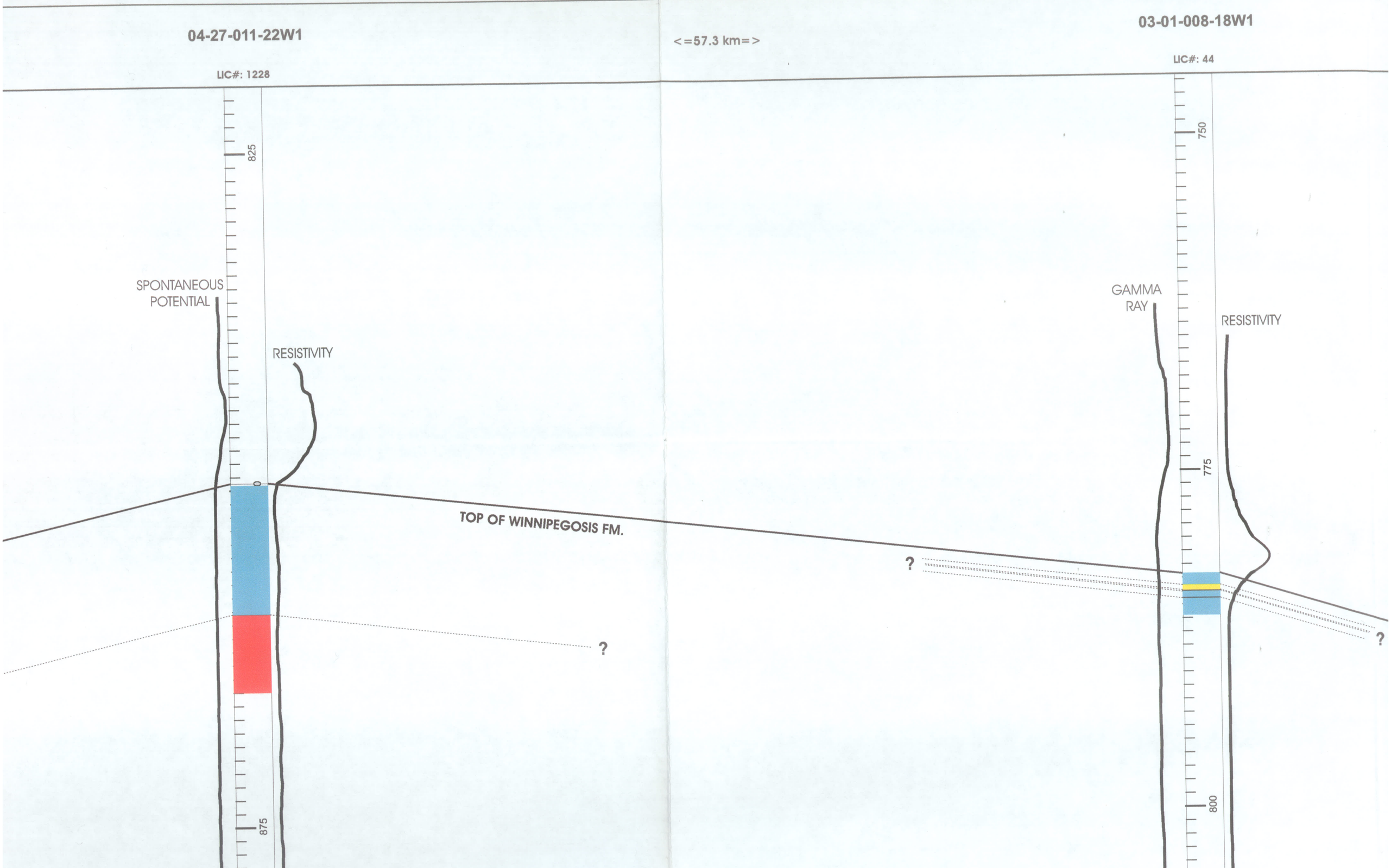
GAMMA RAY

RESISTIVITY

950

TOP OF WINNIPEGOSIS FM.

?


04-27-011-22W1
LIC#: 1228
825
SPONTANEOUS POTENTIAL
RESISTIVITY
0
TOP OF WINNIPEGOSIS FM.
?
875
<=57.3 km=>
03-01-008-18W1
LIC#: 44
750
GAMMA RAY
RESISTIVITY
775
?
?
800

km=>

03-01-008-18W1

LIC#: 44

<=55 km=>

16-33-004-13W1

LIC#: 609

B'

750

775

800

625

650

675

GAMMA RAY

RESISTIVITY

SPONTANEOUS POTENTIAL

?

?

TOP OF WINNIPEGOSIS FM.

70 m

60 m

50 m

40 m

30 m

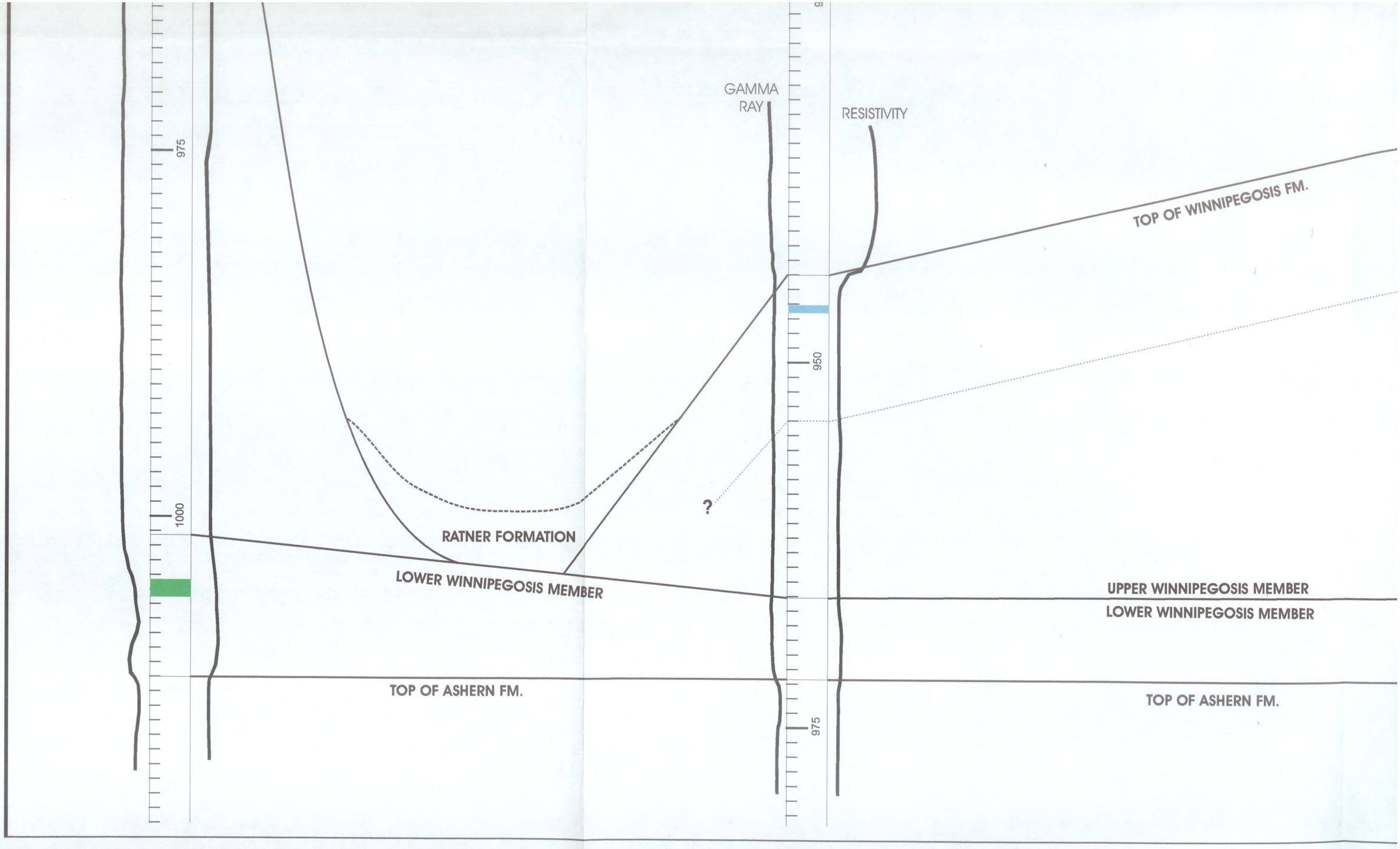
20 m

200'

150'

100'

50'



ENCLOSURE 2: CROSS SECTION B-B'

TOP OF WINNIPEGOSIS FM.

TOP OF WINNIPEGOSIS FM.

?

?

0

875

900

UPPER WINNIPEGOSIS MEMBER

LOWER WINNIPEGOSIS MEMBER

TOP OF ASHERN FM.

UPPER WINNIPEGOSIS MEMBER

LOWER WINNIPEGOSIS MEMBER

TOP OF ASHERN FM.

775

800

825

650

675

?

?

TOP OF WINNIPEGOSIS FM.

UPPER WINNIPEGOSIS MEMBER

LOWER WINNIPEGOSIS MEMBER

?

S MEMBER

IS MEMBER

ERN FM.

TOP OF ASHERN FM.

40 m

30 m

20 m

10 m

0 m

100′

50′

0′

C

09-13-001-26W1

<=4.1 km=>

11-29-001-25W1

<=49.3 km=>

05-13-005-22W1

<=62.3 km=>

LIC#: 184

LIC#: 2543

LIC#: 320

SPONTANEOUS POTENTIAL

RESISTIVITY

GAMMA RAY

RESISTIVITY

GAMMA RAY

RESISTIVITY

1525

1500

50

1550

1175

1575

UPPER WINNIPEGOSIS MEMBER

RATNER FORMATION

TOP OF WINNIPEGOSIS FM.

TOP OF WINNIPE

?

UPPER WINNIPEGOSIS MEMBER

LOWER WINNIPEGOSIS MEMBER

UPPER WINNIPEGOSI

LOWER WINNIPEGOSIS

TOP OF ASHERN FM.

TOP OF ASHERN FM.

TOP OF ASHERI

<=62.3 km=>

04-27-011-22W1

<=130.8 km=>

LIC#: 1228

SPONTANEOUS POTENTIAL

RESISTIVITY

?

?

875

P OF WINNIPEGOSIS FM.

TOP OF WINNIPEGOSIS FM.

R WINNIPEGOSIS MEMBER

WINNIPEGOSIS MEMBER

UPPER WINNIPEGOSIS MEMBER

LOWER WINNIPEGOSIS MEMBER

TOP OF ASHERN FM.

TOP OF ASHERN FM.

04-33-023-16W1

LIC#: 2474

<=63.5 km=>

12-35-024-10W1

M-04-90

C'

SPONTANEOUS POTENTIAL

RESISTIVITY

ONLAPPING BITUMINOUS LAMINITE

200

225

?

UPPER WINNIPEGOSIS MEMBER

LOWER WINNIPEGOSIS MEMBER

TOP OF ASHERN FM.

TD 243.8m

TD 44.7m

50 m

40 m

30 m

20 m

10 m

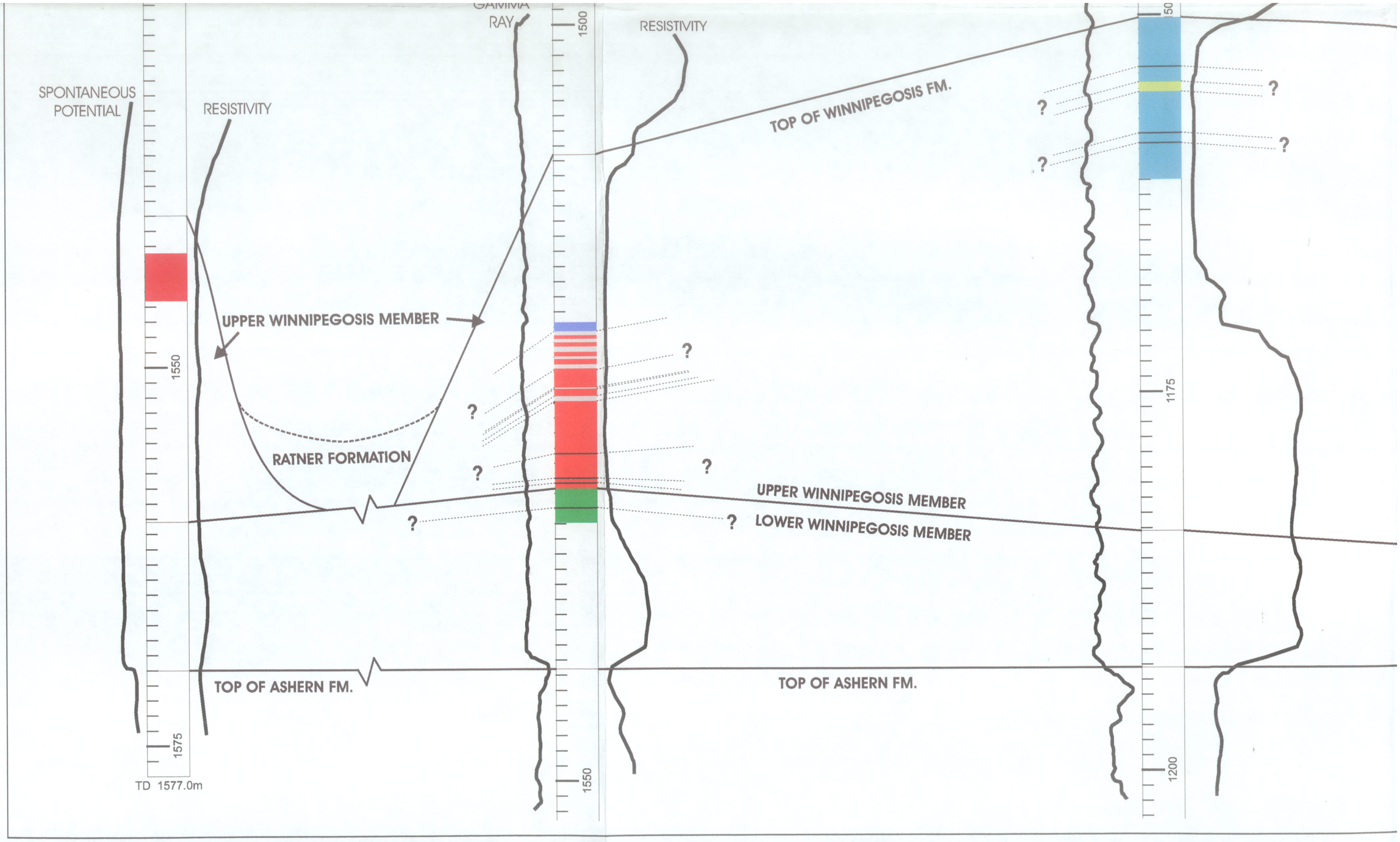
0 m

150'

100'

50'

0'



ENCLOSURE 3: CROSS SECTION C-C'

TOP OF WINNIPEGOSIS FM.

?

?

?

?

UPPER WINNIPEGOSIS MEMBER

LOWER WINNIPEGOSIS MEMBER

TOP OF ASHERN FM.

0

875

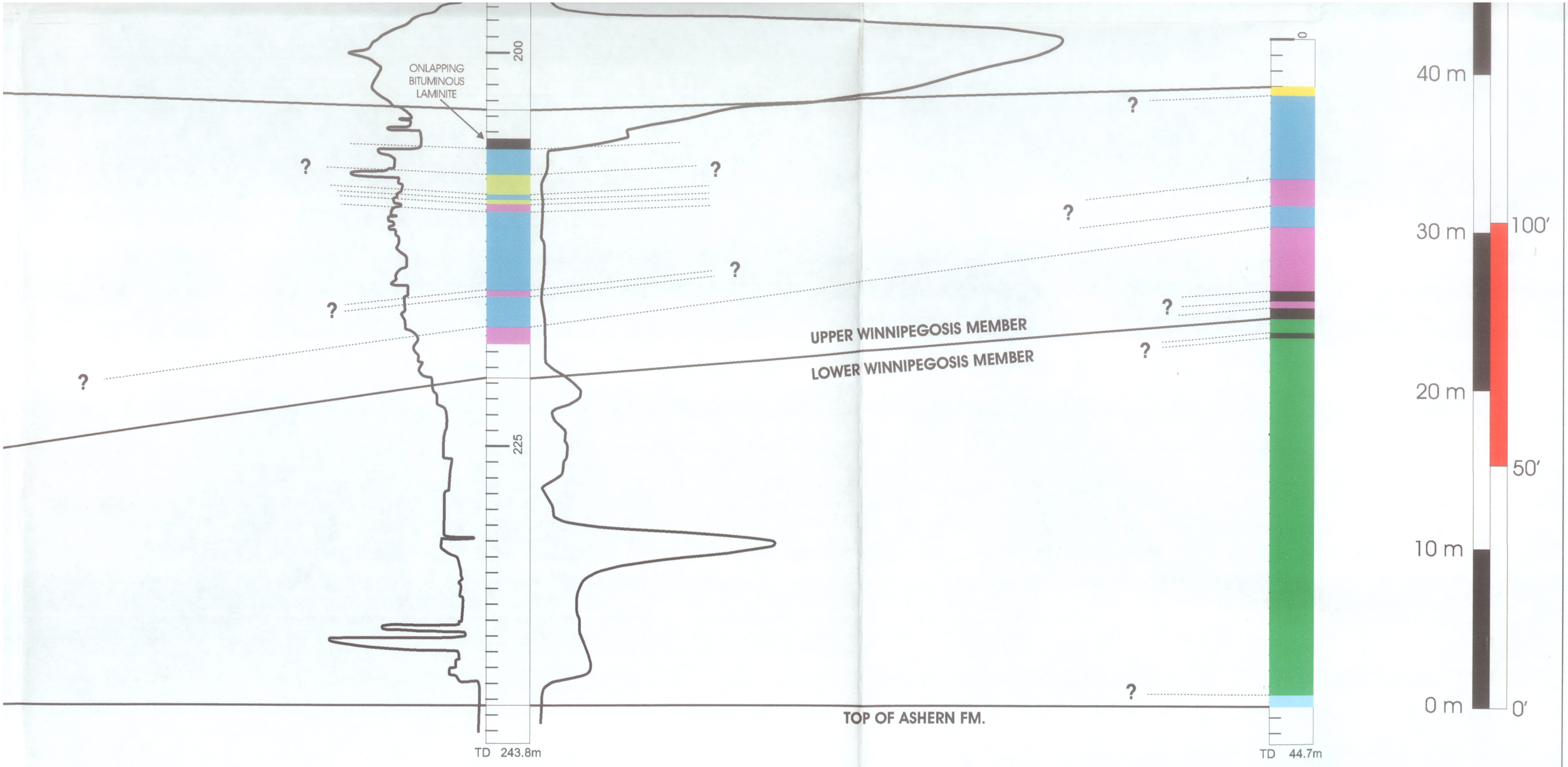
900

TOP OF WINNIPEG

UPPER WINNIPE

LOWER WINNI

TOP O


ONLAPPING
BITUMINOUS
LAMINITE
200
225
?
UPPER WINNIPEGOSIS MEMBER
LOWER WINNIPEGOSIS MEMBER
TOP OF ASHERN FM.
TD 243.8m
TD 44.7m
0
40 m
30 m
20 m
10 m
0 m
100'
50'
0'

D

10-09-001-28W1

<=18.7 km=>

09-06-002-26W1

<=22.7 km=>

05-03-004-25W1

LIC#: 4115

LIC#: 2610

LIC#: 1876

1700

1500

1325

1375

GAMMA RAY

RESISTIVITY

UPPER WINNIPEGOSIS MEMBER

UPPER WI

<=37.3 km=>

08-13-005-29W1

LIC#: 2696

GAMMA RAY

RESISTIVITY

1550

PER WINNIPEGOSIS MEMBER

<=21.1 km=>

02-21-007-28W1

LIC#: 91

1400

GAMMA RAY

1425

<=19.8 km=>

14-13-009-

LIC#: 308

1250

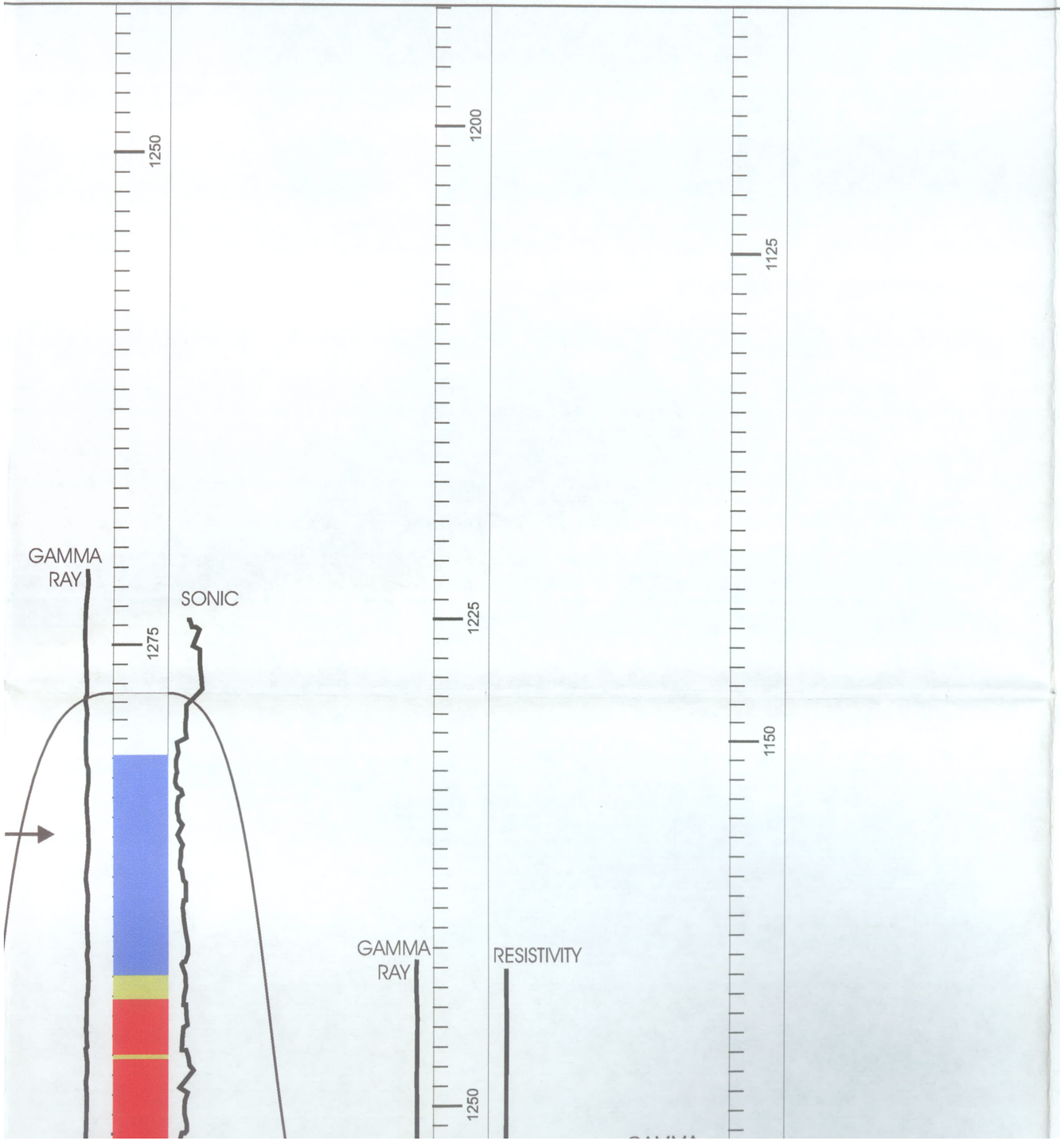
GAMMA RAY

1275

UPPER WINNIPEGOSIS MEMBER

14-13-009-28W1 <=10 km=> 15-18-010-27W1 <=9.3 km=> 103/03-12-011-27W1 <=77.3 km=

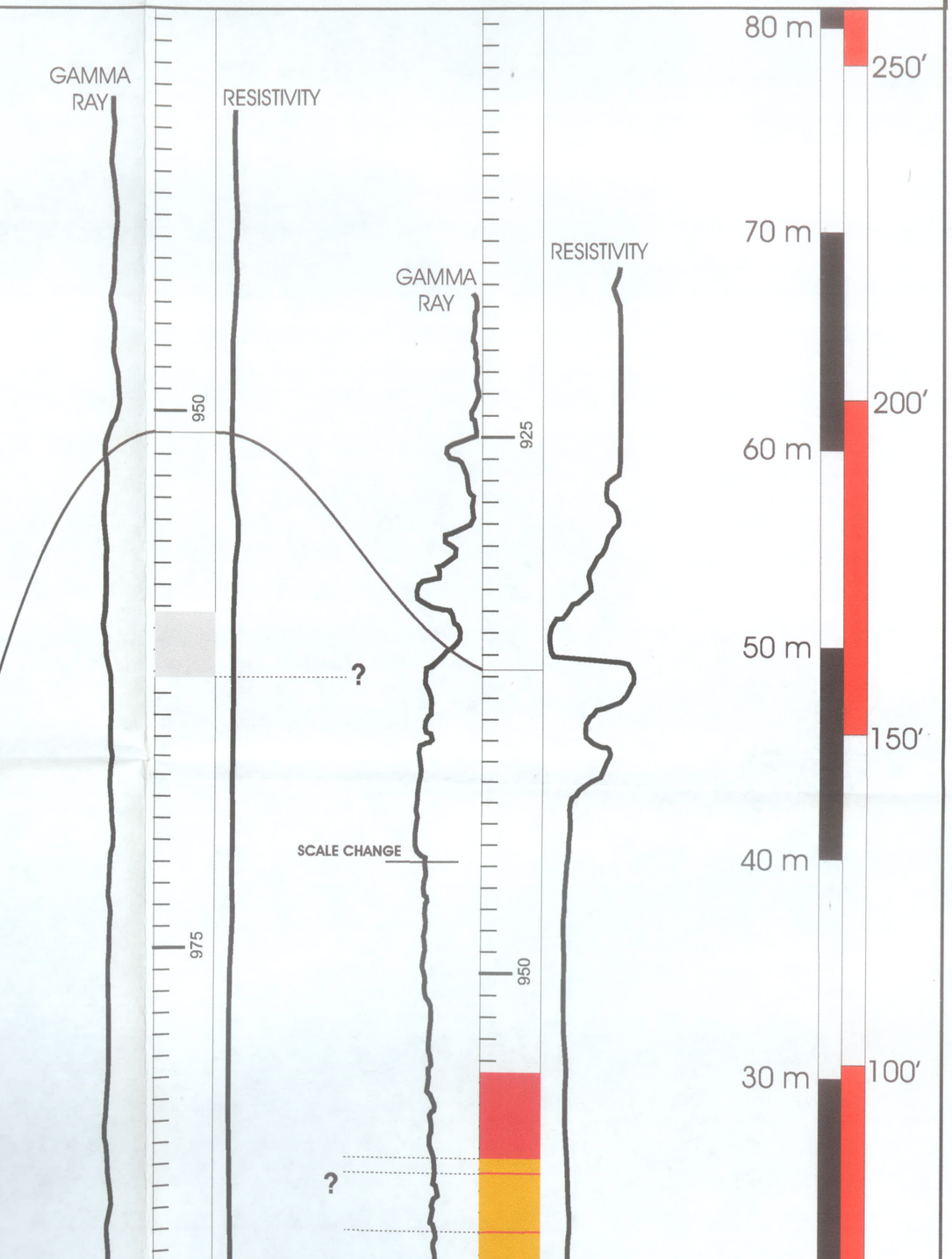
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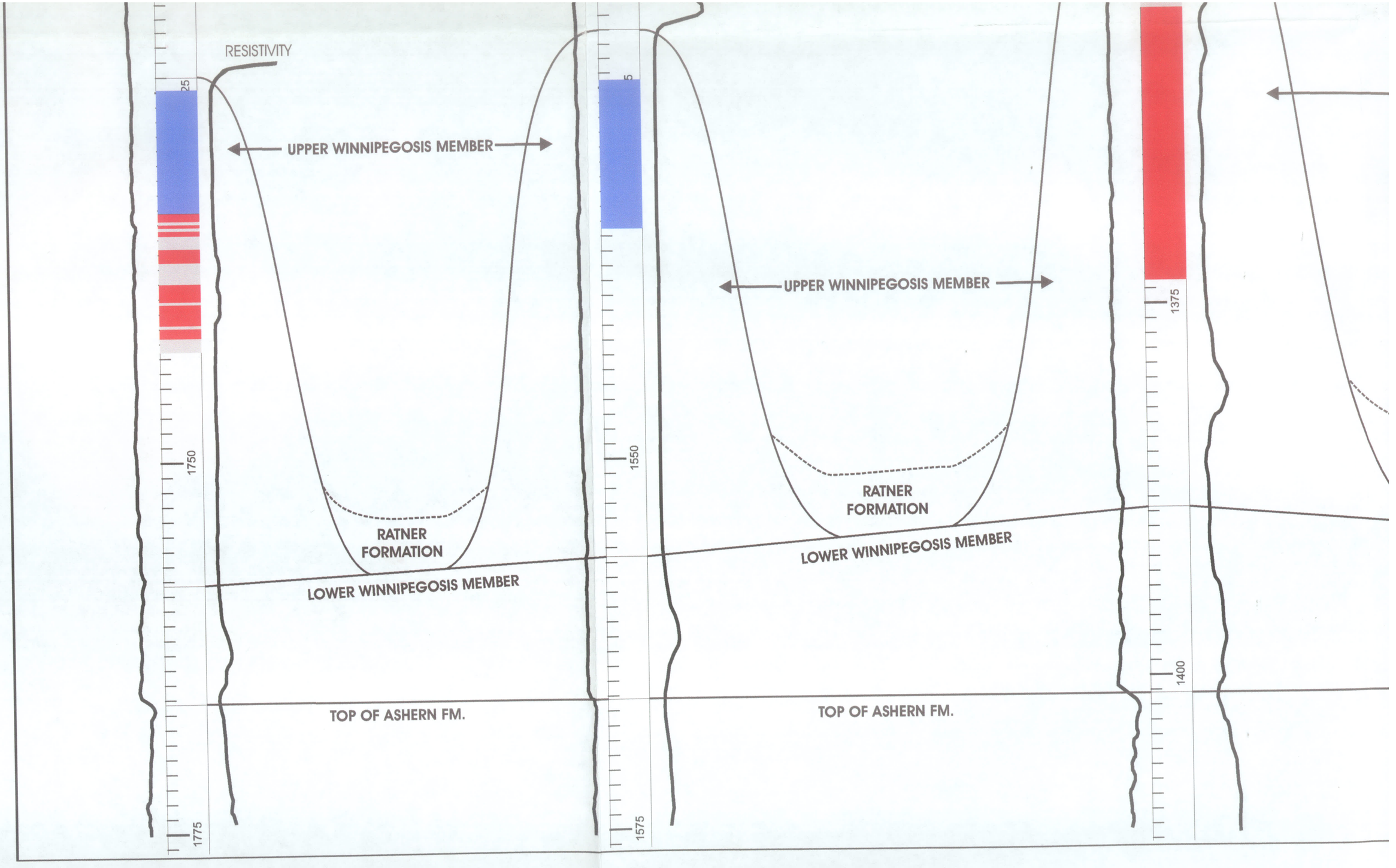


=77.3 km=>

16-18-018-29W1 <=8.9 km=> 04-17-019-29W1

D'





ENCLOSURE 4: CROSS SECTION D-D'

UPPER WINNIPEGOSIS MEMBER

RATNER
FORMATION

LOWER WINNIPEGOSIS MEMBER

TOP OF ASHERN FM.

1550

1575

1600

GAMMA
RAY

1425

1450

UPPER WINN

RATNER
FORMATION

?

LOWI

?

TOP OF ASHE

UPPER WINNIPEGOSIS MEMBER

RATNER FORMATION

? LOWER WINNIPEGOSIS MEMBER

? ?

? ?

TOP OF ASHERN FM.

GAMMA RAY

RESISTIVITY

1250

1275

1325

GAMMA RAY

RESISTIVITY

1150

1175

1200

? ?

RATNER FORMATION

UPPER WINNIPEGOSIS MEMBER

LOWER WINNIPEGOSIS MEMBER

TOP OF ASHERN FM.

975

1000

UPPER WINNIPEGOSIS MEMBER

LOWER WINNIPEGOSIS MEMBER

SCALE CHANGE

975

1000

950

975

?

?

40 m

30 m

20 m

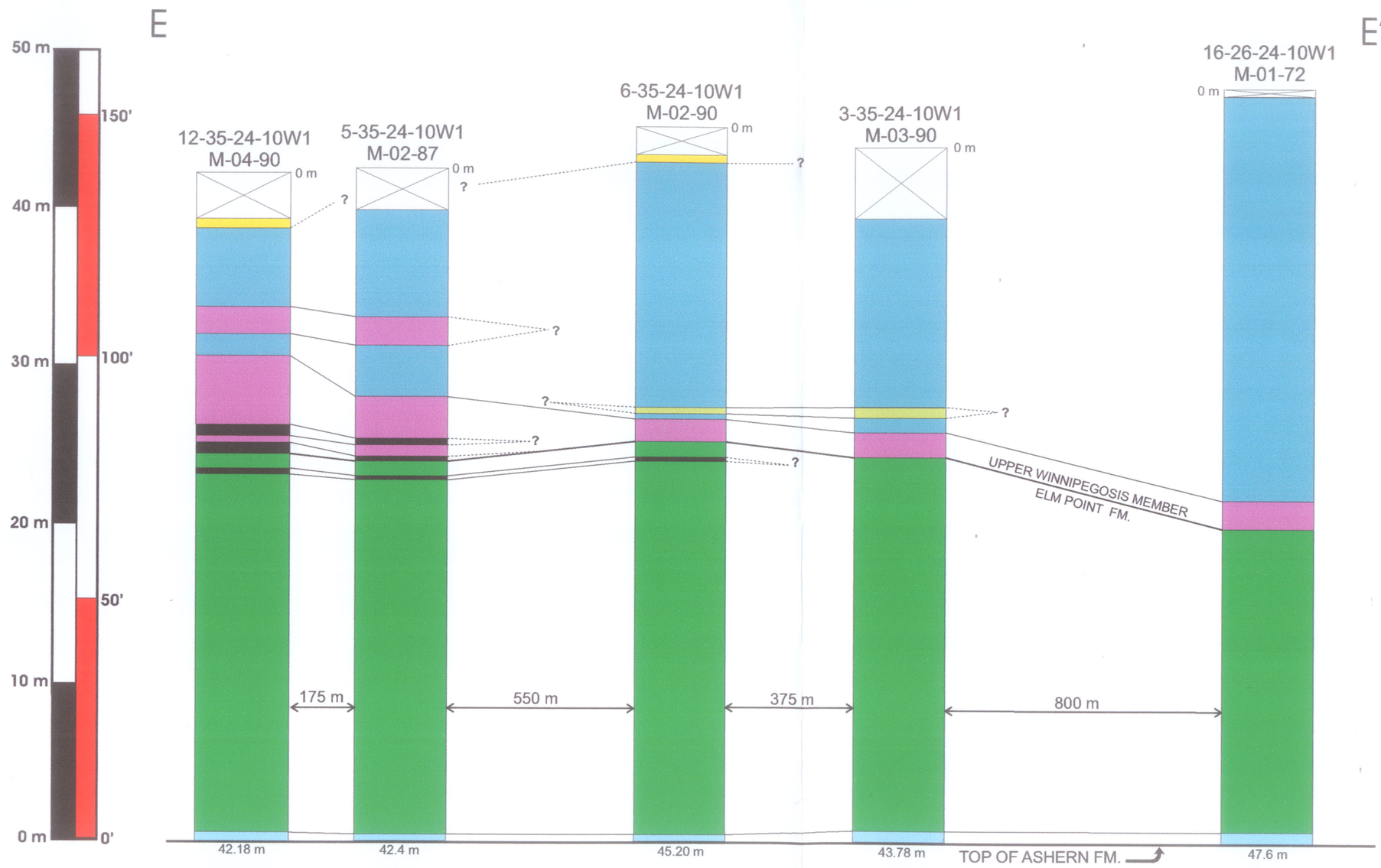
10 m

0 m

100′

50′

0′



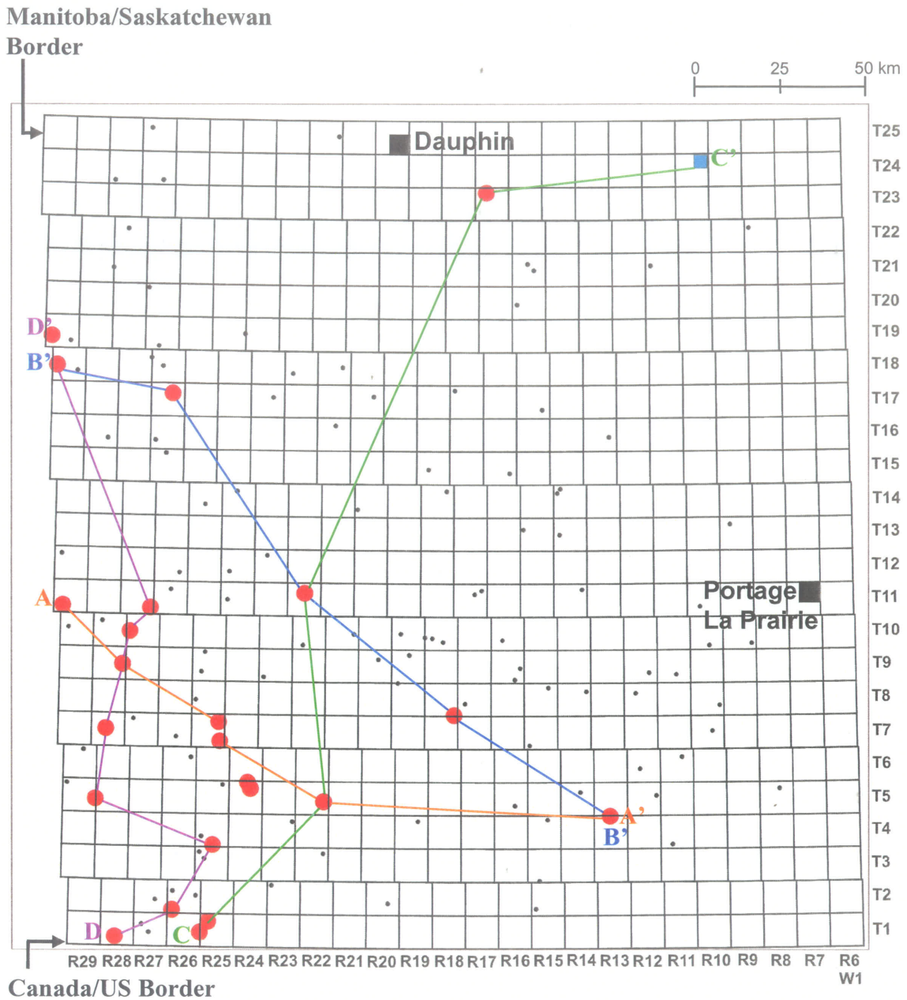
Enclosure 5: Cross Section E-E'

LEGEND

- LITHOFACIES A (non-fossiliferous mudstone)
- LITHOFACIES B (mottled-nodular skeletal wackestone-mudstone)
- LITHOFACIES C (nodular patterned mudstone)
- LITHOFACIES D* (bituminous laminite)
- LITHOFACIES E (interlaminated mudstone-anhydrite)
- LITHOFACIES F (massive - mottled mudstone)
- LITHOFACIES G (nodular skeletal packstone)
- LITHOFACIES H (bedded-massive peloidal packstone-grainstone)
- LITHOFACIES I (intraclast floatstone)
- LITHOFACIES J (bituminous skeletal wackestone-floatstone)
- LITHOFACIES K (peloidal-udoteacean packstone-grainstone)
- LITHOFACIES L (stromatoporoid floatstone)
- LITHOFACIES M (coral-stromatoporoid rudstone-framestone)
- LITHOFACIES N (laminated mudstone-peloidal packstone)
- LITHOFACIES O (microbial bindstone)

*Units thinner than 15 cm are represented by pencil lines and not drawn to scale.

Enclosure 6: Lithofacies legend for enclosures 1-5



Enclosure 7: Map showing the section lines of the regional cross sections. The red dots indicate the locations of wells for which petroleum cores were available. The blue square indicates the general location of cross section E-E' (Enclosure 5).