“In order to succeed, your desire for success should be greater than your fear of failure.”
- Bill Cosby

“The brain is a wonderful organ; it starts working the moment you get up in the morning and does not stop until you get into the office.”
-Robert Frost

“Better to do something imperfectly than to do nothing flawlessly”
-Robert H. Schuller

“To avoid criticism, do nothing, say nothing, be nothing”
- Elbert Hubbard

University of Alberta

SEDIMENTOLOGY, ICHNOLOGY AND DEVELOPMENT OF A SUB-REGIONAL DEPOSITIONAL AND STRATIGRAPHIC FRAMEWORK FOR THE MCMURRAY-WABISKAW SUCCESSION IN THE MACKAY RIVER AREA, NORTHEASTERN ALBERTA

by

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DEDICATION

This thesis is dedicated to the two most supportive people in my life, my parents, Laurie and Rod. There are no words to express my gratitude for the unconditional love, support, and encouragement you have given me over the past 25 years. It is through your guidance and assurance that has instilled in me the confidence and belief, that no dream is beyond reach and that I can achieve anything I put my mind to. Throughout your lives you have come face to face with many obstacles which have led to both successes and failures; through these you have taught me that continued courage, perseverance, strength, and most of all, family support, can get you through any adversity. It is through your example that I have come to appreciate the power of optimism, hard work, and most of all, love. These are the traits that make you extraordinary, and it is your determination to succeed that has been my inspiration. You have both had a great influence on shaping the person I am today, and I am forever grateful to have such amazing role models. I am also privileged and proud to call you both my parents, and my friends.

Thank you for being you.

ABSTRACT

The lower Cretaceous McMurray Formation is a prolific bitumen reservoir in the Athabasca Oil Sands deposit of northeastern Alberta. In the MacKay River area northwest of Fort McMurray, the depositional style, stratigraphy, and reservoir character differ from that of the traditional main valley trend. In this study, strata of the McMurray and overlying Clearwater Formation (Wabiskaw Member) was examined from 100 cored wells, and classified based on the sedimentological and ichnological character. This analysis identified that McMurray-Wabiskaw strata reflect a transition in depositional style from tide-dominated estuarine to shallow marine embayment. A network comprising thirteen cross-sections was also developed across the area, tied to cored intervals and wire-line log data. The complex stratigraphic relationships and stratigraphic surfaces were then examined within the McMurray-Wabiskaw succession. Overall, a third order depositional sequence was identified reflecting a major transgression and a starved sediment supply resulting in overall retrogradation, punctuated with episodes of progradation.

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LIST OF SYMBOLS AND ABBREVIATIONS

FACIES ANALYSIS

ECP	Facies Association 1: Estuary Coastal Plain
IME	Facies Association 2: Inner to Middle Estuary
SMBF	Facies Association 3: Shallow Marine Bay Fill
TSB	Facies Association 4: Tidal Sand Bar
POLS	Facies Association 5: Proximal Offshore to Lower Shoreface
DOS	Facies Association 6: Distal Offshore to Shelf
LSF	Facies Association 7: Lower Shoreface
FA	Facies Associations

ICHNOFOSSILS

Ta	*Taenadium*
Pl	*Planolites*
Cy	*Cylindrichnus*
Sk	*Skolithos*
fu	fugichnia
Mgy	*Microgyrolithes*
Gy	*Gyrolithes*
Ar	*Arenicolites*
Te	*Teichichnus*
As	*Asterosoma*
Rs	*Rosselia*
Bm	*Burrow mottling*
R	*Rhizoliths*
Ch	*Chondrites*
Pa	*Paleophycus*
Ph	*Phycosiphon*
Dp	*Diplocraterion*
Ps	*Psilonichnus*
Zo	*Zoophycos*
Rh	*Rhizocorallium*
Sh	*Schaubcylindrichnus*
Sc	*Scolicia*
Sp	*Spirophyton*
Om	*Ophiomorpha*
Th	*Thalassinoides*
Ma	*Macharonichnus*

ICHNOFOSSIL OCCURRENCE

vr	Very rare
r	Rare
m	Moderately Common
c	Common

STRATIGRAPHY

LEBF	Low Energy Bay-Fill Lithostratigraphic Package
TSB	Tidal Sand Bar Lithostratigraphic Package
LSFO	Lower Shoreface to Offshore Lithostratigraphic Package
PS	Parasequence
SB	Sequence Boundary
TSE	Transgressive Surface of Erosion

TS	Trangressive Surface
FS	Local Flooding Surface
RSE	Regressive Surface of Erosion
RS	Regressive Surface
ES	Local Erosional Surface
MFS	Maximum Flooding Surface
LST	Lowstand Systems Tract
TST	Transgressive Systems Tract
HST	Highstand Systems Tract
FSST	Falling-Stage Systems Tract

MISCELLANEOUS

BI	Bioturbation Index
WCSB	Western Canadian Sedimentary Basin
AOSA	Athabasca Oil Sands Area

AOSC	Athabasca Oil Sands Corp.
OPCO	Dover Operating Corporation

CHAPTER I – INTRODUCTION

With the accelerating depletion of conventional oil resources and a progressive rise in world oil prices, unconventional petroleum resources have become a significant facet to the global economy. Total global consumption of liquid fuels (including both conventional and unconventional liquid supplies) is projected to increase at an average rate of 1.3% per year from 86.1 million barrels per day (2007) to 110.6 million barrels per day (2035) (EIA, 2010). With a projected growth in production by 4.9% per year, unconventional oil resources are estimated to account for 12% of consumed liquid fuels by 2035, with Canada's oil sands as a leading contributor (EIA, 2010). This accounts for approximately 13.27 million barrels per day by 2035, from only 3.4 million barrels per day in 2007 (EIA, 2010). With a continual increase in demand from emerging industrial economies such as India and China, coupled with advancements regarding in-situ bitumen recovery technologies, production of these unconventional deposits should continue to flourish and will ultimately play a crucial role in supplementing the world's energy needs.

Canada's oil sands have become a world class asset, as the Alberta Oil Sands represent the largest single accumulation of crude bitumen on Earth. Development of the Alberta Oil Sands has shown considerable growth in the last ten years, with the rise from non-viable resources to "proven" economic reserves, and over one hundred oil companies invested in their exploitation. With an estimated 1.804 trillion barrels of original bitumen-in-place (OBIP), approximately 10% (176.8 billion bbls) has been established as recoverable reserves (ERCB, 2010). Since commercial bitumen development began in the late 1960's, only 3.9% of the original established reserves has been produced (ERCB, 2010). Of the remaining reserves, recoverable surface mineable bitumen is estimated at approximately 20%, or 34 billion bbls, and the remaining 80%, or 136 billion bbls, by in-situ methods (ERCB, 2010). This volume has placed Canada second in the world for proven oil reserves behind Saudi Arabia, and has promoted the country to the number one exporter of oil to the United States (EIA, 2010).

Three designated oil sands areas (OSAs) are recognized in northern Alberta, covering a combined area of roughly 142 000 square kilometers: Athabasca, Peace River, and Cold Lake (Fig. I-1) (ERCB, 2010). Total bitumen production within these areas is steadily increasing year by year. Current annual

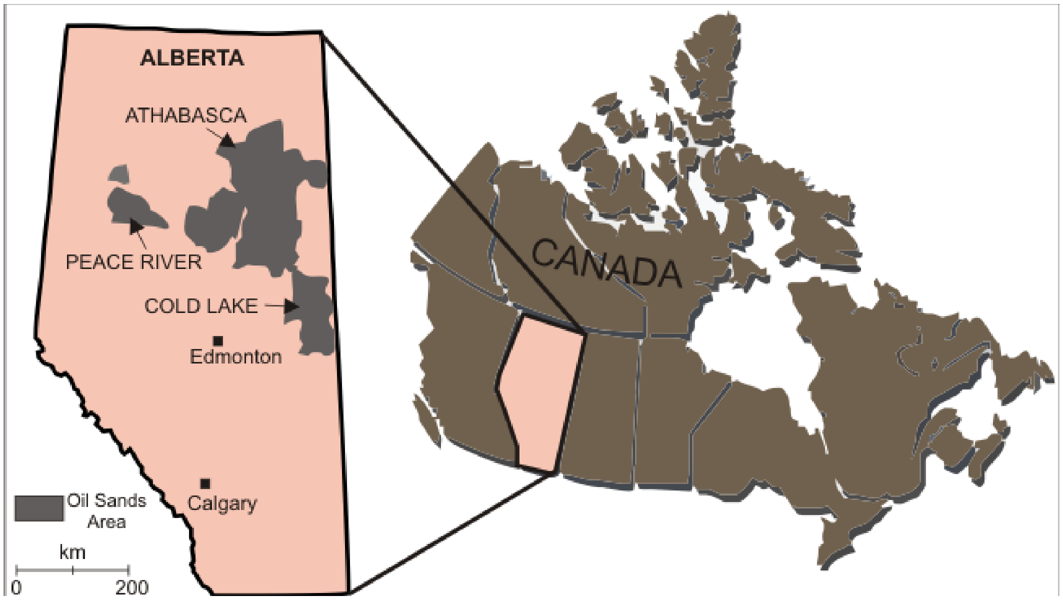

FIGURE I-1: The oil sands areas of western Canada. Modified from Ranger and Gingras (2003).

bitumen production is estimated at 544 million barrels and is expected to increase to about 1 billion barrels by 2019 (ERCB, 2010). Of these deposits, the Athabasca oil sands area (AOSA) is the largest, with OBIP volumes estimated at 1.484 trillion barrels (ERCB, 2010) and the majority of these reserves (959 billion bbl) are contained within loosely consolidated sands of the lower Cretaceous Mannville Group and its equivalents. This essentially contiguous reservoir is referred to as the McMurray-Wabiskaw stratigraphic interval.

Initial production of the Athabasca deposit involved extensive surface mining that has grown into a surface mineable area of 51.5 townships north of Fort McMurray (ERCB, 2010). Since then, in-situ projects have become increasingly important, where enhanced recovery methods are utilized to decrease the viscosity and initiate flow within the subsurface, producing bitumen similar to conventional oil production. Steam injection is the standard form of recovery enhancement, with steam assisted gravity drainage (SAGD) as the preferred leading-edge technology. In-situ projects are forecast to surpass the production rates from surface mining projects by 2015, and will account for 53% of total bitumen production by 2019 (ERCB, 2010).

The lower Cretaceous (Albian - Aptian) McMurray Formation and overlying Wabiskaw Member of the Clearwater Formation characterize a stratigraphically complex interplay of sedimentary facies representing a myriad of depositional environments. This succession exhibits some of the most complex lithofacies variations observed within the Western Canadian Sedimentary Basin

(WCSB) and correlation of these units is often difficult to impossible to interpret over a significant distance. This is largely a factor of the extreme heterogeneity and aerial unpredictability of facies in the subsurface (Ranger and Pemberton, 1997). These complexities have ultimately resulted in the dominance of site specific studies that exhibit good well control in reservoir areas but poor control in outlying areas. This has led to numerous biased and conflicting interpretations across the AOSA regarding the stratigraphy, and corresponding complex environmental regime responsible for these deposits (Mossop and Flach, 1983; Flach, 1984; Flach and Mossop, 1985; Keith *et al.,* 1989; Ranger and Pemberton, 1997; Hein *et al*., 2000; Caplan and Ranger, 2001; Caplan, 2002; Ranger and Gingras, 2003, 2007; Hein *et al.,* 2006; Crerar and Arnott, 2007; Ranger *et al.*, 2007).

The majority of data and knowledge collected on the McMurray-Wabiskaw succession is also predominantly from the main bitumen fairway, leaving adjacent areas relatively unstudied and in a bias regarding interpretations (Beckie and McIntosh, 1985; Wightman *et al*., 1991, 1995; Wightman and Pemberton, 1997; Ranger and Pemberton, 1988; Keith *et al.,* 1989; MacGillivray *et al.,* 1989; Hein and Cotterill, 2006; Hein *et al.,* 2006). The McMurray Formation in the main bitumen fairway has traditionally been subdivided into a tripartite stratigraphy consisting of lower, middle, and upper informal members (Carrigy, 1959) that correspond to broadly characterized depositional environments ranging from continental fluvial, marginal marine estuarine and shoreline deposition, respectively (Nelson and Glaister, 1978; Mossop and Flach, 1983; Keith *et al.,* 1989; Flach and Mossop, 1985). This has become notorious nomenclature, and often results in a notion to force-fit data and interpretations to the model. Although this stratigraphy has been consistently supported in the main bitumen fairway, it does not hold true across the entirety of the AOSA. These caveats have resulted in a lack of understanding from a local to regional perspective, with an unclear understanding in the nature of the bounding surfaces between members, particularly between the middle and upper members (Hein and Dolby, 2001; Hein *et al.,* 2000; Ranger and Gingras, 2003, 2007; Crerar and Arnott, 2007).

Ichnological studies are also relatively sparse across the AOSA. With regards to the McMurray Formation researchers have only undertaken ichnological studies in recent decades; with Pemberton *et al.* (1982) providing the first in-detailed categorization of biological traces commonly observed within the McMurray. Since then, a strong marine ichnological signature has been broadly recognized in the middle and upper McMurray, but the extent and detail of this signature has gone relatively unrecorded. This lack of understanding in the McMurray Formation has ultimately hindered exploitation of this deposit from exploration, production and development aspects, at both a lease and reservoir scale.

The Wabiskaw Member is a regionally extensive shallow marine succession of the Clearwater Formation that disconformably to unconformably overlies the McMurray Formation. This less extensively studied portion of the McMurray-Wabiskaw succession is characterized by three discrete, fine-grained, overlapping shallow marine sands that overlie and are partially interfingered with marine shales (Ranger *et al.,* 1988; Ranger, 1994). A number of interpretations have been developed for deposition of Wabiskaw sands within the AOSA including shoreface-attached marine bars (Ranger *et al.,* 1988), barrier bars (Jackson, 1984), and offshore bars (Bayliss and Levinson, 1976). These bitumen saturated sandstones are intermittently present throughout the AOSA and are estimated to contain 25 billion bbls of the total OBIP within the AOSA (Ranger *et al.,* 1988).

Development of a stratigraphic framework of any sedimentary deposit relies on the interpretation of depositional environments observed in the rock record through time, combined with the observed temporal changes in the process regime operating within those environments. For the most accurate interpretations, an integrated sedimentologic and ichnologic approach is necessary. Trace fossil analysis constitutes a valuable tool in recognizing stresses imparted on an environment and in the identification of major allostratigraphic discontinuities that would otherwise be difficult to discern. In order to enhance understanding of the genetic and stratigraphic aspects of the McMurray-Wabiskaw succession, a superlative understanding of the facies and facies relationships in the subsurface is required. This is especially significant for in-situ development, as stratigraphic analysis is the most important tool in the development of a meticulous geological model that will result in the most successful exploitation of a reservoir.

The focus of this study is on the Lower Cretaceous McMurray-Wabiskaw stratigraphic interval in the MacKay River area, which comprises a significant bitumen resource within the McMurray Formation of the AOSA, west of the main valley system (Fig. I-2). The McMurray sub-basin encompasses the main valley system in the AOSA and is constrained by the Grosmount High to the

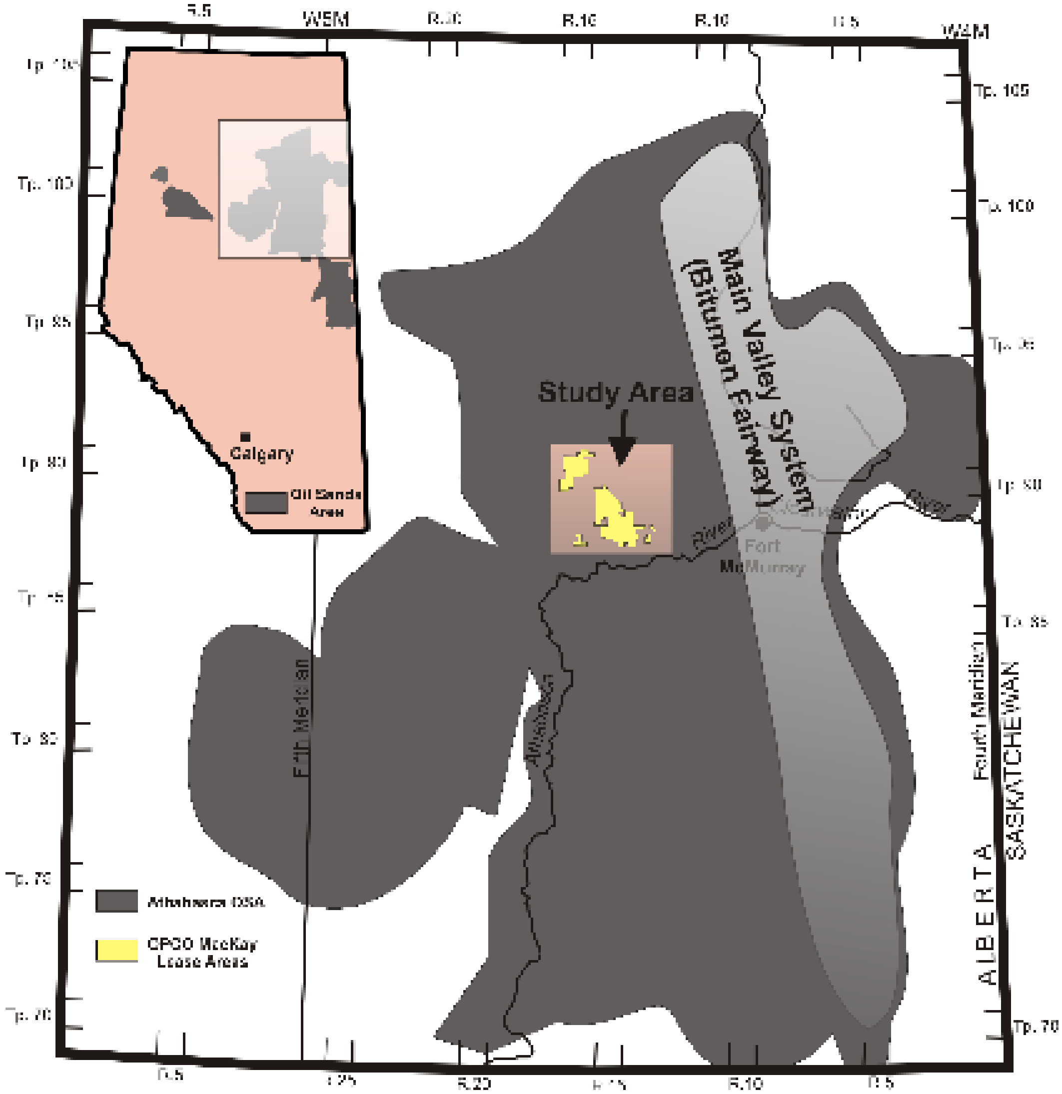

FIGURE I-2: Location of the MacKay River project area and OPCO lease areas featured prominently in this study, with respect to the main bitumen fairway in the AOSA of northeastern Alberta (Modified from Flach, 1984; Keith *et al.* 1989).

west and the Precambrian Shield to the east. This broad northwest to southeast-trending trough is further divided into secondary valleys and sub-basins, and exhibits a ridge and valley paleotopography. The position of the McMurray sub-basin was controlled largely by salt solution of the underlying evaporites and the structural collapse of Devonian carbonates. Sediment was largely sourced into the main valley system through continental drainage systems from the southeast. The MacKay River area is located on the eastern margin of a large tributary system connected to the northwest of the main valley. This secondary system is constrained by the Grosmont High in the west and the Ireton Formation subcrop in the east. The structure of this secondary tributary may have been largely controlled by the structural collapse of the recessive Ireton Formation shales. This would have resulted in a secondary valley system and drainage of the basin from the structural high in the west. This complex structural configuration ultimately influenced the deposition of McMurray-Wabiskaw sediments.

As the McMurray Formation is relatively unstudied in the MacKay River area, an integrated sedimentologic, ichnologic and stratigraphic study was conducted in order to develop a sound understanding of the depositional environments and their relationship in the subsurface. Semi-quantitative ichnological data are also integrated with sedimentological and stratigraphic observations to compare and contrast ichnological trends and stratigraphic relationships across different lease areas of the study area. The bulk of the dataset was collected from drill cores from the MacKay River Project oil sands lease area of Dover Operating Corporation (OPCO). Several additional cores outside of this area were examined to obtain a sub-regional stratigraphic understanding. A total of 100 cored wells were examined, representing approximately 4000 m of logged section. The resulting comprehensive stratigraphic framework will ultimately enhance reservoir predictability, distribution, and overall geologic understanding of the McMurray-Wabiskaw succession in the MacKay River area. The detailed sedimentologic and ichnologic observations will also improve the understanding of the architecture and ichnological trends observed in both tide-dominated estuarine, and shallow marine sand bar deposits. This may ultimately aid in recognizing similar deposits in future studies.

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CHAPTER II - FACIES ANALYSIS OF THE MCMURRAY-WABISKAW SUCCESSION: INTERPRETING THE DEPOSITIONAL SETTING IN THE MACKAY RIVER AREA OF THE ATHABASCA OIL SANDS, NORTHEASTERN ALBERTA

INTRODUCTION

The Lower Cretaceous McMurray-Wabiskaw succession is host to the majority of bitumen reserves within the Athabasca Oil Sands deposit. Understanding facies relationships in the subsurface with regards to this succession has become extremely complicated, as it exhibits some of the most variable and complex lithofacies patterns observed in the Western Canadian Sedimentary Basin (WCSB). Studies of the McMurray Formation have traditionally been concentrated within a relatively small area of the deposit where an informal tripartite stratigraphy (lower, middle, and upper members) has been established (Carrigy, 1959). In this area, these members have been broadly interpreted to reflect continental fluvial, marginal marine brackish/estuarine, and shoreline deposition, respectfully (Carrigy, 1971; Stewart and MacCallum, 1978; Nelson and Glaister, 1978; Mossop and Flach, 1985; Fox, 1988; Mattison, 1991; Hein and Cotterill, 2001; Hein and Dolby, 2001). More specifically, these fluvio-estuarine deposits filled a major northwest-trending valley system entrenched into the underlying Devonian paleo-surface, which then spilled out into a tide-dominated estuary or delta (Flach 1984; Mossop and Flach, 1985; Crerar and Arnott, 2007; Hein *et al*., 2000; Ranger and Gingras, 2003). This informal nomenclature has become notorious and has often resulted in a notion to force-fit sedimentological data and interpretations for the entire McMurray Formation into a preconceived stratigraphic model. Although this depositional framework has been traditionally supported in the main valley system, it does not hold true across the entire AOSA (Broughton, 2009; Mathison, 2003) and may not even be relevant in the MacKay River area.

The vast majority of sedimentological studies have focused on Inclined Heterolithic Stratificiation (IHS) bedded estuarine point bar and tidal channel deposits of the middle McMurray member, as they comprise the main reservoir facies in the main valley area (Flach 1984; Mossop and Flach, 1983; Flach and Mossop, 1985; Ranger and Pemberton, 1988; Ranger and Pemberton, 1992; Ranger and Pemberton, 1997; Ranger and Gingras, 2003; Lettley, 2004; Crerar and Arnott, 2007). Detailed studies conducted solely on the upper McMurray are few and far between. Ichnological studies are also relatively sparse across the Athabasca basin and have only been undertaken in recent decades, with Pemberton (1982) providing the first detailed categorization of biological traces commonly observed within the middle McMurray Formation, followed by Mattison (1991) and Ranger (1994). Since then, ichnological studies have primarily focused on the middle McMurray Formation in the main bitumen fairway, identifying a consistently observed impoverished trace fossil suite interpreted as representing a brackish estuarine environment (Flach and Mossop, 1985; Lettley, 2004; Ranger *et al.,* 2008). Moreover, a marine signature has been broadly characterized in the middle and upper McMurray, but it's extent and detail within the upper McMurray has gone relatively unpublished.

Coarsening-upward cycles have more recently been identified in the upper McMurray and are apparent on wire-line log signatures. This, coupled with sedimentological characteristics, has led to mixed interpretations including IHS bedding and large channels and off-channel facies indicative of tidal processes in a brackish fluvio-estuarine setting and overlying offshore bars (Hein and Cotterill, 2001; Flach and Mossop, 1985; Flach, 1984), and as the progradation of mixed wave/fluvial-influenced bayhead deltas into partially-closed, brackish inland bays (Ranger, 1994; Caplan and Ranger, 2001).

The Wabiskaw Member of the Clearwater Formation has received the least attention in the AOSA as it is a secondary reservoir to the McMurray Formation. However, it has been broadly characterized as three discrete, fine-grained, overlapping shallow marine sandstones that overlie and are partially inter-fingered with marine muds (Ranger *et al.,* 1988; Ranger, 1994; Beckie and McIntosh, 1989). These bitumen saturated sandstones are intermittently present throughout the AOSA and are estimated to contain 25 billion bbls of the total OBIP (Ranger *et al.,* 1988). A number of interpretations have been developed for deposition of Wabiskaw sands within the AOSA including shoreface-attached marine bars (Ranger *et al.,* 1988), barrier bars (Jackson, 1984), and offshore bars (Bayliss and Levinson, 1976).

Reconstructing ancient environments for any sedimentary deposit, particularly in the subsurface, requires a superlative understanding of the facies and facies relationships across an area. Ichnology has become an essential tool in facies analysis, as it contributes a unique blend of sedimentological and paleontological information about environments that can enhance overall interpretations. This is especially significant for in-situ development, as facies analysis is a vital tool in the development of a meticulous geological model that will result in the most successful exploitation of a reservoir. The purpose of this study is to interpret the depositional setting for the McMurray-Wabiskaw succession in the MacKay River area. The main objective is to develop a sound depositional framework through detailed facies analysis that integrates both primary physical and biological observations, with the intent of improving the sedimentological and ichnological knowledge of the McMurray-Wabiskaw stratigraphic interval, particularly within the upper McMurray member and Wabiskaw Member. Based on this integrated approach, a facies classification scheme and corresponding facies association scheme for the MacKay River area is presented. Special attention is paid to the sedimentological and ichnological aspects of the upper McMurray member, which comprises the thickest of the deposits and the reservoir interval in the study area. The influence of tidal and wave processes during McMurray deposition and their implications on the resulting interpretations are discussed and comparisons are also made to McMurray deposits of the main valley system. The nature of bounding surfaces between the middle and upper informal McMurray members, as well as between the McMurray-Wabiskaw transition is also scrutinized. Finally, a depositional model for the study area is presented. The resulting depositional framework will then act as a solid foundation for subsurface correlation and development of a local to sub-regional stratigraphic framework for the MacKay River study area. This will prove to be beneficial in reservoir predictability, distribution, and development within the MacKay River area. It will also aid in the recognition of analogous deposits elsewhere.

Description of the Study Area

The lower Cretaceous McMurray-Wabiskaw succession comprises the most valuable unconventional bitumen reservoir interval of the AOSA in northeastern Alberta (Fig. II-1). With an estimated 959 billion barrels of bitumen reserves, this represents one of the largest single accumulations of hydrocarbons in the world (ERCB, 2010). Historically, production of this reservoir has been dominated by surface-mining of bitumen hosted within sandy point bar and channel deposits of the middle McMurray Formation. As the exploitation of these shallow deposits has increased, a shift in paradigm to deeper in-situ exploration and development has become the standard.

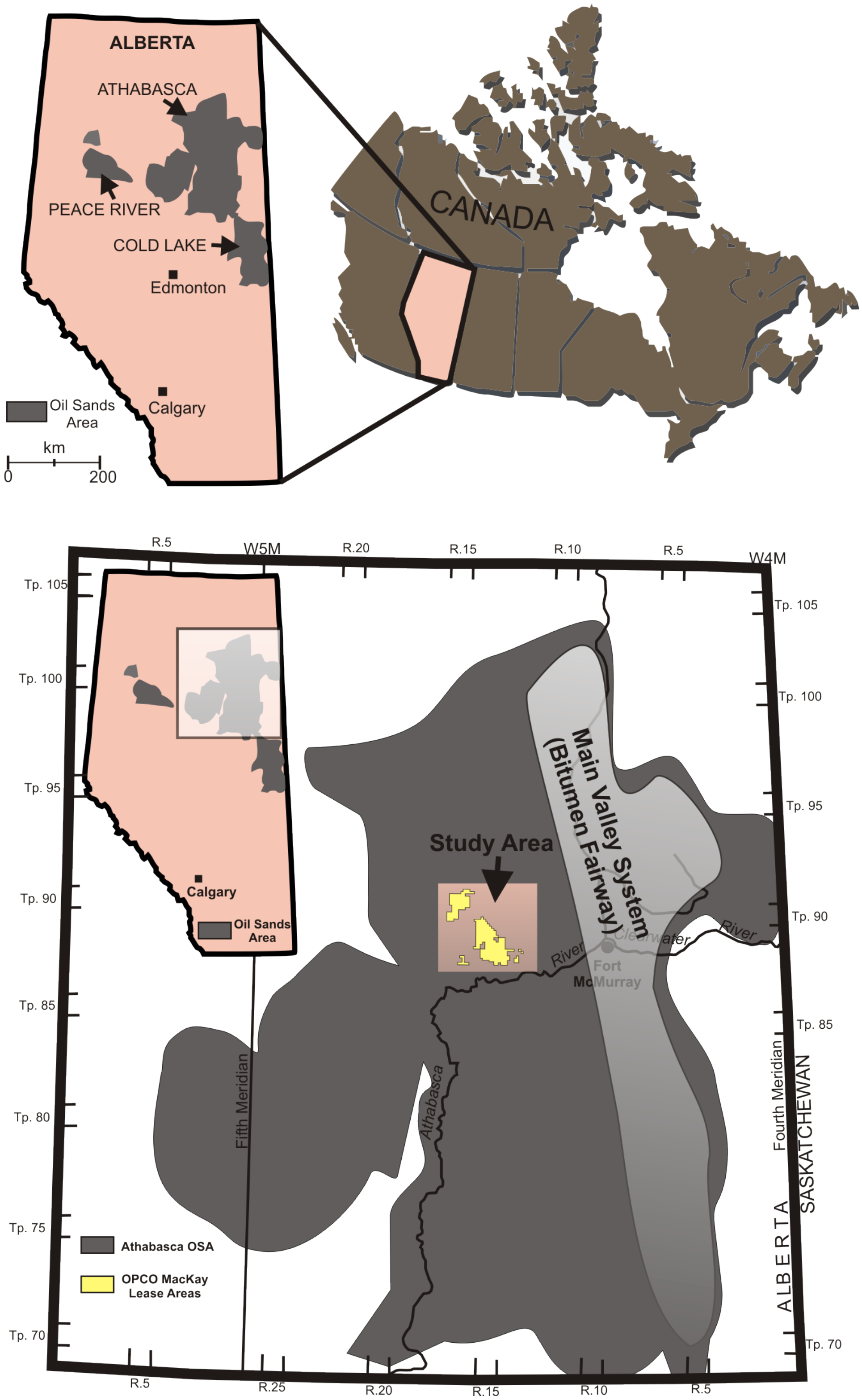


FIGURE II-1: Location of the study area. The MacKay River study area in relation to the main bitumen fairway of the AOSA, one of three oil sands areas in northeastern Alberta (Modified from Flach 1984; Keith *et al.,* 1989).

The McMurray Formation is a clastic succession that comprises the basal portion of the lower Cretaceous Mannville Group, which is a relatively thick sequence that was deposited during Aptian to Albian time on the eastern margin of the WCSB. Disconformably overlying the Mannville are marine clastics of the Joli Fou Formation of the Colorado Group. The Mannville Group varies in thickness from 180 to 280 m and is divided into the McMurray, Clearwater, and Grand Rapids formations (Fig. II-2). In the AOSA, it directly overlies the Sub-Cretaceous unconformity above middle Devonian carbonates of the Beaverhill Lake Formation.

Prior to deposition of the McMurray Formation, erosion of this exposed terrane developed a complex ridge and valley paleo-topography across northeastern Alberta. The McMurray sub-basin encompasses the main valley system in the AOSA, and acted as a clastic catchment for deposition of overlying McMurray and Clearwater sediments (Fig.II-3). This broad northwest to southeast-trending trough was bound to the west by resistant Grosmont carbonates and to the east by the Precambrian Shield (Stewart and MacCallum, 1978). It is also characterized by an intricate arrangement of secondary valleys and sub-basins, due to a combination of salt solution of underlying evaporate deposits and structural collapse of the Beaverhill Lake Formation and Ireton shales. This generated a complex basin configuration that strongly influenced the depositional processes and environments present during McMurray deposition.

Through transgressive pulses of the Boreal Sea during Aptian to early Albian times, the complex paleo-valley system was filled with sediments of the McMurray and Clearwater Formations. These sediments were transported via a major continental drainage system from the southeast, as well as from the Carbonate highlands and Precambrian shield to the west and east, respectively (Lettley, 2004). In the main valley system, lower and middle McMurray deposits are interpreted as point bar to tidal channel sands, representing fluvio-estuarine deposition that filled the major flowing trunk system entrenched into the underlying Devonian paleo-surface (Carrigy, 1971; Nelson and Glaister, 1978; Stewart and MacCallum, 1978; Mossop and Flach, 1983; Hein and Cotterill, 2006). More recently, these deposits are interpreted as an estuary or tide-dominated delta that evolved to a wave/fluvial-dominated delta represented by upper McMurray sedimentation (Ranger 1994; Caplan and Ranger, 2001; Ranger and Gingras, 2003). The overlying glauconitic shoreface and basinal muds of the Wabiskaw Member and Clearwater Formation followed these deposits,

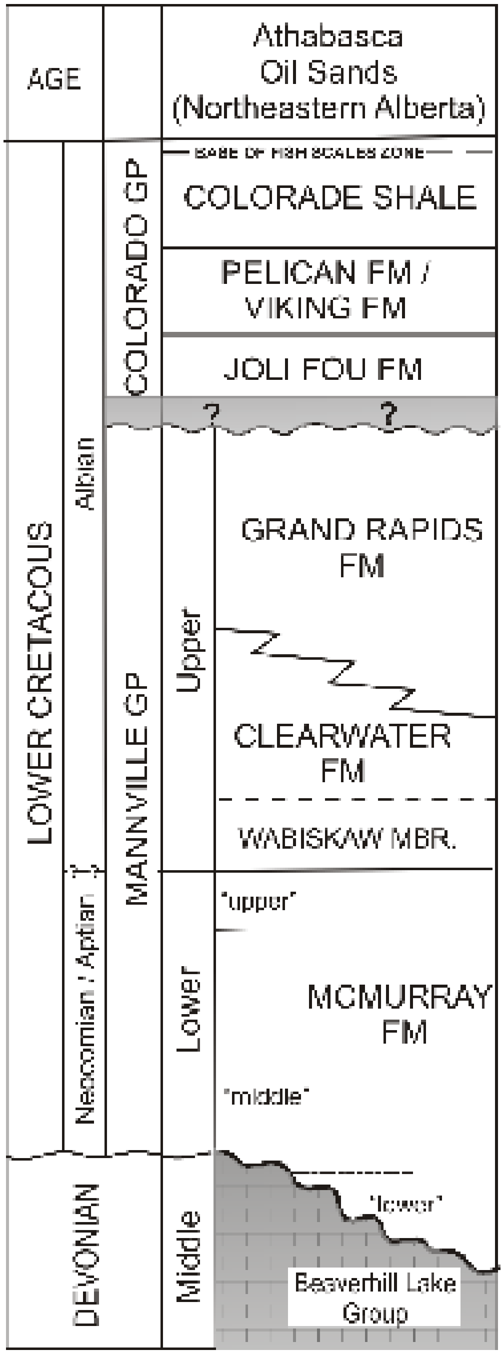


FIGURE II-2: Stratigraphic framework for the McMurray-Wabiskaw succession. Stratigraphy of the lower Cretaceous in the AOSA of northeastern Alberta (modified from Ranger and Gingras, 2003).

representing transgressive sedimentation in response to southward migration of the Boreal Sea.

The MacKay River area straddles the edge of a secondary tributary valley, west of the main valley system (bitumen fairway) (Fig.II-1; Fig II-3). In this area, the sedimentology and stratigraphy of the McMurray-Wabiskaw succession does

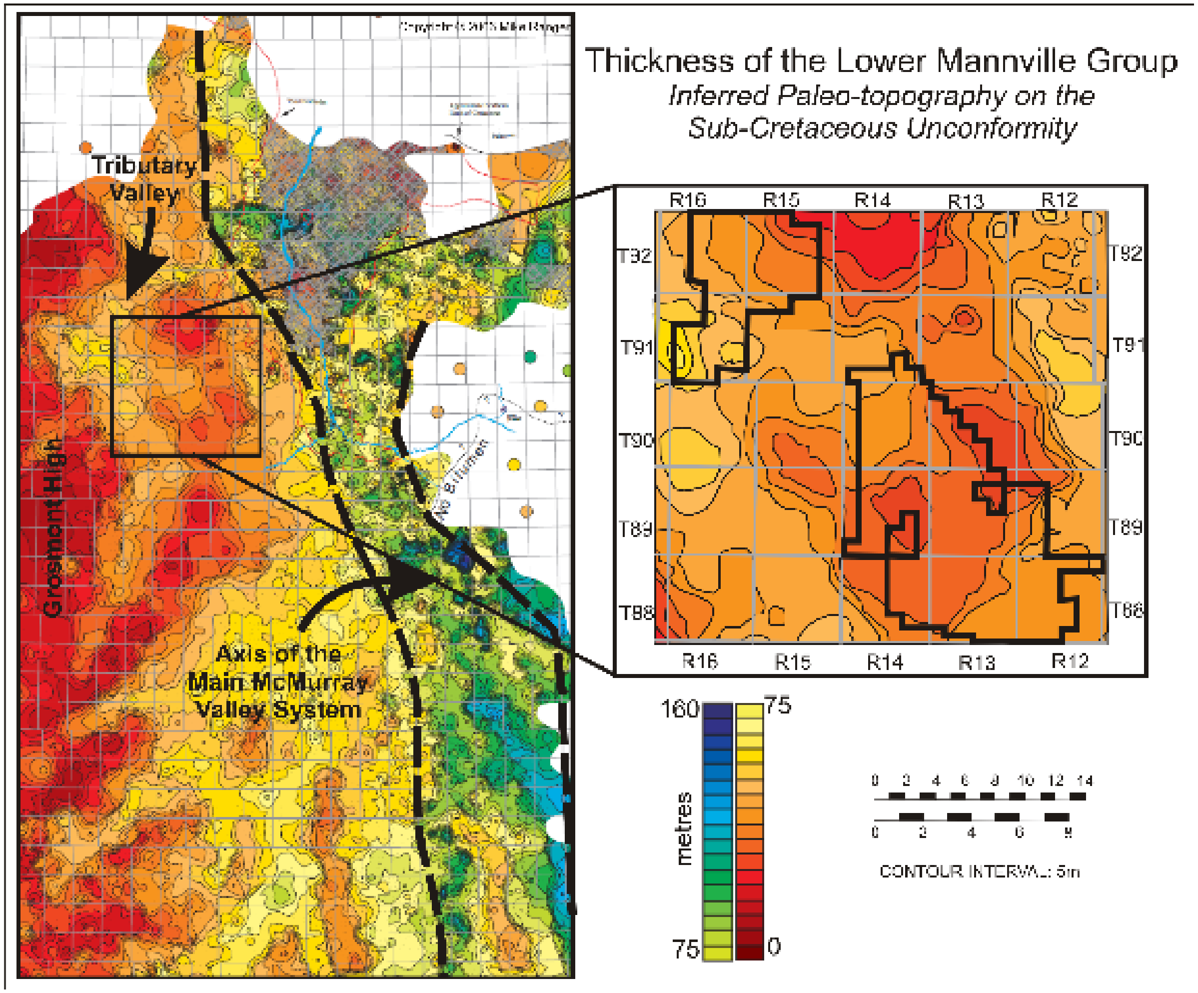


FIGURE II-3: Inferred paleotopography of the sub-Cretaceous unconformity surface expressed by the thickness of the McMurray Formation and its stratigraphic equivalents. Note the position of the study area relative to the main valley system, situated to the west on the flanks of a secondary northwest-trending tributary valley and bound to the west by the Grosmont High (modified from Mike Ranger © 2006). The position of AOSC lands in the study area are not conform to the generally accepted framework. To illustrate this departure, a comprehensive examination of McMurray Formation and Wabiskaw Member strata was conducted from Townships 88 to 92 and Ranges 12 to 16 west of the fourth meridian, covering an area of 684 sections (1771.55km^2) (Fig. II-4). A total of 100 cored wells were examined. 72 cores were examined through core-logging or core photos from Dover Operating Corporation (OPCO) lease areas, and the remaining 28 cores from Suncor Energy (formally PetroCanada) and Southern Pacific Resources lands (Fig.II-4).

METHODS

This paper is based on the collection of sedimentological and ichnological data derived from descriptions and/or photos of one hundred cored intervals and their respective wire-line log suites (Fig.II-4). Petrophysical data was also utilized from an additional 114 wells in the study area, most of which comprised gamma-ray, neutron- and density-porosity and resistivity logs. All core represented a full section of McMurray Formation in the MacKay River area. The overlying Wabiskaw Member and Clearwater Formation varied in thickness from less than a meter to several meters. A 20-50 m thick McMurray-Wabiskaw succession is characteristic in the MacKay River area.

Sedimentological analysis of core focused on a variety of parameters including: lithology, grain size, primary and secondary sedimentary structures, bedding contacts, bitumen saturation, the identification and nature of bounding discontinuities, color, character of bedding, and lithologic/mineralogic accessories (i.e. coal fragments, pyrite, glauconite, etc.). Ichnologic data collected comprised descriptive and semi-quantitative data. Descriptive data included identification of individual ichnogenera and ichnofossil suites which were based upon the best available interpretation. Semi-quantitative data included the measurement of burrow diameters, relative diversities of individual traces, and the bioturbation index. An incremental scale (Fig.II-5) of bioturbation intensity was recorded for all units logged in the study, based on Taylor and Goldring (1993), and Taylor *et al*. (2003). A detailed summary of the sedimentologic, ichnologic, and stratigraphic observations are illustrated as strip-logs, located in Appendix A (cores 1-72; Fig.II-4). Detailed ichnologic data is organized as a table in Appendix A.

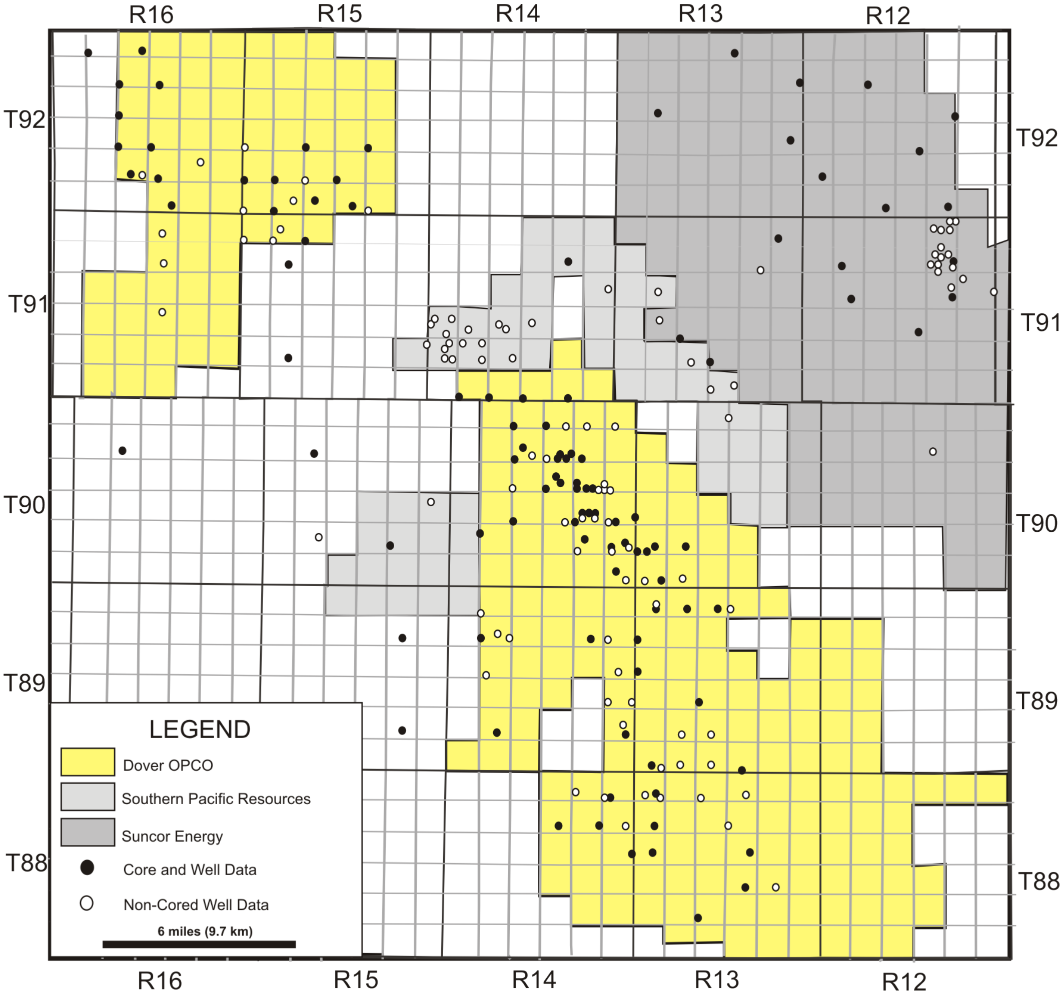


FIGURE II-4: Location of the study area. This study focuses on core examined primarily from Dover Operating Corporation (OPCO) lease areas. Additional core/petrophysical data was used from surrounding MacKay River lease areas.

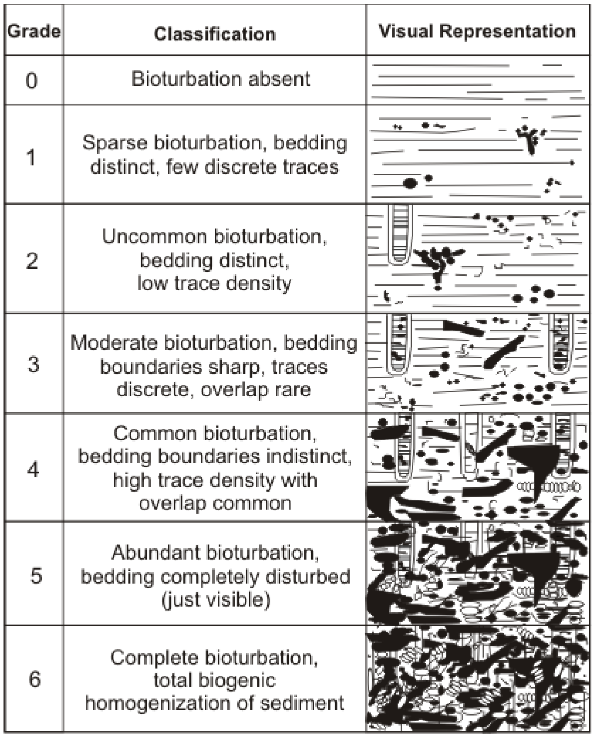
FACIES DESCRIPTIONS AND INTERPRETATIONS

Core analysis of the McMurray-Wabiskaw succession led to the classification and paleoenvironmental interpretation of twenty-one recurring facies, each of which illustrate a distinct combination of sedimentological and ichnological characteristics. The following is a detailed discussion on the facies classification developed for the McMurray-Wabiskaw succession in the MacKay River area. A summary of this facies scheme is presented in Table II-1.

Lower "Middle" McMurray Facies

(F1) Rooted white to light grey mudstone

This facies is less common and restricted to the lowermost portion of the



Grade	Classification	Visual Representation
0	Bioturbation absent	
1	Sparse bioturbation, bedding distinct, few discrete traces	
2	Uncommon bioturbation, bedding distinct, low trace density	
3	Moderate bioturbation, bedding boundaries sharp, traces discrete, overlap rare	
4	Common bioturbation, bedding boundaries indistinct, high trace density with overlap common	
5	Abundant bioturbation, bedding completely disturbed (just visible)	
6	Complete bioturbation, total biogenic homogenization of sediment	

FIGURE II-5: Schematic representation of bioturbation index (BI) values. The BI classification was originally modified after Reineck (1963) (cf. Taylor and Goldring, 1993; Taylor *et al.,* 2003) and was based on broad ranges of percentage of burrow overlap.

McMurray Formation. A massive appearance, white color, presence of rhizoliths and organic debris characterize F1 (Fig.II-6). These soft and friable muds are easily identified by a fractured and blocky, chalk-like appearance resulting from the lack of cementation. Rhizoliths are typically root traces of black, lignitic coal, penetrating ~1-4 cm into the strata (Fig.II-6A). They are rarely pyritized and may display a bleached halo or distinct color contrast to the surrounding mud. Lithological accessories include small pyrite and siderite spherules, typically less than 2 mm in size. Darker grey, subangular mud intra-clasts, up to 2.5 cm, are rare near the base of the facies. These clasts are often stretched and deformed, typically observed with local convolute bedding. Pedogenic slickensides were locally observed. Burnt orange, siderite cemented zones/nodules also occur, typically towards contacts (Fig.II-6B). These iron-beds do not typically exceed 3 cm in thickness, but rare zones up to 15 cm were observed. Facies 1 forms decimeter- to meter-scale successions, ~0.5 m-3 m. Contacts for this facies are gradational, or more commonly, sharp and irregular with F2 and F3 (Fig. II-6E).

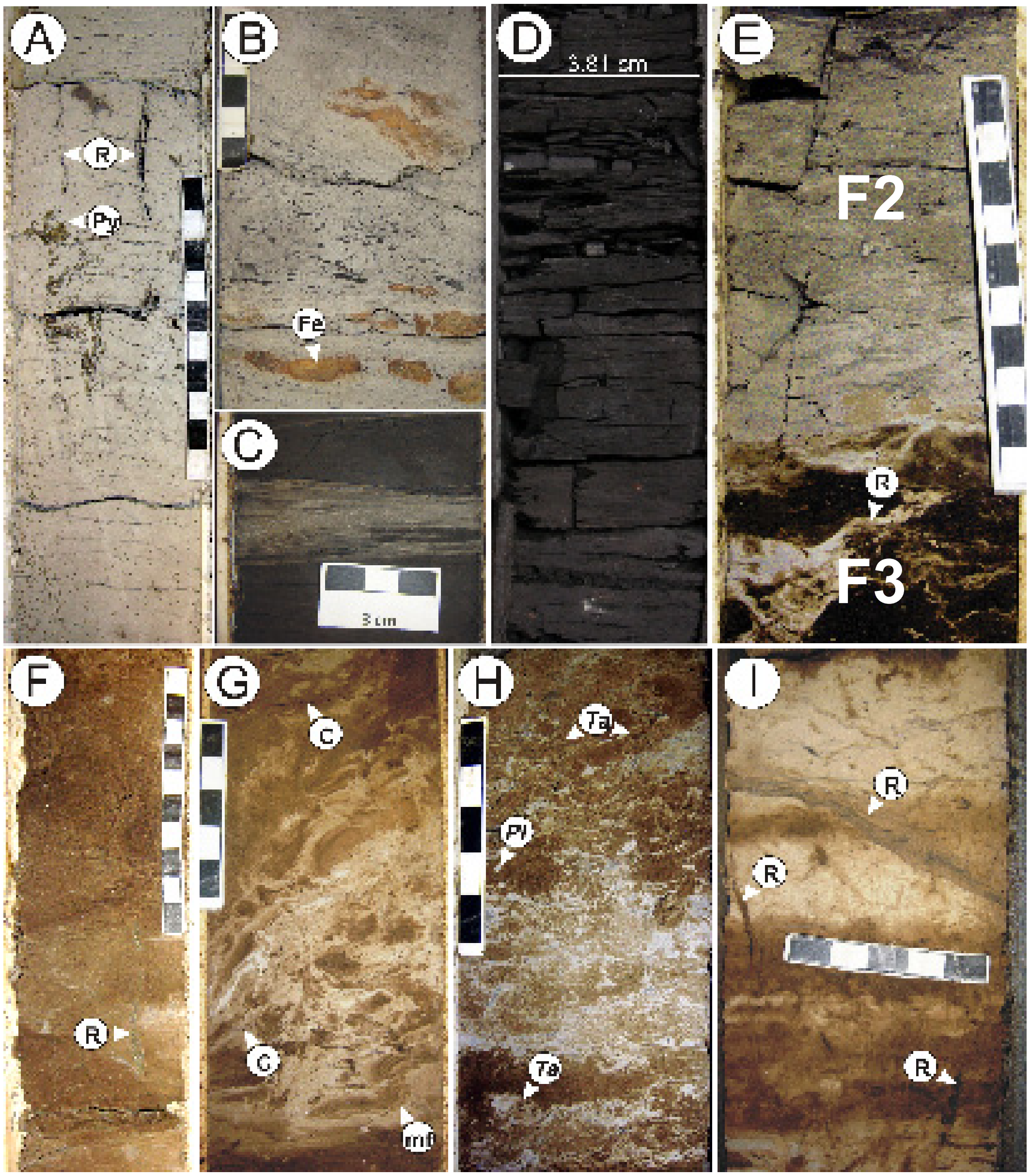


FIGURE II-6: Facies 1-3 from the middle McMurray Formation. (A) Massive white to light grey mudstone with coalified rhizoliths (R) and pyrite spherules (Py). Well 16-11-90-14W4, depth 201.75 m. (B) Convoluted mud with abundant carbonaceous debris. Note the burnt orange Fe-mineral cemented nodules (Fe). Well 12-08-91-14W4, depth 191.4 m. (C) Organic-rich deposits of F2 illustrating intercalated coal and organic mud with ripple-lamination, coal fragments and micro-fractures. Well 16-11-90-14W4, depth 200.4 m. (D) Characteristic coal bed that is blocky to fissile nature, with friable durian layers and rare glossy clarian laminae. Well 10-08-90-14W4, depth 203.1 m. (E) Sharp contact between organic-rich mud (F2) and chaotic rhizoturbated sand (F3). Organic muds are rich in carbonaceous material and exhibit convolute bedding. Note the roots penetrating into the underlying facies and irregular rhizoturbation. Well 10-11-89-14W4, depth 208.5 m. (F) Irregular bedded silts with pyritized root trace (F3). Well 16-11-90-14W4, depth 197 m. (G) Convoluted, chaotic inter-bedded, rhizoturbated very fine grained sand, silt, and mud (F3). Note the soft sediment deformation, micro-folds (mf), and carbonaceous debris (C). Well 6-03-91-14W4, depth 192.1 m. (H) Non-marine burrowing of F3 has resulted in the destruction of primary bedding and development of a unique ichnofabric consisting predominantly of continental (non-marine) ichnoforms. The majorities of these burrows are ellipsoidal packets

FIGURE II-6 CONTINUED: with tightly packed menisci ichnoforms of interpreted as Taenidium (Ta). Discrete marine gently inclined burrows interpreted as *Thalassinoides (Th), Planolites (P),* and *Arenicolites (Ar)* are also observed. Well 7-19-89-13W4, depth 213 m. (I) An abundance of rhizoliths in F3 has disrupted the primary bedding, developing a dense network of vertical to horizontal branching. Note the oxidized rims and leached appearance of the surrounding matrix. Well 10-08-91-14W4, depth 193.8 m. All scales in cms.

Interpretation of F1

Facies 1 is interpreted as continuous sedimentation and vertical accretion of overbank flood deposits in a humid, low-energy supratidal environment. Overbank flows are interpreted to have resulted primarily from high water tables which induced fluctuating water saturations. This is evident from a variety of redoximorphic features including: rhizohaloes, presence of carbonaceous roots in rhizoliths, patchy mottled color textures, pedogenic slickensides, and paucity of burrowing (Kraus and Hasiotis, 2006). Reduced, waterlogged and poorly drained conditions are also inferred from the light color of sediment, presence of siderite nodules and preserved organic matter (Retallack, 1983; Kraus, 1999). These conditions are typical of flood basin deposition further from a channel, where deposits are topographically lower and sediment is less permeable (Kraus and Hasiotis, 2006). Facies 1 is interpreted as weak pedogenesis and the base of hydropomorphic simple paleosols that were deposited away from an active channel in reducing, waterlogged conditions (Kraus and Aslan, 1993; Kraus, 1999; Kraus and Hasiotis, 2006).

(F2) Organic mudstone and coal

Facies 2 comprises thin intercalated deposits of dark grey organic mud and coal (Fig.II-6C). Beds are normally less than 1.5 m thick with gradational or sharp contacts with other fine-grained facies, typically F1 and F4. Rare occurrences of low-angle lamination to ripple-lamination occur in organic muds (Fig.II-6C). Lower contacts can exhibit small (less than 2 cm) angular rip up clasts from underlying facies. Root traces can also penetrate downward into underlying units (Fig.II-6E). Dispersed sand grains, silt laminae, disseminated coal laminae, coal fragments, pyrite nodules and organic detritus are common constituents of F2. Fracturing and rare micro-faulting are also observed. Coal beds are friable with a sooty appearance and appear sub-bituminous in rank. Beds are typically composed of dense durian layers that lack a glossy appearance and conchoidal fracture. Rarely, glossy clarian layers (less than 2 cm thick) are observed.

FACIES	NAME	Lithology	Sand: Mud	Structures	BI	Ichnofossils	Ichnological Distribution	Accessories	Description	Occurrence	Interpretation	FA	Reservoir Quality
Lower FA	ECP												
F1	Rooted white to light grey mud-stone	mud	0:1	Massive to convolute; rhizoliths	0	*none*		Organic debris, intraclasts, siderite cemented zones	Fractured/ blocky; white color, pedogenic slickensides	0.5-3 m thick; gradational or sharp with F2 and F3	Weak pedogenesis of simple hydropomorphic paleosols	**FA1**	Non-reservoir
F2	Organic mudstone and coal	mud and coal	0:1	Massive; rare low angle- to ripple-lamination	0	*none*		Rhizoliths, dispersed sand grains, silt laminae, disseminated coal lamination, coal fragments, pyrite nodules and organic detritus	Autocyclic deposition; lignite	<1.5 m thick; gradational or sharp contacts with F1 and F4	Backswamp vertical accretion deposition distal to an active channel	**FA1**	Non-reservoir
F3	Chaotic inter-bedded, rhizoturbated sand-, silt- and mud-stone	mud, silt, v.f.g. sand	1:2	Rhizoturbation; convolute bedding	0-3	Obscure “scratchmark” burrowing mottling; *Taenidium (c)*	sporadic and heterogeneous	organic detritus, coal fragments, brownish-yellow color, pyrite nodules, sub-rounded silty mud clasts	Coalified rhizoliths or branching network common	10cm-3m thick; sharp or gradational with F1 or F5	Paleosol coastal plain deposition with fresh-water overbank flows	**FA1**	Non-reservoir
F4	Inter-bedded to iter-aminated mud-, silt- and sand-stone	v.f.g. sand, silt, silty mud	1:3	Convolute; parallel- to current ripple-lamination; local aggradational combined ripples, and lenticular bedding; syneresis cracks	0-1	*Planolites* (m), *Skolithos* (r), *Thalassionides* (vr), *Teichichnus (vr)*; indistinct burrow mottling	sporadic and heterogeneous	coal fragments, disseminated coal laminations, organic detritus	Sanding-upward	<2 m thick, gradational with F3 or F5 or sharp with other f.g. facies	Levee-crevasse splay deposition with fresh- and brackish-water overbank flows	**FA1**	Non-reservoir
F5	Laminated to burrowed v.f.g. sand	v.f.g. sand, silt	1:0	Low-angle parallel lamination, ripple lamination; subordinate flaser bedding, combined ripples; syneresis cracks	1-4	*Taenidium (m)*; *Planolites* (m) with subordinate *Skolithos (r), Arenicolites* (vr), *Thalassinoides* (vr); *i*ndistinct mottling	sporadic and heterogeneous	rhythmic interlaminae with organic detritus, shell fragments, pyritized zones, rhizoliths	Three ichnofabrics	<3 m thick, gradational with F4, may be sharp with other f.g. facies	Sandy intertidal flats with fresh- and brackish-water overbank flows	**FA1**	Non-reservoir

TABLE II-1

Lower FA	IOE												
F6	Cross-bedded to ripple-laminated fine-grained sand with helical- and cylin-drichnus-dominated silt and mud inter-beds	f.g.-m.g. sand and silty mud/ mud	10:1	Current ripple-lamination, Small-scale to large scale cross beds,bi-directional cross-strata, grain-size striping/rhythmites, reactivation surfaces, rhythmic wavy to parallel sand and mud laminae	1-4	*Cylindrichnus-Skolithos* association *(c); Gyrolithes* monospecific suites (c); *Planolites* (m), fugichnia (r), *Teichichnus* (r), *Arenicolites* (vr), *Palaeophycus* (vr), *Chondrites* (vr)	regular heterogeneous	Abundant organic detritus, coal fragments, mud drapes at cross-strata foresets/toesets; brecciated mud clast zones	f.g. quartz arenite sands with mud (couplets), low to moderate bitumen; inclined to flat beds (IHS)	2-3 m thick (up to 15m), sharp or gradational with F8 and F9	Laterally accreting tidal channel bar deposition	**FA2**	Non-reservoir
F7	Flat-lying to inclined inter-bedded to inter-laminated heterolithics	mud, silt, sand	variable	Small-scale cross-bedding, grain-size striping, current and wave ripple-lamination, rhythmic inter-lamination, wavy- and flaser-bedding; massive to contorted muds with wavy/lenticular to parallel sand laminae; double mud drapes, horizontal grading; local herringbone cross-strata, climbing and combined flow ripples	0-3	*Planolites (c)*, *Cylindrichnus* (c), *Gyrolithes* (c), *Teichichnus* (m), *Skolithos (m),* fugichnia *(r), Thalassionides (r), Arenicolites (r), Palaeophycus (vr)*	regular to sporadic heterogeneous	f.g.-m.g. sand-filled burrows, organic flakes drape cross-lamination; syneresis cracks, pyrite/siderite	low bitumen; well preserved structure	1-10 m thick, avg. 1-3 m; gradational to intercalated with F6 and F8; may truncate F6; muddying/ fining upward	Sub-tidal lateral accretion bedding of channel point bars	**FA2**	Non-reservoir
F8	Well bioturbated heterolithics	mud, silt, v.f.g. sand	variable	Typically destroyed by biogenic reworking; local flaser, wavy and lenticular bedding; convoluted media, rhythmic interlaminae	4-6	*Cylindrichnus* (c), *Gyrolithes* (c), *Planolites (c), Teichichnus* (c), *Arenicolites* (m), *Skolithos* (m), *Thalassinoides* (r), *Palaeophycus* (vr)	homogeneous	rare organic debris, coal fragments; sideritized intervals	weak bitumen saturation	decimeter to 10 m scale; gradational (typically above) or sharp with F6 and F7; forms stacked fining successions	Mixed Intertidal flats	**FA2**	Non-reservoir

TABLE II-1 (Continued)

Upper FA	SMBF												
F9	Well burrowed interbedded sand, silt, and light grey mudstone	f.g. sand, silt, mud	variable	Rhythmic interlamination and wavy bedding; structures typically destroyed by biogenic reworking; local current and oscillation ripples	1-6	high diversity density assemblage; Robust ichnoforms; *Asterosoma* (c), *Thalassionides* (c), *Planolites* (c), *Zoophycos* (c), *Rosselia* (r), *Rhizocorallium* (m), *Teichichnus* (r), *Diplocraterion* (r), *Scolicia* (m), *Chondrites* (r), *Skolithos* (r), *Phycosiphon* (vr)	homogeneous	Shell fragments, bivalves, disseminated organic debris, coal fragments, pyrite/ siderite, coarse-grained burrow fills	Fining- or coarsening-upward successions; character-istic bluish grey mudstone; poor-fair bitumen saturation	5-10 m thick; gradational or sharp with F11 and F10; sharp with F17, F12 and F13	Fully marine background bay fill / interbar sedimentation	**FA3**	Non-reservoir
F10	Well burrowed sand with silt and mudstone-filled burrows	f.g. sand with silt and mud	4:1	Current generated stratification (ripples, small scale cross-beds, climbing ripples); symmetric ripples; fines restricted to burrow-fills and linings	3-5	high diversity assemblage; *Rosselia socialis* (c), *Asterosoma* (c), *Teichichnus* (c), *Planolites* (m), *Chondrites* (m), *Zoophycos* (m), *Spirophyton (r)* *Skolithos* (r), *Scolicia* (vr), *Rhizocorallium* (vr), *Ophiomoprha* (vr), *Diplocraterion* (vr), *Cylindrichnus* (vr), *Macaro-nichnus segregatis* (vr), *Phycosiphon / Helminthopsis* (vr)	homogeneous	Shell fragments, bivalves, intraclasts, coal fragments, pyritized burrows	Coarser fine-material than F9; clean-upwards (sand upwards); good bitumen saturation	5-10 m thick; gradational with F9, F11; sharp with other facies; may truncate F9	Fully marine background bay-fill / interbar sedimentation (i.e. more proximal than F9)	**FA3**	Low reservoir quality

TABLE II-1 (Continued)

F11	Weak to moderately burrowed wavy bedded fine-grained sand	f.g. sand	10:1	Rhythmic wavy bedding/inter-lamination, current/ oscillation ripple-lamination, parallel-lamination	2-3	Moderate diversity and low density assemblage; *Planolites* (m), *Skolithos* (m), *Teichichnus* (m), *Thalassinoides* (m), *Asterosoma* (r), *Diplocraterion* (r), *Spirophyton (r), Paleophycos* (vr), *Rosselia* (vr), *Mono-craterion* (vr) *and* fugichnia (vr)	homogeneous	5-15% sharp based to burrowed silt/mud laminae and thin beds; disseminated shells/ carbonaceous debris, pyrite, influxes of m.g.-c.g. sand burrow fills	excellent bitumen saturation; poor-moderately sorted sands	5-10 m thick; sharp/ gradational with F12 or F10; or truncated by F13/F14/F15	Fully marine background bay-fill / interbar sedimentation (i.e. more proximal than F10)	**FA3**	Moderate reservoir quality
Upper FA	TSB												
F11	Weak to moderately burrowed wavy bedded fine-grained sand	f.g. sand	10:1	Rhythmic wavy bedding/inter-lamination, current/ oscillation ripple-lamination, parallel-lamination	1-2	Moderate diversity and low density assemblage; *Planolites* (m), *Skolithos* (m), *Teichichnus* (m), *Thalassinoides* (m), *Diplocraterion* (r), *Palaeophycos* (vr), fugichnia (vr)	regular heterogeneous	5-15% sharp based to burrowed silt/mud laminae and thin beds; disseminated shells/ carbonaceous debris, pyrite, influxes of m.g.-c.g. sand burrow fills	excellent bitumen saturation; poor-moderately sorted sands	5-10 m thick; sharp/ gradational with F12 or F10; or truncated by F13/F14/F15	Toesets of laterally accreting shallow marine bay-margin tidal sand bar complex	**FA4**	Moderate reservoir quality
F12	Weakly burrowed fine-grained sand	f.g. sand	1:0	Current ripple- to parallel-lamination; aggradational-oscillation and combined flow ripples; rare cross-beds, grain size striping, and starved silty mud lamination	0-2	*Planolites* (c), *Thalassinoides* (c); *Teichichnus* (m), *Ophiomorpha* (m), *Skolithos* (r), *Fugichnia* (r), *Palaeophycus* (vr), *Arenicolites* (vr), *Scolicia* (vr), *Siphonichnus* (vr)	sporadic heterogeneous	large coal fragments, coal laminae, rip up clasts, pyritized burrows disseminated along foresets or singular; bivalves and shells in localized beds	excellent bitumen saturation; mod-well sorted clean fine-grained sands; coarsens-upwards	5-20 m thick, average 7-10 m; gradational or sharp with F9-F14; Truncated by F15/F16/F17	Laterally accreting shallow marine bay-margin and island medial tidal sand bars	**FA4**	Excellent reservoir quality

TABLE II-1 (Continued)

F13	Weakly burrowed rippled to small scale cross-bedded sand	f.g.-m.g. sand with sharp based mud-stone beds / laminae	20:1	Current ripple lamination to small scale cross-beds with dip reversals, wavy and flaser bedding, mud drapes, rhythmites; rare syneresis cracks	0-2	Low diversity/low density brackish-water dominated suite; *Planolites* (c), *Thalassinoides* (c), *Skolithos* (c), *Teichichnus* (c), *Ophiomorpha* (m), fugichnia *(r), Siphonichnus* (vr)	sporadic heterogeneous	2-10% sharp based mud/silty mud laminae and thin beds; disseminated shells/carbonaceous debris, thin coal laminae form rhythmic interlaminations with muds or drape foresets; mud intraclasts, gravity faults	excellent bitumen saturation; mod-well sorted clean f.g.-m.g. sands; coarsens- and cleans-upwards	5-10 m thick; gradational with F15; sharp with F17	Laterally accreting shallow marine bay-margin and island proximal-medial subtidal sand bars	**FA4**	Excellent reservoir quality
F14	Upper fine- to medium-grained large scale cross-stratified sand	f.g.-m.g. sand	1:0	Large-scale cross-bedded with dip reversals and grain size striping; subordinate planar bedding	0-1	Rare to absent bioturbation; discrete *Planolites* (vr), *Skolithos* (vr) *or* fugichnia (vr)	sporadic heterogeneous	local mud laminae ,coal fragments, organic debris drape toesets, intraclasts	excellent bitumen saturation, mod-well sorted sands	1.5-3.5 m thick; Sharp/ erosive with F9, F10,F13; gradational with F15; sharp with F16 and F17	Laterally accreting shallow marine bay-margin proximal subtidal sand bars	**FA4**	Excellent reservoir quality
F15	non-bioturbated to weakly bioturbated medium-grained sand	f.g.-m.g. sand	1:0	low angle planar to trough cross-beds; heavy mineral lamination	6	Cryptobioturbated to weak bioturbation; *Macaronichnus* (m), *Skolithos* (vr), *Diplocraterion* (vr)	homogeneous	shell fragments, coal fragments, disseminated organic debris	good-poor bitumen saturation; fining-upward trend	1.5-2 m thick; gradational lower contacts with F13/ F14, sharp to erosive with F16/F17	Laterally accreting shallow marine bay-margin proximal subtidal sand bars	**FA4**	Good reservoir quality
Upper FA	POLS												
F16	Moderately burrowed f.g. sand with silt and mudstone-filled burrows	f.g.-v.f.g. sand	20:1	low angle to planar laminated, small-scale cross bedding	3-4	*Asterosoma* (c), *Rosselia* (c); *Schaubcylindrichnus* (m), *Diplocraterion* (r), *Scolicia* (r), *Skolithos* (r), *Planolites* (r), *Teichichnus* (vr), *Thalassinoides (r)*	homogeneous	wavy beds of disseminated coal/ organic flakes, coal fragments and rare mud laminae/clasts; Rare shell fragments; Pyrite/siderite	silt and mud trapped burrows (0-5%); good bitumen saturation	2 m thick average; gradational with F10/F11 or sharp with F9/F12/F13/ F18; Truncated by F15/F17/ F18/ F19	Mixed influenced fairweather to storm deposition; fully marine lower shoreface	**FA5**	Good reservoir quality

TABLE II-1 (Continued)

F17	Well bioturbated to planar laminated sand	v.f.g.-f.g. sand	1:0	Low angle planar to horizontal stratification, HCS, trough cross-bedding	0-6	*Diplocraterion* (m), *Chondrites* (c), *Schaubcylindrichnus* (c), *Asterosoma* (c); *Subordinate Skolithos* (m), *Planolites* (m), *Thalassinoides* (r), *Rosselia* (r), *Teichichnus* (r), *Scolicia* (vr), *Conichnus* (vr)	homogeneous	glauconite laminae/ burrow fills; heavy mineral laminae, shell fragments, dissimenated organic debris, small intraclasts	moderate to good bitumen saturation; coarsening-upward trend	0.5-1.5 m thick; sharp lower contacts with F16/ F15/F14/F12/ F11; sharp overlying contacts with F18/F19	Mixed-influenced fair-weather to remnant tempestite deposition; fully marine lower shoreface	**FA5**	Good reservoir quality
F18	Burrowed argillaceous mudstone with silt and sand inter-beds	mud, silt, sand	variable	Wavy to planar bedding; oscillation and combined ripple flow; tubular tidalites / tempestites	3-5	*Thalassinoides* (c), *Planolites* (c), *Chondrites* (c), *Psilonichnus (m), Teichichnus (m), Asterosoma* (m), *Zoophycos* (m), *Skolithos* (r), *Scolicia (r), Schaubcylindrichnus* (r), *Diplocraterion (vr),* fugichnia (vr), *Phycosiphon* (vr) and *Cosmoraphe* (vr)	homogeneous	disseminated organic debris, shell fragments, coal fragments, intraclasts, siderite/ pyrite, passively filled glauconite, coarse burrow fills	mud dominated; coarsening- and fining-upward successions; poor bitumen saturation	0.5-5 m thick average; sharp lower contacts with F14, F113, F17, F10; gradational upper contacts with F17, F11 or sharp with F19	Mixed influenced fully marine proximal offshore	**FA5**	Non-reservoir
Wab FA	DOS												
F19	Burrowed planar-parallel glauconitic sand to sandy mud	glau-conitic sand, silty mud, mud	1:2	Low angle planar to horizontal stratification; wavy interbeds; HCS	2-6	*Chondrites* (c), *Asterosoma* (c), *Planolites* (m), *Skolithos* (m), *Teichichnus* (m), *Diplocraterion* (r), *Thalassinoides* (r), *Ophiomorpha* (r), fugichnia (r), *Rosselia* (vr), *Zoophycos* (r), *Phycosiphon/ Helminthopsis* (r)	homogeneous	Glauconite, siderite/ pyrite, coal fragments, thin coal laminae, disseminated organic debris, shell fragments	Forms the overlying unit of a *Glossifungites* firm-ground surface	1-5 m thick; fining-mudding upward succession; gradational with F20; erosive base with underlying facies	Mixed influenced fully marine distal offshore deposits above storm wave base (i.e. distal tempestites)	**FA6**	Non-reservoir

TABLE II-1 (Continued)

F20	Bluish silty mud to moderate grey mudstone with sand inter-beds	silty mud and mud with rare sand	0:1	Massive, lenticular bedded, parallel- and wave-rippled mud and local glauconitic sand interbeds	0-3	*Chondrites* (c), *Phycosiphon/ Helminthopsis* (m); *Subordinate Teichichnus* (r), *Planolites* (r), *Thalassinoides* (vr), *Asterosoma* (vr), *Skolithos* (vr)	homogeneous	shell fragments, quartz pebbles, coal fragments, pyrite nodules, thin interlaminated coal and sand, siderite/ pyrite	fining-upward succession; mud becomes darker upward	3-5 m thick; gradational to sharp with F19; upper contacts erosional to gradational with F21	Fully marine distal offshore to shelfal mud deposition at/ below storm wave base	**FA6**	Non-reservoir
Wab FA	LSF												
F21	Moderately burrowed fine- to medium-grained sand	sand	3:1	Trough cross-beds, parallel to low angle stratification and wave-ripple lamination	3-6	*Chondrites (c), Skolithos (m), Asterosoma (c), Diplocraterion (c), Thalassinoides (m), Teichichnus (c), Rosselia (r), Ophiomorpha (r), Scolicia (r), Planolites (c)*	homogeneous	thick clay-lined burrows; laterally extensive geometry	good bitumen saturation in thicker beds; sand-upwards	decimeter to 10 m thick; gradational to sharp-based with F17/F18; overlying silts/ muds of the Clearwater Fm	Wave-influenced fully marine lower shoreface	**FA7**	Potential reservoir

TABLE II-1 (Continued): Summary of facies descriptions and classification scheme based on sedimentological and ichnological observations during core logging of McMurray Formation and Wabiskaw Member strata (MacKay River Area, northeast Alberta). For further detail refer to main body of text. Abreviations and terminology are defined in list of abbreviations at beginning of thesis.

Interpretation of F2

Organic mud and coals indicate high organic content and deposition in reducing conditions. This coupled with rooting indicates a high accumulation of terrestrial vegetation in a low energy, humid environment experiencing overbank flows. Rip up clasts, coal fragments and dispersed grains were likely deposited by the baffling effect of plants during overbank flows. Rare ripple-lamination may have been generated by wind action. As the coal beds are not laterally extensive, they are interpreted to reflect contemporaneous overbank deposition and autocyclic sedimentary control. These beds also form multiple organic horizons which are hydromorphic features associated with soil formation on a floodplain (Kraus, 1999). Paleosols are normally capped by autochthonous coals that exhibit features of reducing and waterlogged conditions such as preserved organic matter and rootlets (Collinson, 1996). Based upon these observations, Facies 2 is interpreted as back-swamp deposition reflecting a high water table in the supratidal zone, and vertical accretion distal to an active channel.

(F3) Chaotic, inter-bedded, rhizoturbated sand-, silt- and mud-stone

Facies 3 is characterized by rhizoturbation; an abundance of rhizoliths which has resulted in the reworking and destruction of primary sedimentary structures. Sands of F3 are poorly-sorted, ranging from silty to fine-grained sand with chaotically dispersed silt and silty mud, and may contain local low-angle parallel- to ripple-lamination. Silt- and mud-dominated beds are lighter colored with a “leached” appearance. Rhizoliths occur as large, coalified and/or pyritized root traces up to 5 mm in diameter (Fig.II-6F/I). They may also form a dense network of vertical to horizontal branching silt- or mud-filled tubes that contrast with the surrounding matrix and exhibit bleached haloes or rims enriched in Fe or Mn oxides (i.e. rhizohaloes) (Fig.II-6I). Rhizoturbation typically caps convoluted media, evident from folding, faulting, and contorted beds of silty sand and mud (Fig.II-6G). Other characteristic features include organic detritus, coal fragments, and the brownish-yellow color of sediment. Synaeresis cracks were locally observed. Additional lithologic accessories include pyrite nodules, rare organic mud laminae, sub-rounded silty mud clasts, and disseminated coal laminae. Bioturbation intensities are absent to moderate (BI 0-3). Indistinct burrow mottling was most commonly observed, characterized by obscure, texturally heterogeneous “scratch-mark” type bioturbation, with horizontal to vertical, tightly spaced, nested, ellipsoidal burrows and tightly packed subparallel menisci

(Fig.II-6H). The majority of indistinct burrows are interpreted as *Taenidium* ichnofossils or adhesive meniscate backfill (AMB) (Smith *et al.,* 2008). Successions of F3 exhibit sharp and irregular lower contacts and gradational or sharp upper contacts with F1 and F5.

Interpretation of F3

The higher degree of pedogenic alteration and abundance and diversity of rhizoliths, suggests a prolonged period of subaerial exposure and development of a paleosol representing higher soil profiles (Kraus and Aslan, 1993; Kraus, 1999). Facies 3 is interpreted as topographically higher deposition than F1 and F2, where coarser more permeable sediment was deposited such as a levee/crevasse splay. The water table was also lower allowing for oxidation process to enrich the sediment in Fe oxides (Kraus, 1999). Convoluted media typically represents rapid deposition. This coupled with sub-rounded intraclasts, the coarser nature of sediment, and the thickness of the unit, is consistent with a levee interpretation (Pemberton and MacEachern, 2006). This unique and sparse nature of indistinct burrowing is consistent with traces of the non-marine *Scoyenia* ichnofacies, likely produced by the activity of arthropod-tracemakers (Buatois and Màngano, 1995; Hasiotis, 2002). Overall, F3 is interpreted as flood plain deposition dominated by freshwater overbank flows.

(F4) Inter-bedded to inter-laminated silty mud, silt and sand

Facies 4 is characterized by a paucity of rooting and bioturbation with varying proportions of light-grey silty-mud, silt, and light-brown very fine-grained sand. Facies 4 comprises decimeter to meter successions (up to 2 m) that typically show a sanding-upward trend (Fig. II-7A). Contacts are most commonly gradational with F3 or F5, but may be sharp with other fine-grained facies. Silty mud beds are non-bioturbated, fractured, blocky to indurated, and massive to irregular bedded. Deformation structures include convolute bedding, synsedimentary faults and folding and flame structures. Silt and sand beds exhibit very weak bitumen saturations, sharp contacts with mud beds, and parallel-lamination with subordinate incipient current-ripple cross-stratification (Fig.II-7C). Aggradational current ripples, combined-flow ripples, and lenticular bedding are observed locally. Minor constituents include: coal fragments, disseminated coal laminae, and organic detritus. Indistinct burrow mottling and a low diversity, sparse, trace suite dominated by diminutive *Planolites,* characterize F4. Discrete

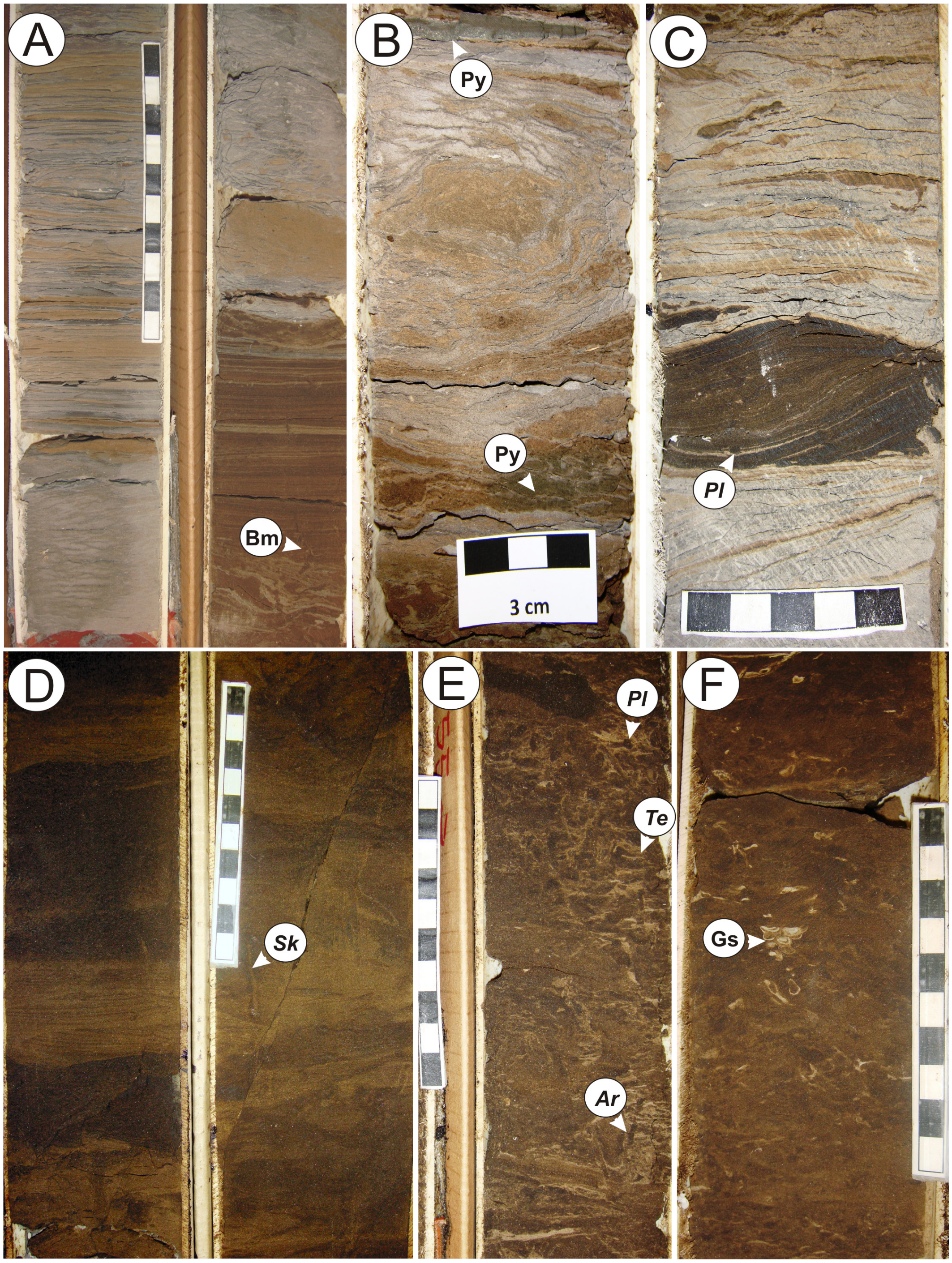


FIGURE II-7: Facies 4-5 from the middle McMurray Formation.
Inter-bedded to interlaminated silty mud, silt and very fine-grained sand (F4) illustrating parallel-lamination, convolute-bedding and indistinct burrow mottling (Bm) in a sanding-upward succession. Note the lack of bioturbation and rooting. Well 16-11-90-14W4, depth 200 m. (B) Convolute bedding and localized pyrite (Py) (F4). Well 4-27-90-14W4, depth 191.5 m. (C) Inter-bedded to inter-laminate sand and silty mud (F4). Sharp contacts and incipient current ripple-lamination are common. Note the diminutive *Planolites (Pl).* Well 4-13-90-14W4, depth 197.6 m. (D) Low-angle parallel- to ripple-lamination and burrowed zones in very fine-grained sand of F5. Diminutive *Skolithos (Sk)* and *Planolites* occur in laminated zones. Well 7-19-89-13W4, depth 211 m. (E) *Taenidium*-dominated fabric *(Ta)* to indistinct mottling with heterolithic linings typical

FIGURE II-7 CONTINUED: of F5. (F) Indistinct burrow mottling with gastropod shells (Gs) of F5. Well 6-3-91-14W4, depth 192.5 m. All scales in cms.

Skolithos, Thalassinoides, and *Teichichnus* are present locally. Burrowing intensities are low and occur sporadically, showing a slight increase upwards in sandier beds (BI 0-1).

Interpretation of F4

The sporadic nature of bioturbation and presence of *Teichichnus*, suggests events of high-energy sedimentation or episodic emplacement in a subaqueous marine setting (Pemberton *et al.,* 2001; Pemberton and MacEachern, 2006; Pemberton *et al.,* 2009). Soft sediment deformation structures also suggest rapid deposition from sediment-laden waters. A mixing of subaqueous and subaerial biogenic structures within different beds, indicated by burrow mottling interpreted as the *Scoyenia* ichnofacies, and marine softground traces interpreted as the *Teichichnus* ichnofacies, respectively, are both observed. This mixed ichnological assemblage coupled with the presence of aggradational current climbing-ripples, and alternating sand, silt and clay are characteristic to levee/crevasse splay deposition (Pemberton and MacEachern, 2006). A low diversity suite of morphologically simple deposit-feeding structures dominated by *Planolites* is also typical of a stressed environment (Pemberton and Wightman, 1992; MacEachern *et al.*, 2005). In this case, physico-chemical stress is the result of fluctuating salinities in the system and rapid sedimentation. This coupled with a rarely observed impoverished suite of *Skolithos, Thalassinoides*, *Planolites* and *Arenicolites* in different beds suggests there was a salinity stress in the environment and likely indicates a non-marine to marine transition zone (Pemberton *et al.,* 1992). Overall, F4 is interpreted as levee/crevasse splay deposition, where overbank flows were both fresh- and brackish-water influenced.

(F5) Laminated to burrowed very fine-grained sand

Facies 5 comprises decimeter to meter successions that are gradational with F4 but may have gradational or sharp contacts with other facies. Bioturbation intensities are low to common and occur in sporadic heterogeneous with rare homogenous distributions (BI 0-2; BI 3-5). Sands are moderately-well sorted and exhibit weak bitumen saturation. When structures are preserved and discernable, low-angle parallel-lamination and current ripple-lamination are dominant with subordinate wave ripple-lamination, flaser bedding, and combined-flow ripples (Fig.II-7D). Laminated bedding is typically demarcated by rhythmic interlaminae of organic detritus and sand. Minor synsedimentary faulting was also observed. Lithologic accessories include planar silty mud laminae, small silty mud clasts, gastropod shells, shell fragments and pervasively pyritized zones. Two recurring ichnofabrics were observed. The most common is a moderately dense *Teichichnus*-dominated assemblage and is typically associated with shell fragments (Fig.II-7E/F). The second is dominated by a low diversity, low density assemblage of extremely sparse, diminutive *Planolites* with discrete subordinate *Skolithos*, *Arenicolites,* and *Thalassinoides* that occur in laminated zones (Fig. II-7D). These separate ichnofabrics typically occur in alternating beds and bioturbation typically increases upwards.

Interpretation of F5

Facies 5 is interpreted to have accumulated in a marginal marine environment experiencing sporadic sub-aerial exposure, shifting sandy substrates, and fluctuating salinity. Facies 5 represents sandy bedforms of sandy flats with minor distributary channel or feeder tidal channels in the intertidal zone. This is evident from the very-fine nature of sedimentation, primary sedimentary structures, and the gradational vertical relationship with overlying supratidal deposits of F1-F4. This facies can also be in gradational contact with underlying subtidal deposits of F6-F8 (Fig.II-10). Increased sediment shifting, due to wave-exposure and presence of tidal run-off creeks, results in the presence of primary sedimentary structures as well as sporadic heterogeneous trace fossil distribution (Gingras and MacEachern, in press). The sporadic heterogeneous distributions alternating with homogeneous distributions are also consistent with sandy intertidal flat deposition (Gingras and MacEachern, in press). The presence of flaser bedding, rhythmic interlamination, and terrestrial organic detritus or “coffee grounds” draping laminae is evidence of tidal sedimentation (Dalrymple, 1992). Fine lamination and small ripples are deposited under low-energy, shallow, quiet water conditions and are evidence of waning flow. The sparse, mixed-ethology suite of small, simple deposit-feeding and suspension feeding traces observed are also characteristic to marginal marine environments and represent an impoverished marine assemblage (Pemberton and Wightman, 1992). This is attributed to fluctuations in salinity and the influence of brackish water. Salinity fluctuations are also evident from the presence of syneresis cracks.

Escape structures indicate variations in sedimentation rates. Furthermore, a *Teichichnus*-dominant fabric represents episodes of higher sediment accumulation as tracemakers try to keep up with sedimentation (Pemberton et al., 2009). *Teichichnus*, *Skolithos, Arenicolites* and *Planolites* are also all opportunistic species that can prevail in variable and unpredictable conditions common to the intertidal zone (Ekdale and Bromley, 1983; Pemberton and MacEachern, 2006, Gingras and MacEachern, in press).

(F6) Cross-bedded to ripple-laminated fine-grained sand with helical- and *Cylindrichnus*- dominated silt and mud inter-beds

Facies 6 occurs in the lower portion of the McMurray Formation, and averages 2-3 m thick, but can reach up to 15 m thick. Contacts are sharp or gradational with very fine-grained laminated sand (F5), bioturbated heterolithics (F9), or inter-bedded to interlaminated sand, silt and mud (F8). Facies 6 is dominated by cross-bedded to ripple-laminated quartz-rich sands with burrowed mud inter-beds and rhythmically interlaminated sand and mud couplets. Sands are typically fine-grained with subordinate medium-grained inter-beds and poor to moderate bitumen saturations. Sigmoidal cross-bedded sands dominate the base of the succession but are less commonly preserved (Fig.II-8A/B). These sands illustrate dip-reversals (bidirectional bedding) and reactivation surfaces between adjacent sets, and range in thickness from 5 – 100 cm, in decimeter to meter thick successions. Cross-beds typically show a slight fining-upward trend, and brecciated zones up to 2.5 m thick locally occur (Fig. II-8D). These clasts are subangular to angular, composed of mud/silty mud and often contain disseminated organic material. Above these sands, the intercalation of smaller scale cross-beds and current ripple-lamination becomes dominant, with ripple-lamination increasing in abundance upwards (Fig. II-8C). A transition into low angle planar to horizontal stratification near the top of a bedset may also occur.

Cross-strata are often exemplified by grain-size striping, fine organic lamination and/or disseminated coal lamination. Mud drapes and double mud drapes are widespread along the foresets and set boundaries of all cross-stratification types. Medium-sized sand grains, pebbles and clasts can also occur as a sparse millimeter lag near the base of a set. Rippled sands decrease in thickness and abundance upwards, forming an overall muddier-upward trend. Grey mud and light brown silt inter-beds are up to 30 cm thick, averaging 5-10 cm, and are typically massive to paired sand and mud laminae. Laminae are

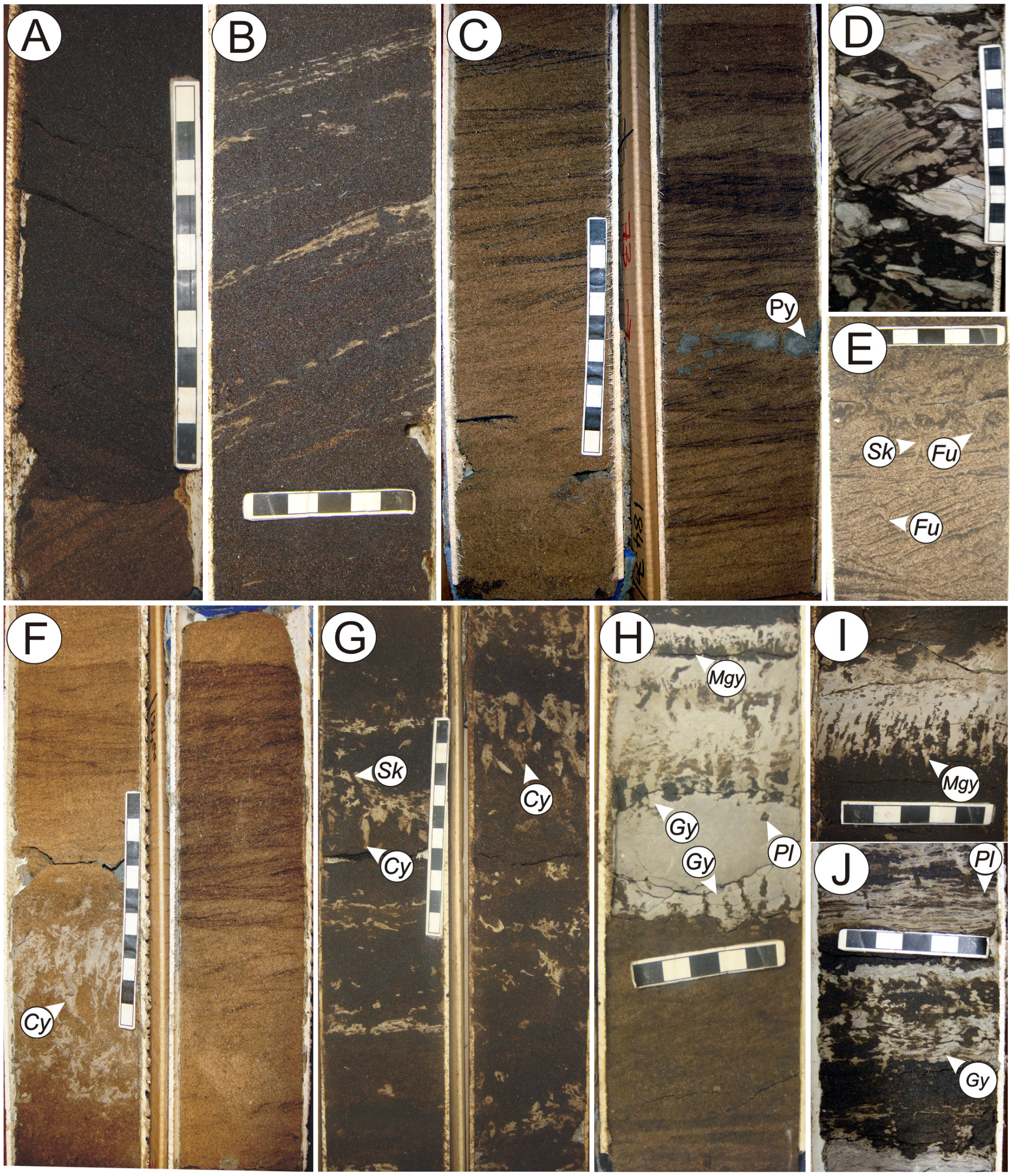


FIGURE II-8: Cross-bedded to ripple-laminated sands (F6) from the middle McMurray Formation.

(A) Cross-bedded sands illustrating bi-directional bedding. Cross-strata are also highlighted by the organic debris on strata foresets. Note the overall low to moderate bitumen saturation and lack of trace fossils. Well 12-26-88-14W4, depth 204.5 m (B) Cross-bedded sands with grain-size striping and thin mud drapes along foresets. Well 10-27-88-14, depth 207.4 m. (C) Tidally-influenced current ripple-laminated sands with organic debris and coal fragments draping foresets and bedsets. Well 12-08-91-14W4, depth 189.5 m. (D) Brecciated zone and heterolithic clasts characteristic to cross-bedded intervals. Well 15-2-92-12W4, depth 117 m. (E) Disruption of small-scale cross-bed and ripple-lamination through biogenic reworking. Traces appear as small chevrons to vertical burrows of fugichnia *(Fu)* and *Skolithos (Sk)* burrows representing dwelling and escape behaviors, respectively. Well 15-19-88-13W4, depth 189 m. (F-G) Examples of bi-specific *Cylindrichnus- (Cy)* and *Skolithos*-dominated suites in ripple-laminated sand. Note the abundance of organic debris draping ripple cross-lamination. Well 14-22-88-13W4, 179.7 m, Well 7-29-89-14W4, 192 m. (H-J) Examples of *Gyrolithes*-dominated suites in mud inter-beds

FIGURE II-8 CONTINUED: of ripple-laminated sands. Both helical forms *Gyrolithes (Gy)* and *Microgyrolithes (Mgy)* are represented. Note the rhythmic lamination in (J). Well 13-24-88-13W4, depth 183.3 m; 6-5-91-14W4, depth 182.4 m; and 5-36-88-14W4, depth 186 m, respectively. All scales in cms.

planar to wavy and locally produce flasers. Rare syneresis cracks are observed. Contacts between sand and silt/mud are sharp to erosive and commonly distorted by burrowing. Primary bedding also appears predominantly inclined. Bioturbation is typically associated with finer media but intensities are variable and typically increase upwards (BI 1-4).

Cross-bedded sand beds are usually non-bioturbated (BI 0-1) and ichnofossils are rare and sporadic if present, identified only in rip-up clasts as *Cylindrichnus* or *Planolites*. Diminutive sand-filled *Skolithos* burrows and rare *fugichnia* locally occur (Fig. II-8E). Thicker ripple-laminated sands also contain well bioturbated intervals of diminutive silt-filled *Skolithos* and *Cylindrichnus* burrows. Helical traces are common within highly bioturbated silt and mud beds where traces can subtend into the underlying sand up to 10 cm. Helical burrows consist of *Gyrolithes* and *Microgyrolithes* or *Spirascensus conferti* (Lettley, 2004). The aforementioned forms illustrate two distinct high density monospecific suites that develop a preferred burrow fabric unique to this facies (Fig.II-8H/I/J). Sporadic heterogeneous distribution may also occur. Within weakly bioturbated silt and mud beds, small, singular sharp-walled, sand-filled *Planolites* near bed tops are dominant. In sands, subordinate traces observed include *Teichichnus, Arenicolites, Palaeophycus*, *Chondrites,* and *fugichnia*. *Arenicolites* and *Thalassinoides* burrows from this facies may also penetrate into underlying facies.

Interpretation of F6

Facies 6 is interpreted as lateral accretion bedding that corresponds to point bar accretion along environmentally stressed tidal channel margins. Cross-bedded sands at the base of F6 are interpreted as higher energy deposition of tidal channels, reflecting the migration of subaqueous dunes at the base of an active channel fill. This higher energy setting is supported by the lack of burrowing and/or escape structures, large-scale cross bedding, grain size, higher bitumen saturations, and abundance of sand. Tidal channels are distinguished from fluvial channels by the dominance of bi-directional cross-beds, presence of discontinuous mud beds, and grain-size striping which are evident of deposition by tidal currents with fluctuating current speed and direction (Pemberton and MacEachern, 2006). Although rarely preserved throughout the area, these thick sigmoidal successions indicate that sediment accumulation occurred at deeper flow depths. Grain size coupled with the size of cross-bedding, tidal currents likely exceeded 1 m/s locally (Dalrymple, 1992). Mud beds that are thick, structureless and lack bioturbation are interpreted as fluid-muds, which are often associated near the base of tidal channels (Dalrymple, 1992; Dalrymple and Choi, 2007; Gingras and MacEachern, in press). Cyclic thickening and thinning of foresets within cross-sets also indicates rhythmic changes of neap and spring tides (Nio and Yang, 1991). Above these cross-beds, regular inter-beds of smaller-scale cross-beds and current ripple laminated sandstones, with weak to moderately burrowed carbonaceous silts and muds occur.

A number of criteria indicative of tidal currents during sedimentation have been identified to support a tidal interpretation. These include: reactivation surfaces, abundance of rip up clasts, grain-size striping, mud drapes and flasers, syneresis cracks, heterolithic sedimentation, and dominance of current ripple-lamination (Dalrymple, 1992). The inclined nature of bedding and heterogeneous character illustrating dm-scale sand / mud couplets of F6 is consistent with inclined heterolithic stratification (IHS) of Thomas *et al*. (1987) which is widely accepted as a common characteristic in mesotidal marginal marine environments (Ranger and Pemberton, 1992; Gingras *et al.,* 1999; Gingras *et al.,* 2002; Pemberton and MacEachern, 2006). This is particularly true for the middle McMurray in the main bitumen fairway, where similar deposits are interpreted as estuarine point bars (Mossop and Flach, 1983; Flach and Mossop, 1985; Ranger and Gingras, 2003; Pemberton and MacEachern, 2006). Shoaling is evident in this facies from the transition of large- to small-scale sedimentary structures, increasing bioturbation and the muddying upward nature. This indicates that these sand bodies accumulated in laterally accreting channel bars (Dalrymple, 1992). Lateral accretion bedding is further supported from the finer nature and poor sorting of sands compared to cross-beds lower in the succession, and a general fining-upward trend (Pemberton and MacEachern, 2006). A brackish marginal marine environment is strongly suggested by the mix of horizontal and vertical forms, typical of a brackish-water trace fossil suite as defined by Pemberton and Wightman (1992). The regular heterogeneous trace fossil distribution of F6 is evidence of a tidal response and seasonal rhythmicity between tidal and fluvial waters, common to migrating tidal dunes and IHS in tidal settings (Gingras and MacEachern, in press).

The monospecific suites dominated by helical burrows are commonly observed in facies characterized by IHS interpreted as lateral accretion point bar deposits (Pemberton and MacEachern, 2006). In the middle McMurray Formation within the main valley trend, *Gyrolithes*-dominated suites have been interpreted as abandoned channel associations or brackish-water bay like environments (Pemberton *et al.,* 1982; Ranger and Pemberton, 1992). The *Skolithos-Cylindrichnus* association common in F6 is also typical of estuarine channel sands and sand-dominated IHS (Pemberton *et al.,* 1982; Ranger and Pemberton, 1992; Pemberton and MacEachern, 2006). The more sporadically distributed diminutive trace assemblage of the opportunistic species *Planolites, Cylindrichnus, Teichichnus, Arenicolites* and *Skolithos* are the third ichnofabric observed in F6 which is also characteristic of general brackish water conditions (Pemberton and Wightman, 1992; MacEachern, 2001; Gingras and MacEachern, in press). A range in bioturbation intensities and presence of both monospecific and general brackish-water ichnofabrics illustrates the variability in environmental stresses likely related to salinity, turbidity in the system and sedimentation rates. Where the base of this facies is erosive and comprises *Arenicolites* and *Thalassinoides* burrows, a *Glossifungites* ichnofacies is interpreted which are commonly observed in these subtidal conditions (Gingras and MacEachern, in press).

*(*F7) Flat-lying to inclined inter-bedded to inter-laminated heterolithics

Facies 7 occurs in the lower portion of the McMurray Formation and is characterized by flat-lying to gently inclined inter-bedded to inter-laminated heterolithics illustrating varying degrees of bioturbation intensities as well as proportions of sand, silt and mudstone (Fig. II-9(A-F)). Facies 7 ranges in thickness from 1 to 10 m, averaging 2 m, and is intercalated with F6 and F8.

Individual bed contacts are typically inclined and sharp, and successions show an overall fining-upward trend. Beds are on a centimeter- to decimeter-thick scale and rhythmic in nature (Fig. II-9(G-J)). Sand is moderately-well sorted, very fine- to upper fine-grained with low to moderate bitumen saturations. Coarser sand occurs as burrow fills and thin beds.

Small-scale cross-beds transitioning to current ripple-lamination and/or wavy- and flaser-bedding are the dominant sedimentary structures in sand dominated successions. Cross-bed foresets tend to alternate in dip direction and grain size striping is locally observed. Sand beds are non-burrowed or may contain rare *Skolithos*, fugichnia and small angular intraclasts of silty mud. Muds are light- to dark-grey, range from millimeter-thick laminae to decimeter thick,

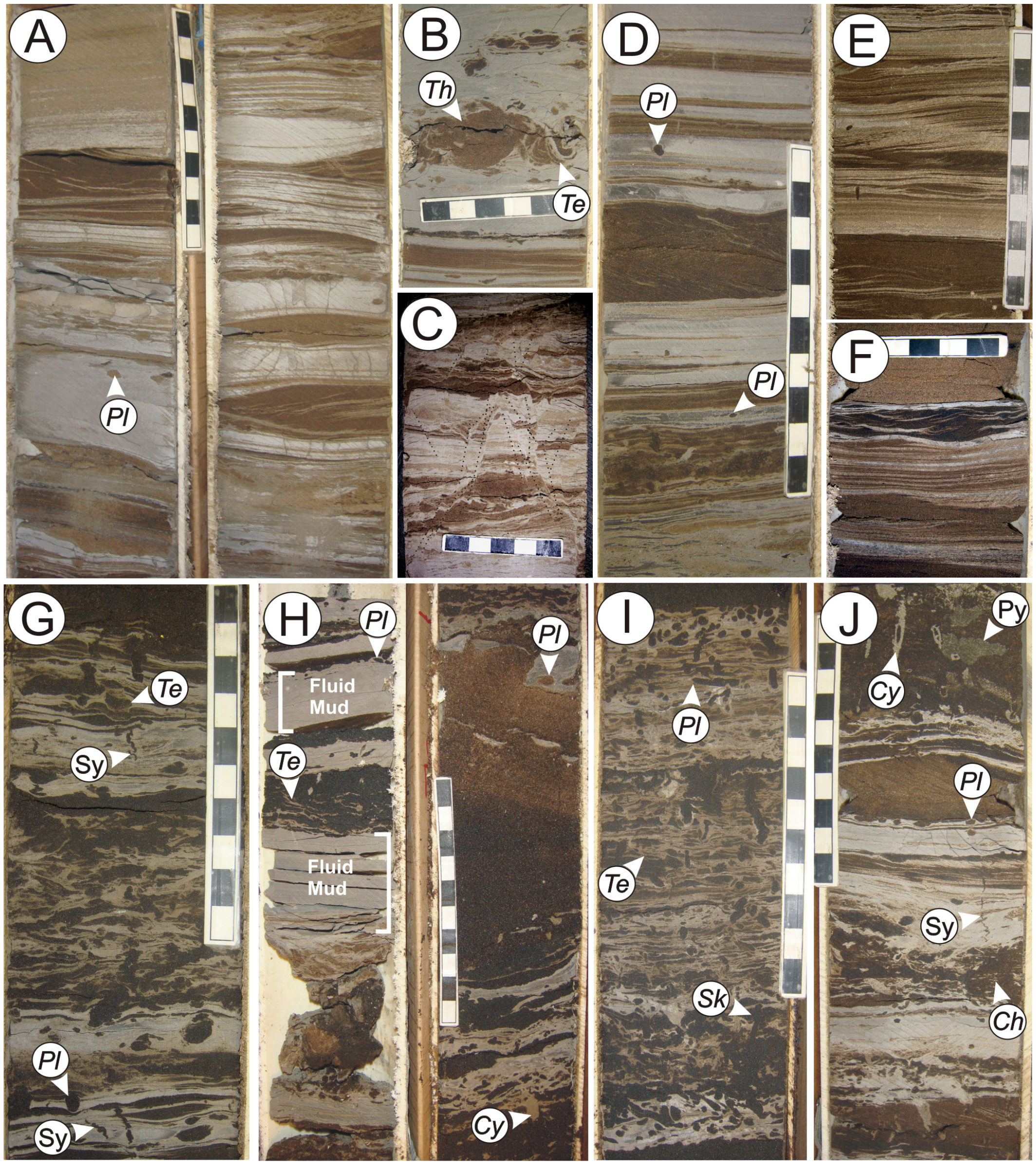


FIGURE II-9: Flat-lying to inclined inter-bedded to inter-laminated heterolithics (F7) of the middle McMurray Formation.

(A) The lack of burrowing is indicative of a hostile environment for benthic colonization. Tidal indicators: flaser bedding, wavy bedding, rhythmic lamination and current ripples. Normal and reverse grading of beds is common and represents slow slack-water deposition. Well 10-15-88-13W4, depth 181.8 m. (B) Illustrates an impoverished trace suite illustrated by discrete *Thalassinoides (Th), Teichichnus (Te)* and *Planolites (Pl)*. Well 7-19-89-13W4, depth 207.8 m (C) Examples of convoluted sediment by micro-faulting. The laminated nature and low to moderate bioturbation intensity indicates physico-chemical stress due to fluctuating salinity as well as sedimentation and burial rates outpacing biogenic colonization. Well 10-08-90-14W4, depth 196.5 m. (D) Ripple-stratified sand inter-bedded with planar inter-laminated mud and sand. Note the sharp sand and mud contacts, indistinct mottling and carbonaceous debris. Well 10-30-88-13W4, depth 184.6 m. (E) Well preserved sedimentary structures including climbing current ripples, graded beds, and flaser bedding. Climbing ripples with mud laminae indicate that the water column was charged with high concentrations of clay that was deposited under rapid sedimentation. 10-15-88-13W4, depth 177.7 m. (F) Wave-influence indicated by oscillatory

FIGURE II-9 CONTINUED: ripples. Well 10-30-88-13W4, depth 186.9 m (G) Moderately bioturbated wavy bedded interval illustrating *Planolites, Teichichnus, Cylindrichnus (Cy)* and syneresis cracks, typical of an impoverished marine assemblage under salinity stress. Well 12-26-88-14W4, depth 185 m. (H) Sharp-based muds with top down colonization by *Planolites* represent fluid mud deposition in F7b. The coarser nature of sand and higher-energy structures indicates that major stresses were likely related to turbidity and sedimentation effects. Bi-directional cross-beds indicate tidal influence. Well 10-22-90-14W4, depth 192.8 m. (I) Moderately bioturbated rhythmic inter-laminated sand, silt and mud interval. The assemblage is dominated by a brackish-water suite including diminutive *Skolithos, Planolites* and *Teichichnus*. Well 11-31-88-13W4, depth 191 m. (J) Wavy bedding and current ripples illustrate higher energy deposition. Syneresis cracks indicate salinity fluctuations. The heterolithic sedimentation of F7 is interpreted as lateral accretion bedding of tidally influenced point bars. Well 10-22-90-14, depth 192 m. All scales in cms.

and beds are typically sharp-based. Muds may appear structureless, contorted, or highly burrowed. They may also contain rhythmic millimeter-thick, horizontal to lenticular, silt or sand laminae. Individual mud contacts are typically sharp and distorted by burrowing. Mud-dominated intervals are typically wavy-, to flaser-bedded with current- and wave-generated cross-strata.

Double mud drapes and horizontal grading (reverse and normal) are also common. Climbing ripple-lamination, combined-flow ripples, and low-angle to horizontal stratification are subordinate. Coal fragments and coffee grounds typically drape cross-laminae or are randomly disseminated. Syneresis cracks and pervasive pyrite/siderite nodules were observed near facies contacts and synsedimentary faults and folds locally occur.

The overall bioturbation intensity is absent to moderate (BI 0-3). Burrowed beds are typically intercalated with un-burrowed beds and trace fossil distribution is regular to sporadic heterogeneously. Mud-dominated intervals can exhibit non-bioturbated intervals or are dominated by well burrowed intervals of monospecific diminutive *Microgyrolithes, Gyrolithes* and *Cylindrichnus* suites. A low to moderate density assemblage of small to medium sand-filled *Planolites* and *Teichichnus* may also penetrate bed/laminae tops. Subordinate ichnogenera include *Thalassinoides* and *Skolithos*. In sand-dominated intervals a low density assemblage of *Planolites, Skolithos* and *Arenicolites* penetrate mud bed tops and rhythmic inter-beds. Rare *Palaeophycus* have been observed to subtend into sand beds. Inter-laminated beds are moderately burrowed, wavy, rhythmic alternations. Bioturbation intensity typically increases up-section (BI 2-3).

Interpretation of F7

The flat-lying to inclined, and heterolithic nature of sedimentation is interpreted as lateral accretion bedding of tidally influenced point bars in the subtidal zone (Fig. II-10). A preponderance of tidal indicators and a characteristic brackish water trace fossil assemblage characterize this facies. Wavy-, flaser-, and lenticular bedding are characteristic of tidal sedimentation. Fluid muds are interpreted as massive, non-bioturbated, sharp-based muds lacking bioturbation, and are common in tidal channel settings. Neap-Spring cycles were observed indicating deposition by fluctuating current speeds relating to tidal processes. The presence of coarser sand beds and burrow fills represents an influx of sediment and stronger tidal currents in a higher energy setting (Dalrymple, 1992). Higher energy current speeds are also indicated by thicker sand deposition and migration of mega-ripples. The dominance of rhythmically laminated or bedded sand / mud couplets and the overall inclined nature points to an IHS interpretation (Fig. II-10). An overall-fining upward trend from sand-dominated to mud-dominated successions suggests shoaling, and a change from a distal to more proximal landward position of the channel in the subtidal zone. Wave reworking is subordinate, but indicated through locally observed symmetrical ripples. Syneresis cracks are also observed near mud-sand transitions indicating that muds were deposited under suppressed salinity compared to sand deposition. This also illustrates the participation of river processes as they represent freshwater input, or variable salt concentrations (Carmona *et al.,* 2009; Donovan and Foster, 1972). The development of both regular and sporadically heterogeneously distributed brackish water trace fossil suite illustrates the fluctuating environmental parameters during deposition. The regular heterogeneous distribution of alternating burrowed and un-burrowed beds reflects seasonality (Gingras and MacEachern, in press). The attenuation of bioturbation to near absent levels (BI 0-1) indicates environmentally hostile conditions for benthic colonization, likely owing to fluctuating salinities, sedimentation rates, turbidity, and water energy. Coupled with the dominance of diminutive horizontal and vertical trace fossil forms in both monospecific and bi-specific suites, provide good evidence of deposition within the medial portion of a channel/bar in a tidal setting (Gingras and MacEachern, in press). The gradational nature with F6 and F8 further supports this interpretation.

(F8) Well bioturbated heterolithics

Facies 8 occurs in the lower portion of the McMurray Formation and is characterized by highly bioturbated heterolithic media that occurs as cyclic fining-upward, gradational successions that are typically gradational with, and

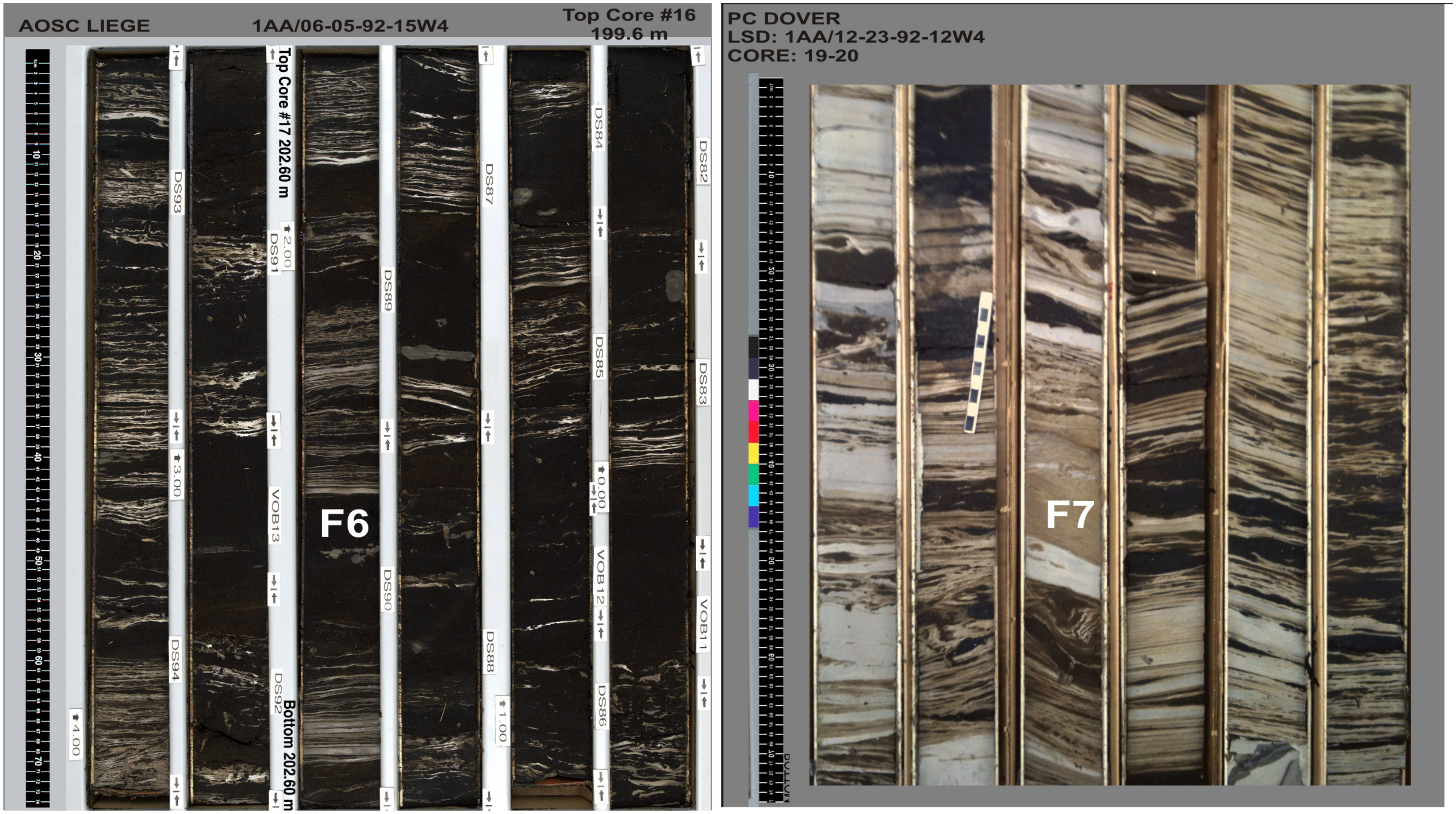


FIGURE II-10A: Examples of inclined heterolithic stratification and associated tidal flats of the middle McMurray Formation.

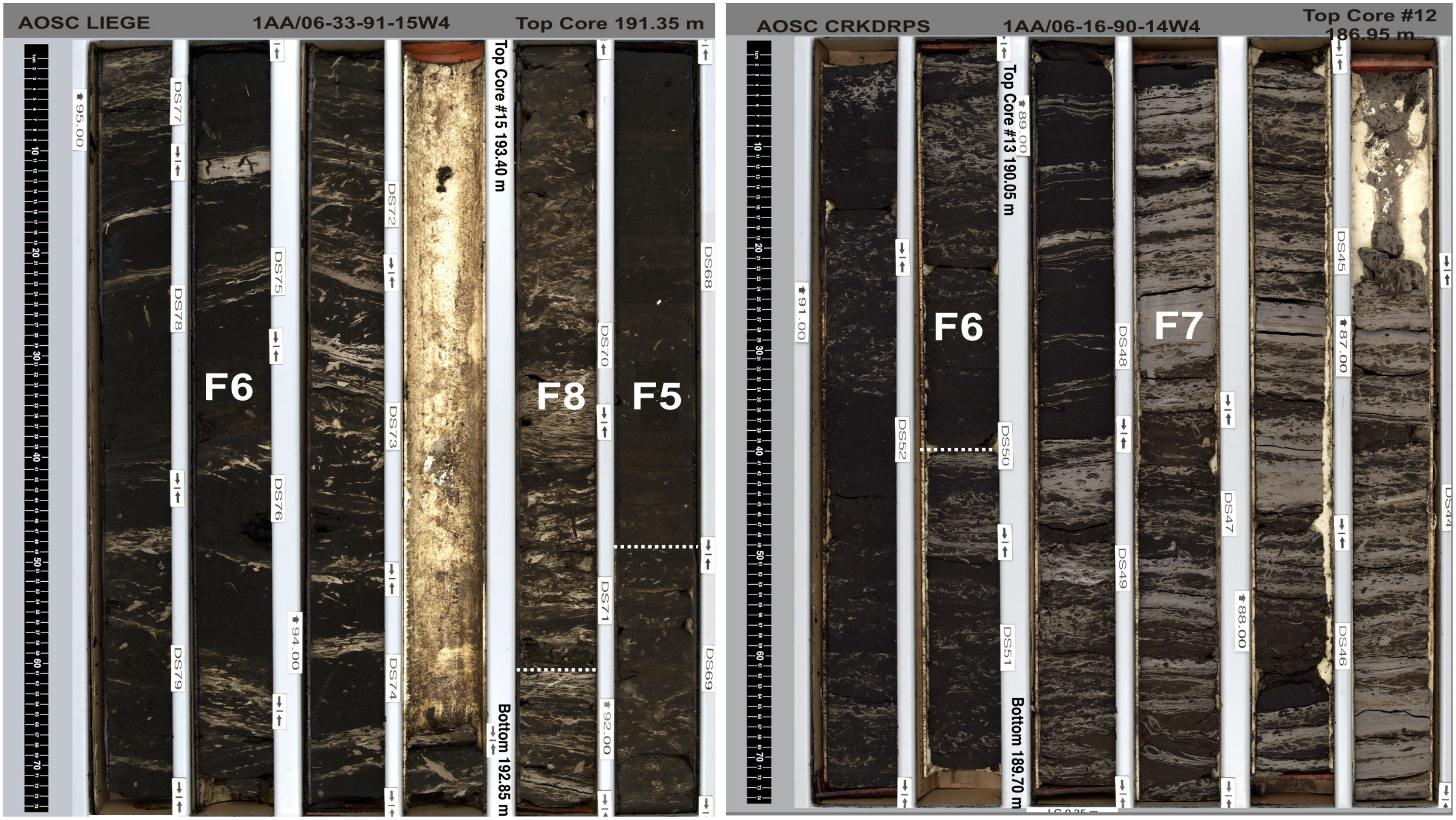


FIGURE II-10B: Examples of inclined heterolithic stratification and associated tidal flats of the middle McMurray Formation.

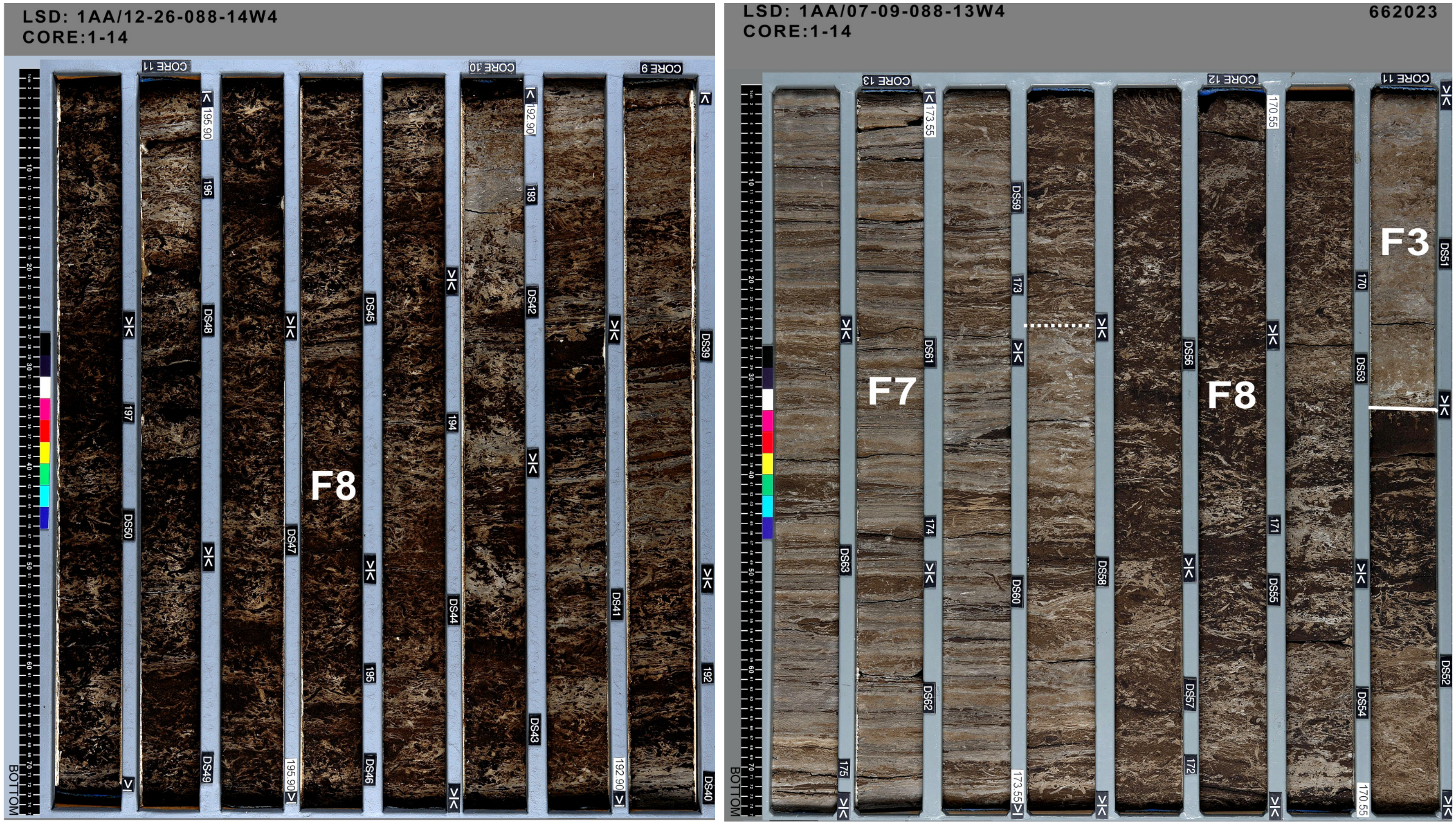


FIGURE II-10C: Examples of inclined heterolithic stratification and associated tidal flats of the middle McMurray Formation. Heterolithic sedimentation is interpreted as lateral accretion bedding (F6-F7) of tidally influenced point bars. Tidal influence is evident from rhythmic bedding of sand / mud couplets, wavy to flaser bedding, double mud drapes, bi-directional cross-bedding and current ripples. An overall brackish-water trace fossil assemblage is represented by a low diversity impoverished suite dominated by diminutive *Cylindrichnus, Gyrolithes, Teichichnus,* and/or *Planolites*. Core examples are arranged in an overall N-S orientation from the top left, to bottom right corner (box core photos courtesy of Athabasca Oil Sands Corp).

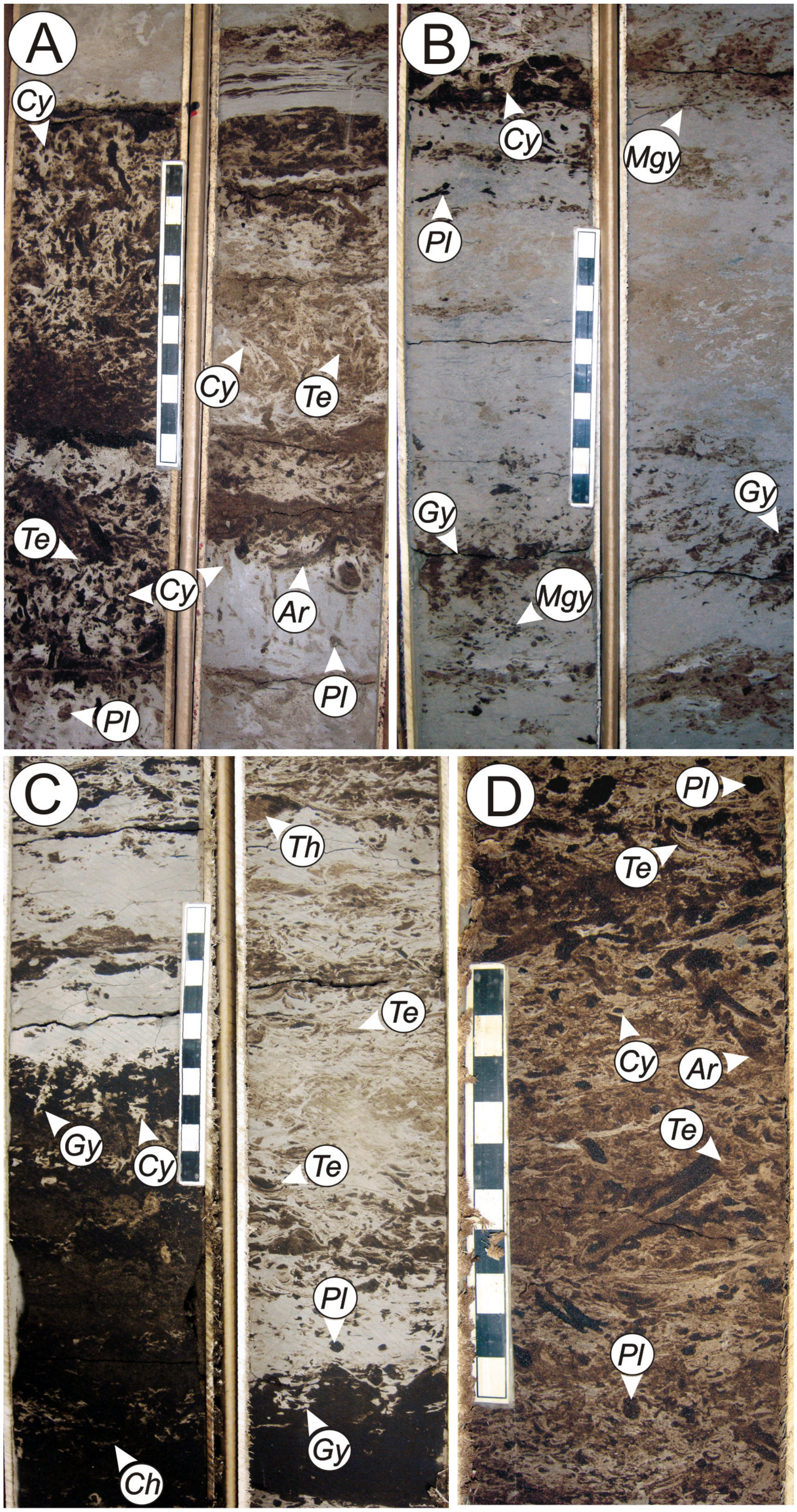


FIGURE II-11: Well bioturbated heterolithics (F8) of the middle McMurray Formation. Heterolithic strata is characterized by a brackish-water trace fossil assemblage dominated by

FIGURE II-11 CONTINUED: brackish-water trace fossil suites of diminutive horizontal deposit-feeding and vertical suspension-feeding traces. Tidal sedimentation is evident from the cyclic nature of bedding and locally preserved rhythmic mud drapes, flaser- and wavy-bedding. Bioturbation is pervasive in both sand and mud which is characteristic of an intertidal setting. (A) Note the sharp to bioturbated contacts between sand and silt/mud-dominated units, and the local preservation of mud drapes. The pervasive bioturbate texture consists of a *Cylindrichnus*-dominated suite *(Cy)* with subordinate *Teichichnus (Te), Arenicolites (Ar),* and *Planolites (Pl).* Well 6-5-91-14W4, depth 182 m. (B) Example of mud-dominated heterolithics dominated by helical burrow forms. Subordinate *Cylindrichnus* and *Planolites* are also observed. Well 7-29-89-14W4, depth, 188.8 m. (C) Cyclic stacked successions of sand- to mud-dominated heterolithics. Note the massive non-bioturbated mud beds with *Gyrolithes (Gy)* subtending into the underlying sand. Other ichnoforms include *Teichichnus, Planolites, Cylindrichnus* and *Chondrites (Ch).* Well 10-15-88-13W4, depth 173 m. (D) Sand and silt-dominated heterolithics with pervasive burrowing of a typical brackish-water trace fossil suite. *Teichichnus, Planolites, Cylindrichnus*, and *Arenicolites* are the dominant ichnoforms. Well 15-19-88-13W4, depth 191.4 m. All scales in cms.

occur above, F6 and F7 (Fig.II-10). This facies ranges in proportions of sand, silt, and mud, but is typically mud-dominated. Successions illustrate decimeter to meter scale fining- and muddier-upward trends. Bitumen saturation is relatively weak, and primary structure is typically destroyed by homogeneously distributed burrowing (Fig.II-11). Rhythmic flasers or weakly bioturbated alternations of horizontally bedded sharp-based sand and structureless mud laminae and thin beds are locally preserved. Slumping is also evident from folded bioturbated media. Silty- to fine-grained sand-, and mud-dominated beds contain bioturbated and gradational or sharp contacts. Low proportions of organic debris and lignitic coal fragments up to 2.5 cm are observed. Centimeter-scale sideritized intervals also occur locally. Strata exhibits a unique bioturbate texture where bioturbation intensities are high showing complete bioturbation (BI 4-6) by small- to moderate-sized burrows (Fig.II-11). Individual ichnoforms identified include *Cylindrichnus, Gyrolithes, Microgyrolithes, Teichichnus, Arenicolites, Planolites, Skolithos, Thalassinoides,* and *Palaeophycus. Cylindrichnus, Gyrolithes, Planolites* and *Teichichnus* are the dominant ichnoforms and traces are passively sand- and mud- filled in equal distribution within sand- versus mud-dominated heterolithics.

Interpretation of F8

Facies 8 is interpreted as intertidal flat deposition in a mesotidal brackish tidal setting. Tidal evidence is evidenced from the heterolithic and cyclically bedded nature of deposition, as well as the presence of rare flaser-, wavy-, and lenticular-bedding. Regular waxing and waning of bioturbation intensity is also observed at the bed and bed-set scale. Facies 8 is dominated by a mix of deposit- and suspension-feeding behaviors representing an impoverished, mix of horizontal and vertical trace fossils typical of a brackish water expression (Pemberton and Wightman, 1992). The admixture of sand and mud by a high degree of bioturbation is also characteristic of an intertidal deposit (Gingras and MacEachern, in press). The homogeneous distribution of bioturbation indicates slow sedimentation coupled with readily available food and oxygen. In tidal settings, this indicates a regular influx of marine to brackish waters, and resupply of food materials which is characteristic of micro- to mesotidal intertidal flats (Gingras and MacEachern, in press). This facies is interpreted to represent more landward deposition (i.e. middle intertidal flat) than lateral accretion tidal channel deposition of F6 and F7. Bioturbate textures are typically more diverse and abundant along estuarine margins rather than in deeper channels (Pemberton and MacEachern, 2006), and the shift to homogeneous burrowing distributions and high intensities correspond to the outer portion of middle intertidal flats in modern settings (Gingras and MacEachern, in press). The brackish water signature from F6 to F8, coupled with the gradational change in the ichnological distribution, fining-and muddying-upward vertical relationship, represent shoaling and preserved tidal bar successions through the subtidal to intertidal zones.

Upper McMurray Facies

(F9) Well burrowed inter-bedded sand, silt and light grey mudstone

This facies occurs in the mid- to upper-portion of the McMurray Formation and is characterized by varying proportions of variably bioturbated (BI 1-6) inter-bedded sand, silt, and mud. Sand- or mudstone-dominated successions average 5-10 meters in thickness and occur in both fining- and coarsening-upward successions. Facies 9 is gradational to sharp with F11 and F10 and upper contacts may be sharp with F17 or truncated by F12 or F13. Inter-beds are on a centimeter to decimeter scale, and both sandier- and muddier-upward trends are observed. Bitumen saturation has a direct relationship to the ratio of sand to mud, but is typically poor.

Fine sediment varies significantly in character but is most distinguishable by the bluish-grey color and presence of sharp-based, massive, non-bioturbated mud beds. These beds are rare to abundant in occurrence and may contain ultra-thin wavy- to parallel-laminae of very fine-grained sand, silt or disseminated

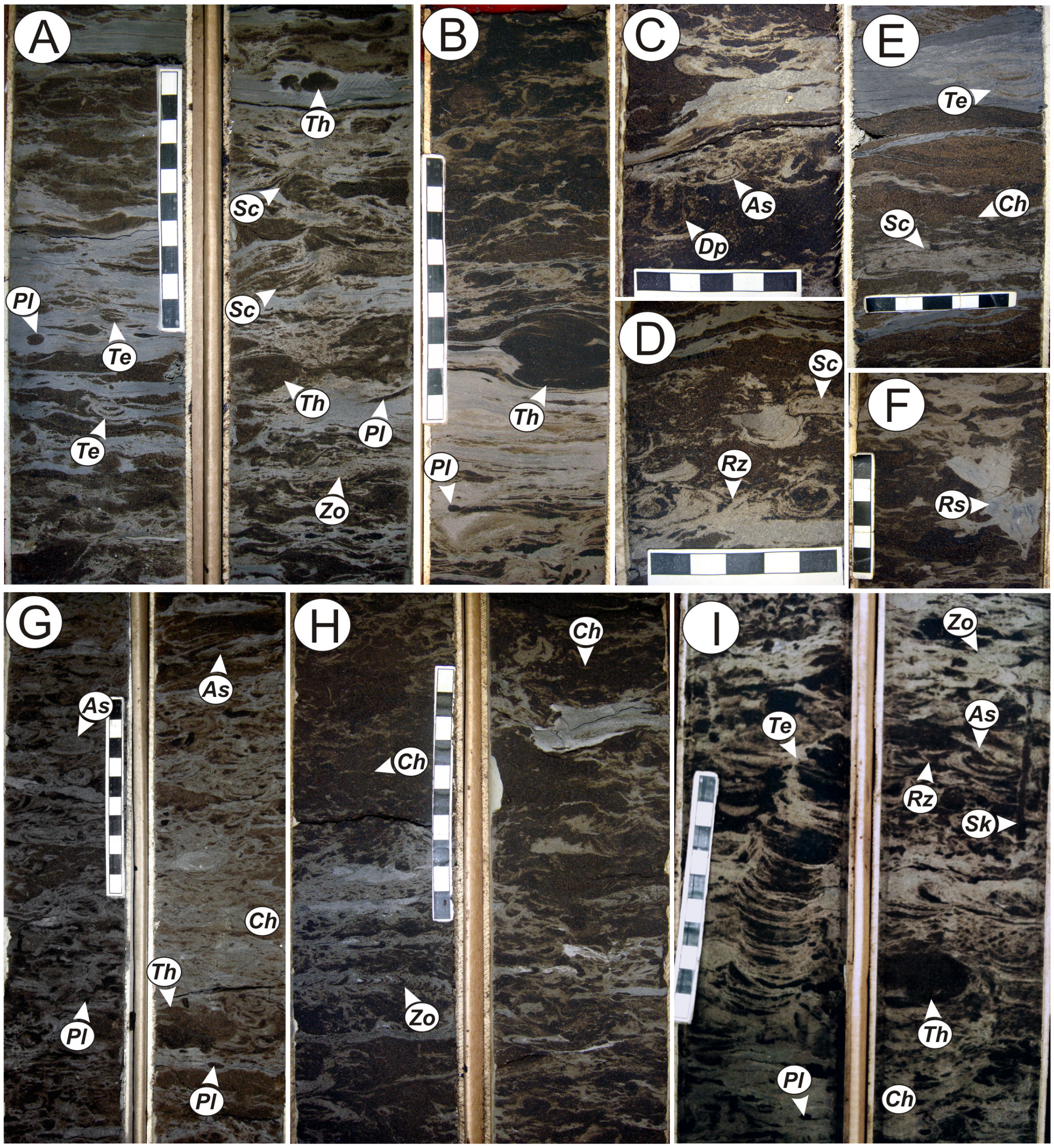


FIGURE II-12: Well burrowed inter-bedded sand, silt, and light grey mudstone (F9) of the upper McMurray Formation.

This facies illustrates a high diversity and density assemblage of larger marine traces representing an overall proximal *Cruziana* ichnofacies. Individual ichnogenera can be difficult to distinguish due to intense bioturbation and cross-cutting relationships. (A) Preserved wavy inter-laminae and rhythmic bedding and sharp-based massive mud beds. These muds illustrate a distinct bluish-grey color and are typically colonized by discrete *Planolites (Pl), Teichichnus (Te)* and *Thalassinoides (Th)*. Additional ichnogenera include *Scolicia (Sc), Rosselia (Rs), Chondrites (Ch)* and *Zoophycos (Zo)*. Well 16-01-90-14W4, depth 209.5 m. (B) Robust *Thalassinoides* burrow within rhythmic inter-laminated silt, sand and mud. Well 10-07-90-13W4, depth 204.5 m. (C) Examples of *Teichichnus, Diplocraterion (Dp),* and *Asterosoma (As)* structures. Well 16-01-90-14W4, depth 208.9 m. (D) Examples of the spreiten structures *Rhizocorallium (Rz)* and *Scolicia*. Note the coal and shell fragments which are common accessory features. 16-01-90-14W4, depth 212 m. (E) Illustrates preserved ripple-lamination with overlying sharp-based mud bed. Traces observed include *Scolicia* and *Chondrites*. Well 10-33-89-13W4, depth 226 m. (F) Example of stacked *Rosselia* bulbs which may indicate recolonization during a storm event. Well 10-07-90-13W4, depth 196.5 m. (G) Intensely bioturbated heterolithic media (BI 5-6) illustrating a complex, assemblage with multiple tiers. Individual ichnogenera include *Asterosoma*,

FIGURE II-12 CONTINUED: *Planolites, Thalassinoides, Chondrites*, and *Scolicia*. Well 10-32-89-13W4, depth 213.5 (H) Examples of a common *Zoophycos-Chondrites* dominant association. Well 10-08-90-13W4, depth 208.5 m. (I) intensely bioturbated heterolithic media (BI5-6) with a diverse array of robust to medium-sized ichnogenera including *Teichichnus, Thalassinoides, Skolithos, Rhizocorallium, Planolites, Chondrites, Zoophycos,* and *Asterosoma*. Multiple tiers are evident as cross-cutting and overprinting is common. Such intense bioturbation indicates slow, continuous rates of deposition. This coupled with the extensive re-burrowing of larger complex structures reflects stable, well oxygenated fully marine conditions and an abundant supply of food. Well 9-29-91-12W4, depth 141.2 m. All scales in cms.

organic debris. Discrete *Planolites* burrows and *Thalassinoides* can penetrate mud bed tops (Fig.II-12A). Muds are also commonly homogenized by burrowing. Contorted bedding and micro-faulting occur locally. Silty-muds are also abundant as beds, burrow-fills, or mottled with sand by burrowing.

Sand is moderate to poorly-sorted and silty to fine-grained with local reverse grading and lower- medium quartz grains and pebbles. Coarse sand may also infill burrows. Wavy-bedding and rhythmic interlaminae of sharp-based sand and mud are common (Fig.II-12B). Current- and oscillation ripple-lamination occur locally and shell fragments, small bivalves, disseminated organic debris and coal fragments are also sporadically distributed (Fig.II-12D). Pervasive pyrite/ siderite may occur near sharp facies contacts and locally as burrow replacement.

A high diversity and density assemblage of traces is most typical, where high bioturbation intensities (BI 4-6) make individual ichnogenera difficult to identify. Horizontal forms of *Asterosoma, Thalassinoides, Planolites, Rhizocorallium* and *Zoophycos* are the most robust and easily identifiable ichnogenera (Fig.II-12). *Asterosoma* typically have smaller central tubes, on the millimeter scale, but thick, circular to oval silty mud lobes up to 5 cm wide. Mud lobe arms typically illustrate concentric lamination of sand and mud, and may be re-burrowed with *Chondrites*. *Thalassinoides* are unlined, sand-filled, and burrows up to 5 cm have been observed. *Zoophycos* consist of branching, silt- and mud-filled spreitin structures. *Rosselia* bulbs are less common and less robust than observed in subsequent facies, and form vertical, 1-2 cm silt and mud-filled cones penetrating up to 5 cm. Stacked bulbs locally occur and central tubes are less commonly preserved (Fig. II-12H). *Rhizocorallium, Teichichnus, Diplocraterion* and *Scolicia* are typical spreitin structures (Fig. II-12). *Chondrites, Phycosiphon, Skolithos* and *Schaubcylindrichnus* are sporadic in distribution. In rare cases, media exhibit low levels of bioturbation (BI 1-3) and are dominated by wavy bedding with moderate sized *Planolites, Thalassinoides,* and *Teichichnus*.

Interpretation of F9

Facies 9 is interpreted as background fully marine sedimentation of a shallow embayment. More specifically, it represents a bay-margin shoreface (bay-fill and/or interbar deposition) in a sheltered embayment dominated by tidal processes and subordinate wave influence. The high bioturbation intensity and the overall homogeneous trace fossil distribution of robust marine ichnoforms indicate that the environment was exposed to fully marine salinities (Na concentrations above 35 ppm). This is reflected by a very diverse mixture of robust and pervasive complex deposit-feeding structures (e.g. *Asterosoma, Rosselia, Rhizocorallium*), horizontal grazing structures (e.g. *Phycosiphon*), deep-tiered mining structures (e.g. *Chondrites and Zoophycos*), and a variety of simple deposit-feeding structures (e.g. *Planolites, Teichichnus, Thalassinoides*). The extensive reworking of larger complex structures by smaller ichnogenera reflect stable, well oxygenated, fully marine conditions with abundant deposited food (Bann *et al.,* 2008). Such intense bioturbation also indicates slow, continuous rates of deposition indicating shelter from storm and fair-weather wave processes.

This complex suite of traces represents a proximal *Cruziana* ichnofacies with contributions from the *Skolithos* ichnofacies, consistent with stable, fair-weather deposition in a protected setting. Variations in the ichnological signature, where bioturbation becomes sporadic in distribution and intensity levels and diversity are reduced, indicate areas of high physico-chemical stresses.

In these deposits, fluid muds are inferred by thin, sharp-based mud drapes that are un-burrowed or only sparsely burrowed by *Planolites*. These muds are attributed to rapid clay flocculation associated with heightened water turbidity and high depositional rates related to hypopycnal flows. (MacEachern *et al.,* 2008). Thus, fluid muds lead to soupgrounds for organisms and are un-burrowed, unless subsequently colonized after burial (MacEachern *et al*., 2008). Where fluid muds are highly concentrated in this facies, impoverished suites are reflected (Fig. II-17E). These departures also typically exhibit dark-grey, organic-rich, parallel-laminated muds, which are interpreted as phytodetrital fluid muds. These muds may reflect an additional stress attributed to oxygenation, as they have also been related to periods of dysoxia or anoxia near the seabed (Rice *et al*., 1986; Dalrymple, 1999; Dalrymple *et al.,* 2003).

Tidal sedimentation is further identified by preservation of rhythmic inter-lamination, dominance of wavy-bedding and current-generated stratification. Wavy-bedding indicates alternations of bedload transport and suspension fallout during slack-water periods. The intermittent distributions of organic detritus and mud drapes may also indicate influxes from either tidal or storm processes. Storm deposition may be evident from the local, passively in-filled coarse-grained sand burrows, typically associated with the opportunistic species of *Thalassinoides,* or *Diplocraterion*. These structures may represent tubular tempestites (cf. Wanless *et al.,* 1988) that formed due to strong and rapid fluctuations in hydrostatic pressure operating through the burrows during intense oscillatory wave action (Webb and Theodore, 1968; Bann *et al.,* 2008). Stacked *Rosselia* bulbs may also record re-establishment following a storm event (Pemberton and MacEachern, 2006).

Wave influence is additionally inferred by locally observed symmetrical ripples. As the trace fossil suite does not reflect a brackish water setting and there is no sign of river generated-structures, the system must be characterized by a complete lack of fluvial input. Due to the widespread environmental variability in tide-dominated marginal marine settings, they are often characterized by low bioturbation intensities and an impoverished marine trace fossil assemblage (typically a brackish-water assemblage). As this is not the case for this facies, a relatively stable mixed influenced fully marine setting is inferred.

(F10) Well burrowed sand with silt and silty mud-filled burrows

Facies 10 is common to the middle portion of the McMurray Formation and is characterized by upper-very fine- to fine-grained, highly bioturbated sands with moderate (10-25%) brown to grey silty-mud and silt (Fig.II-13). This facies is gradational with F9, F11, and/or sharp with F12, and may also truncate F9. Beds range from 5-10 m thick and typically clean-upward (less burrowing and less fines). Sand is moderately-sorted with good bitumen saturations. When preserved, sedimentary structures consist of small-scale cross-bedding and current-generated cross-stratification (ripple cross-lamination and climbing ripples), to wavy-bedding (Fig.II-13C/H). Fine material differs from the previous facies due to the lack of grey sharp-based structureless mud beds. Instead, mud accumulations are dominantly burrow-fills and linings, with extremely rare, typically discontinuous or starved, singular, wavy-laminae and thin beds (less than 2 cm). Thin beds exhibit a mottled or grungy appearance with normal grading and/or ultra-fine sand lamination. Soft sediment deformation is evident from minor folding and presence of flame structures. Thin beds and laminae are often disrupted by large traces and may often have disseminated organic material, organic mud, and continuous coal inter-laminae (Fig.II-13K). Additional

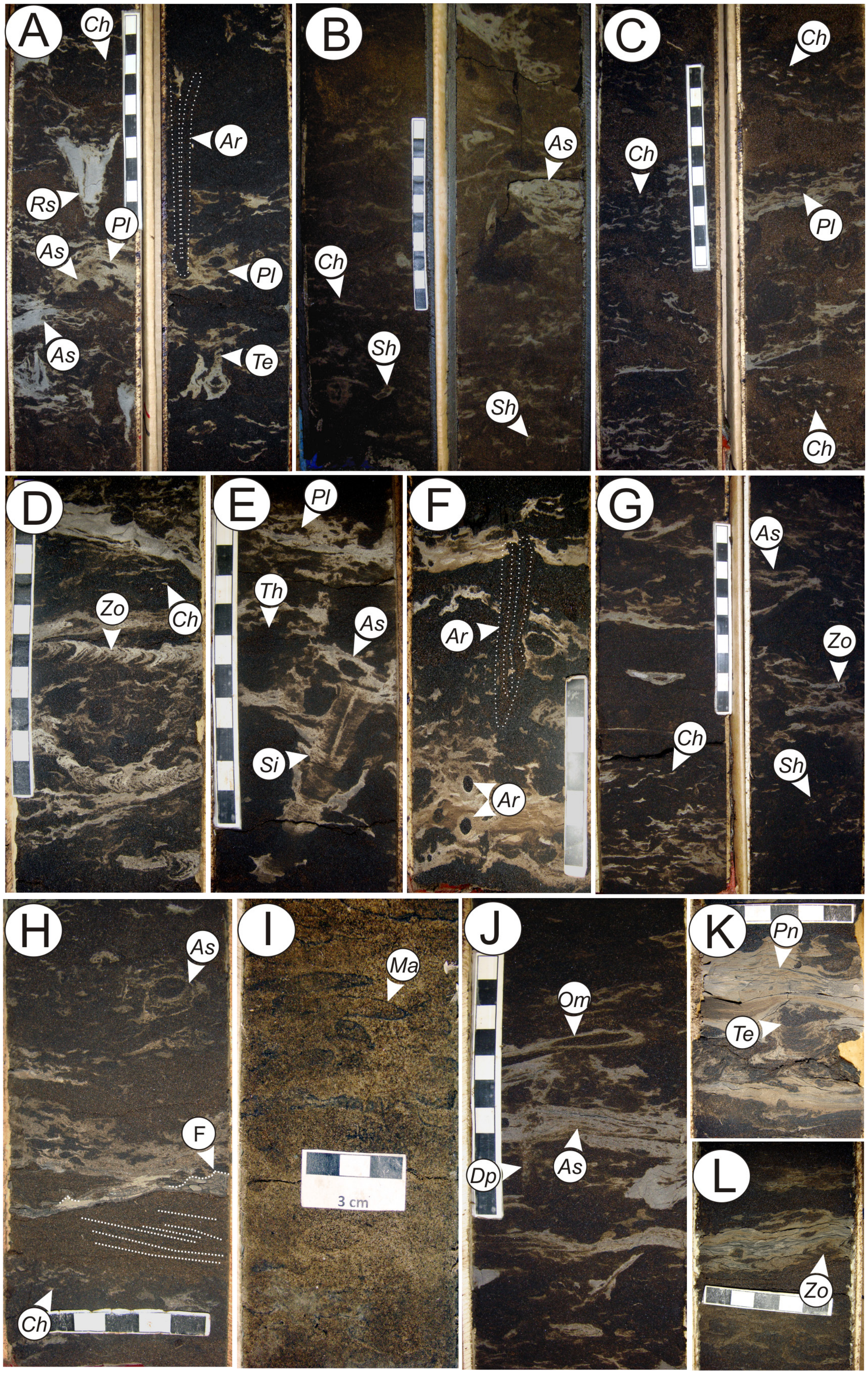

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FIGURE II-13: Well burrowed fine-grained sand with moderate silty mud burrows (F10) of the upper McMurray Formation.
F10 lacks sharp-based mudstone beds that are characteristic to F9 as fine-grained sediment has predominantly been flocculated by organisms and concentrated as burrow linings and fills. F10 exhibits a mix of moderate to large horizontal and vertical trace fossils and homogeneously distributed bioturbation. (A-B) Examples of common ichnoforms observed including *Rosselia (Rs), Asterosoma (As), Teichichnus (Te), Chondrites (Ch), Planolites (Pl), Arenicolites (Ar), Schaubcylindrichnus (Sh)* and *Palaeophycus (Pa).* Note that the more complex feeding structures *Rosselia* and *Asterosoma* are re-burrowed by deeper tiered traces of *Planolites* and *Chondrites*, and that composite traces may occur. Well 6-03-91-14W4, depth 186.2 m and Well 10-08-90-14W4, depth 184 m, respectively. (C) A typical *Chondrites* suite. Well 7-19-89-13W4, depth 203.5 m. (D) Examples of grazing behaviors observed, illustrated by *Zoophycos (Zo)* burrows. Well 10-08-90-13, depth 211 m. (E) A robust *Spirophyton (Si)* is a common trace fossil observed. Well 6-05-91-14W4, depth 170.8 m. (F) Variable Arenicolites burrows illustrating lined tube margins of paired openings in plan view, and a non-lined U-shape burrow in full relief. Well 10-30-88-13W4, depth 175 m. (G) Typical assemblage of F10. Note the abundance of *Schaubcylindrichnus (Sh)* in this example. Well 10-08-90-13W4, depth 113 m. (H) Destruction of primary structures by biogenic reworking is common. If preserved, current-generated stratification such as current ripple-lamination and wavy bedding are most common. Note the soft sediment deformation indicated by flame structures (F). Well 10-08-90-13W4, depth 215.8 m. (I) A unique trace fossil characterized by a colonial grouping of diminutive burrows are observed and interpreted as *Macaronichnus (Ma).* Sediment infill contrasts with surrounding sand and there is an apparent lining, caused by the shifting of ferromagnesian grains by active sediment processing of a selective deposit-feeding strategy. Note the lined appearance and lack of interpenetration or cross-cutting of burrows. This assemblage is also typically associated with fugichnia. Well 16-01-90-14W4, depth 217.3. (J) Evidence of localized soft sediment deformation is indicated by the stretched/strained *Asterosoma*. Well 10-32-89-13W4, depth 206.5 m. (K) Disruption of silty mud beds by a robust *Teichichnus* trace. These beds are also colonized by discrete *Phycosiphon (Pn).* Note the wavy sand laminae and overall normal grading of fine-grained beds. 16-28-90-14W4, depth 182 m. (L) A silty mud bed colonized by *Zoophycos*. Well 10-27-90-14W4, depth 182.4 m. All scales in cms.

lithologic accessories include: shell fragments (up to 3 cm), intraclasts, coal fragments, and pyritized burrows (Fig.II-13G).

Bioturbation intensities range from moderate to complete (BI 3-6) but can be difficult to discern due to a high degree of bitumen saturation. The trace assemblage consists of a high diversity of ichnoforms similar to that of F9 but exhibits a lower density assemblage, and dominance of robust *Rosselia socialis, Asterosoma, Teichichnus* and *Spirophyton*. Burrow linings can also be so thick that burrows appear as mud-clasts. *Chondrites* and a unique trace interpreted as a robust form of *Macaronichnus segregatis* are also common to locally observed (Fig. II-13I). When present, the latter occurs in moderate densities in a lower diversity assemblage associated with *Skolithos* and fugichnia. Thin beds and laminae may also contain discrete *Planolites, Teichichnus* and local *Phycosiphon/ Helminthopsis* burrows (Fig. II-13K/L). Sands contain a diverse array of subordinate trace fossils including: *Thalassinoides, Planolites, Zoophycos, Skolithos, Scolicia, Rhizocorallium, Ophiomorpha,* and *Diplocraterion.*

Interpretation of F10

Facies 10 is interpreted as background bay-fill and/or interbar sedimentation of a stable, fully marine, shallow sheltered marine embayment. The gradational relationship with F9 indicates a laterally adjacent environment of a low-energy bay-margin shoreface. This may also indicate more proximal deposition, as there is a progressive increase in the bulk grain size, reflected by a gradual thickening and coarsening of sandy beds, and a corresponding decrease in the thickness and abundance of mud inter-beds. Erosional contacts with F9 may reflect local scouring of tidal currents during higher energy sand deposition. This is common to strong tidally influenced deltaic environments (Dalrymple and Choi, 2007).

Facies 10 also exhibits a high diversity assemblage of mixed vertical and horizontal ichnoforms with a dominance of deposit-feeding strategies. Homogeneously distributed bioturbation and large ichnoforms indicates a relatively stable low energy environment with limited physico-chemical stresses (i.e. fluctuations in energy and sedimentation rates) and an abundant source of deposited food. These characteristics coupled with an overall lack of obvious tidal sedimentation and/or brackish-water trace fossil assemblage suggests there was a small tidal prism. Wave influence is supported through the presence of local oscillatory ripples. Fine material accumulated from flocculation by organisms, evidenced by the abundance of mud-filled burrows and linings, and overall lack of mud beds (Ichaso and Dalrymple, 2009). The lack of tubular tidalites within these burrow-fills coupled with trace fossil occurrence and distributions reflect that tidal processes had a relatively low impact on deposition (i.e. there is no evidence of stresses related to tidal mixing or fluctuating energy conditions) (Gingras and MacEachern, in press).

(F11) Moderately burrowed wavy-bedded fine-grained sand

Facies 11 consists of a moderately abundant and laterally extensive reservoir facies of the middle portion of the McMurray Formation. It is in gradational or sharp contact with F10 and F12, or truncated by F13, F14 or F15, and forms a coarsening-upward succession. Successions average 5 to 10 m thick and exhibit excellent bitumen saturated fine-grained, poor to moderately sorted sands. Medium to coarse-grained sand may also occur as burrow fills. Rhythmic to wavy-bedding and current and oscillation ripple- to parallel-lamination are dominant sedimentary structures (Fig. II-14(A-E)). Sharp based to burrowed silt/

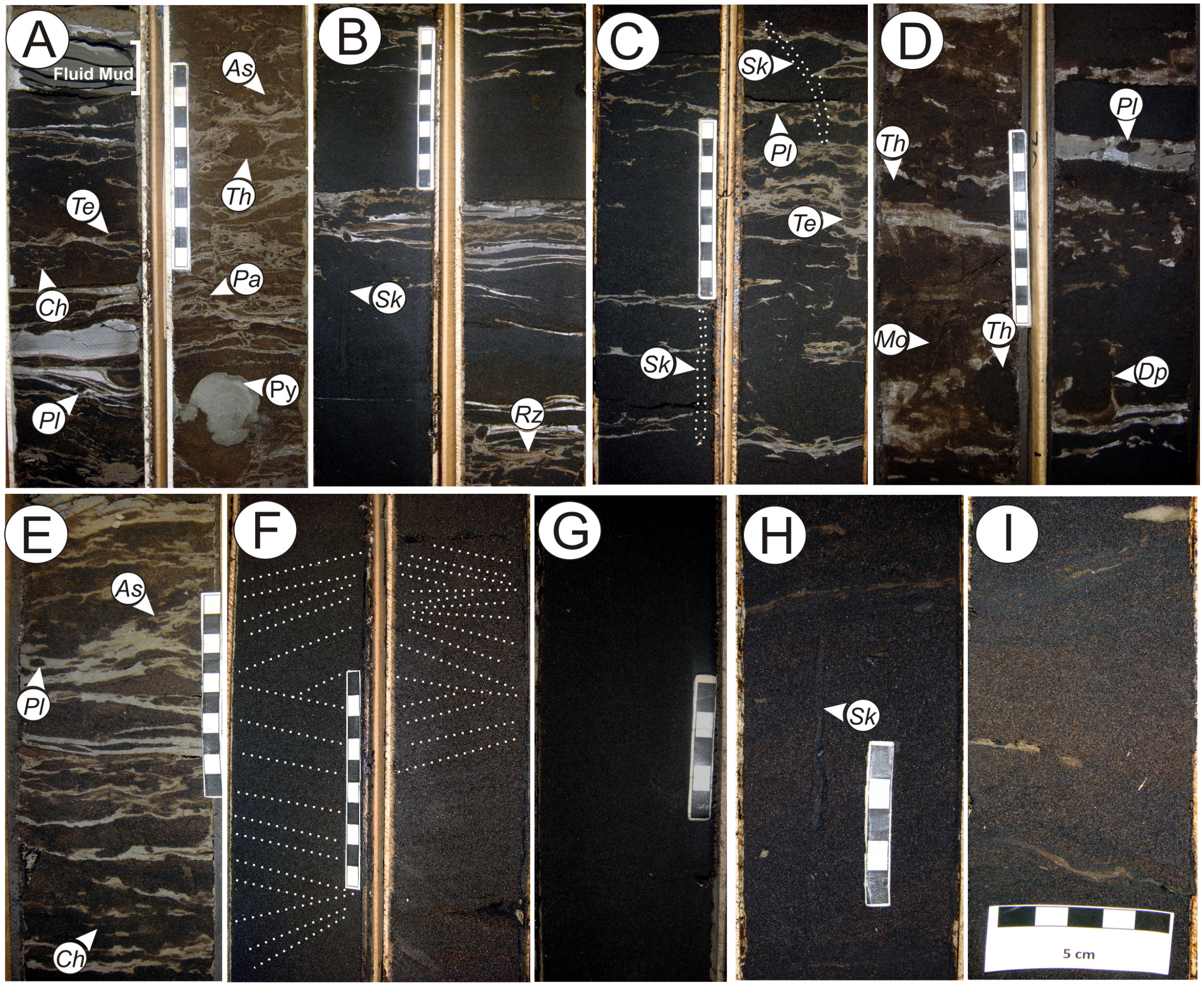

FIGURE II-14: weak-moderate burrowed ripple-wavy bedded fine-grained sand (F11) and weakly burrowed sand (F12) of the upper McMurray Formation.

FIGURE II-14 CONTINUED: (A) F11 illustrating moderately burrowed sand with wavy bedding, flasers, and rhythmic mud drape deposition. Non-bioturbated muds are normally graded to massive and represent fluid muds. A tide-influenced trace fossil assemblage is illustrated and includes ichnogenera: *Planolites (Pl), Teichichnus (Te), Thalassinoides (Th), Palaeophycus (Pa), Chondrites (Ch),* and *Asterosoma (As).* Note the disseminated shell fragments, organic detritus, rip-up clasts and partially pyritized *Thalassinoides* burrow, all of which are common characteristics. Well 15-19-88-14W4, depth 176.7m. (B) Current ripple- to parallel-lamination are characteristic sedimentary structures of F11, highlighted by with double mud drapes and starved ripple-laminae. Sands are typically non-burrowed but may contain discrete *Skolithos (Sk)*. Other ichnogenera include *Planolites* and a diminutive *Rhizocorallium (Rz*). Well 15-19-88-14W4, depth 173.2 m. (C) Examples of typical *Teichichnus (Te)* traces of F11. Note the good bitumen saturation in sands. Well 10-30-88-13W4, depth 178.8 m. (D) Additional ichnogenera characteristic of F11 include *Monocraterion (Mo), Thalassinoides,* and *Diplocraterion (Dp*). *Monocraterion* represent vertical burrows with a distinct funnel-like top, projecting downward into the sand and represents a combination of dwelling and feeding strategies. Well 12-08-91-14W4, depth 175.5 m. (E) Silt and mud character of F11. Double mud drapes and thin laminae are wavy and typically burrowed by diminutive *Planolites*. Flame structures also indicate minor soft sediment deformation. Well 10-08-90-14W4, depth 182.5 m. (F-G) Highly bitumen saturated, moderately-well sorted, clean, fine-grained reservoir sands of F12. Examples are characteristic of this facies and illustrate non-bioturbated small-scale cross-bedding and parallel-lamination, with grain-size striping and dip reversals. Well 10-22-90-14W4, depth184 m and well 11-31-88-13W4, depth 182.2 m, respectfully. (H-J) Weak bioturbation of F12 illustrating *Skolithos (Sk),* and *Planolites (Pl).* Fine-grained material is extremely rare and concentrated to burrow linings/fills. Coal fragments and mud clasts are common constituents. Note the rippled bedding and flasers. (H) Well 12-13-90-14W4, depth 191.6 m, (I) Well 16-14-90-14W4, depth 179.4 m, (J) Well 16-14-90-14W4, depth 174.6 m. All scales in cms.

mud laminae and thin beds represent 5-15% of the sediment volume and decrease in occurrence upward. Silt and mud beds/laminae may also exhibit contorted laminae and contacts with sand, and are typically parallel- to rhythmic inter-laminated. Disseminated shells and carbonaceous debris may occur in laminated zones or as drapes on cross-strata foresets.

Bioturbation intensities are moderate (BI 2-3) with a moderate diversity, low density assemblage of traces. Individual ichnogenera identified include: *Planolites, Skolithos, Teichichnus, Thalassinoides, Asterosoma, Zoophycos, Chondrites, Diplocraterion, Palaeophycus, Rosselia, Monocraterion, Spirophyton* and fugichnia (Fig. II-14(A-E)). Bioturbation is regular heterogeneous to homogeneous in distribution and more abundant in muddier intervals where many burrows penetrate into underlying sands via mud bedding planes.

Interpretation of F11

This facies is interpreted as fully marine bay fill and/or interbar sedimentation of a shallow sheltered embayment. More specifically it is a transitional facies between background bay-fill and tidal sand bar deposition and may reflect tidal bar toe-sets. Tidal sedimentation is evidenced by the dominance of rhythmic interlaminae and bedding, wavy- and flaser-bedding, material draping cross-strata foresets, and current-generated structures. Wave reworking is also indicated by oscillatory ripple-flow. Individual ichnogenera define a stressed proximal *Cruziana* assemblage with a mix of horizontal deposit-feeding and vertical suspension-feeding ichnoforms. Traces common in sands are dominated by the opportunistic strategies of *Skolithos, Arenicolites, Teichichnus* and fugichnia*,* indicating a higher energy environment than F9 and F10 with increased sedimentation rates. This is further supported by the lower bioturbation intensities and trace fossil distribution indicating higher physico-chemical stresses in the system, likely related to fluctuating energy conditions. Wavy-bedded muds are typically burrowed by *Thalassinoides* and *Planolites* indicating slower suspension fallout attributed to slackwater periods. Facies 11 demonstrates a lower diversity and density assemblage of fully marine ichnogenera indicating near normal salinities, but illustrates an impoverishment of the background marine trace fossil suite or "ichnological baseline" (Gingras and MacEachern, in press).

(F12) Weakly burrowed fine-grained sand

Facies 12 is common and laterally extensive across the area and illustrates successions ranging from 5 to 20 meter thick, averaging 7-10 m thick. Facies 12 is gradational or sharp with F11, F13 and F14. It may also truncate F9, F10, and F11, and may be truncated by F15, F16 and F17. As one of the main reservoir facies it is characterized by highly bitumen saturated, moderately-well sorted, clean, fine-grained sands that exhibit a coarsening-upward profile. Grain size is relatively consistent but may coarsen-upward to lower- medium-grained sand.

Sands are most commonly current ripple cross-laminated to parallel-laminated (Fig. II-14(F-J)). Small-scale cross-bedding, aggradational ripple-, oscillation ripple-, and combined ripple-lamination are locally observed. Small-scale cross-bedding locally exhibit grain size striping and re-activation surfaces. Burrowed brownish to grey silt, silty mud beds (<2 cm) and flasers are rare to absent (<3%). Continuous to starved sharp-based laminae may also be very finely inter-laminated (<1 mm) with silt and very fine-grained sand. Lithologic accessories include large coal fragments up to 10 cm long, discontinuous very thin coal laminae, rip-up clasts and pyritized burrows. Rip-up clasts may occur as small clasts in concentrated layers along stratification foresets or as large singular clasts. Disarticulated bivalves, large shell fragments (up to 5 cm) as well as small shell fragments in localized beds are also present (Fig. II-14G).

A low to moderate diversity suite of small to moderate sized traces with low bioturbation intensities (BI 0-2) is also observed. The ichnological distribution also exhibits sporadic heterogeneous distribution. Un-lined, sand-filled, *Planolites* and *Thalassinoides* are the dominant ichnogenera and are common in silty-mud beds and near bedding planes. Discrete *Teichichnus, Ophiomorpha, Skolithos* and *fugichnia* are sporadically distributed in sands. *Ophiomorpha* is distinguished by the agglutinated pelletoidal mud lining. Small *Palaeophycus, Arenicolites, Siphonichnus* and *Scolicia* are locally observed.

Interpretation of F12

Facies 12 is interpreted as shallow marine tidal sand bar deposition. More specifically, they represent a medial position of laterally accreting bay-margin and island bars of a tidal sand complex in an embayment. Tidal sand bars are also likely overprinted by compound sand dunes due to the abundance of migrating mega-ripple and dune bedforms, in a coarsening- and cleaning-upward profile (Mutti *et al.,* 1985; Dalrymple and Choi, 2007). Thus, these deposits likely represent both forward and lateral accretion. Tidal influence is evident from grain-size striping and reactivation surfaces. Thin mud drapes and flasers draping cross-strata exhibiting silty and organic rich material are also attributed to tidal processes in areas of high-suspended sediment concentrations (Dalrymple and Choi, 2007; Van den Berg *et al.,* 2007). The lack of IHS and cleaning-upwards profile further suggests deposition in areas of low sediment concentrations (Dalrymple and Choi, 2007). A moderate to high energy shallow marine environment is suggested by the lack of mud, low bioturbation intensities, and sedimentary structures. A low degree of wave reworking is indicated from rare combined flow, oscillation ripples, and lack of storm events. There is also a complete lack of river-generated structures suggesting minimal fluvial input in the system.

A low diversity, mixed assemblage dominated by vertical dwelling and feeding structures is observed. This assemblage is also more consistent of a more physico-chemical stressed environmental expression, landward of F9, F10 or F11. Stresses imparted on the system are likely a combination of elements including fluctuations in water turbidity, sedimentation rates, water energy and salinity. *Fugichnia* indicate high sedimentation rates.

(F13) Weakly burrowed rippled to small-scale cross-bedded sand

Facies 13 represents a common and laterally extensive reservoir facies of the mid- to upper-portion of the McMurray Formation, averaging 5-10 m thick. Facies 13 coarsens- and cleans-upward, and is gradational with F12 and F11 or sharp with F11, F14, F15, F16 or F17.

It is highly bitumen saturated and consists of moderately-well sorted, current ripple-laminated and small-scale cross-bedded sands with low bioturbation intensities (BI 0-2) (Fig. II-15(A-F)). Bidirectional cross-bedding, aggradational current ripples, flasers and rhythmites are also common. Ripple-lamination and less commonly parallel-lamination, cap cross-bed co-sets. Combined-flow ripples and oscillation ripples were locally observed. F13 is further defined by fine- to medium-grained sand and non-continuous, non-bioturbated, sharp-based, light-grey mud/silty mud interlaminae and thin beds that comprise 0-10% of the total volume. Silt and mud are most dominant at the base of the facies, with wavy-beds up to 3 cm thick that decrease in thickness and occurrence upward. Thin beds and laminae have contorted and/or bioturbated upper contacts and may also contain fine interlaminae of very fine-grained sand and silt. Mud intraclasts and large lignitic coal clasts are usually aligned with the surrounding cross-strata and are on the millimeter to centimeter scale and may be pyritized. Intraclasts also occur as local brecciated beds or as dispersed fragments. Small-scale gravity faults were also observed. Bitumen saturation may be depleted near higher proportions of mud.

Bioturbation is regular to sporadic heterogeneous and shows an increase upwards. Burrowing is absent to weak in mud laminae and thin beds. Common ichnogenera include a low diversity, low density assemblage of small to moderate-sized *Planolites, Skolithos, Teichichnus,* and *Thalassinoides*. Sand contains well preserved biogenic structures with discrete *Ophiomorpha, Siphonichnus* and *Fugichnia* (Fig.II-15A). Rare occurrences of *Arenicolites* are also observed. Disseminated shell fragments, carbonaceous debris, and thin, discontinuous coal lamination are common lithologic accessories and form rhythmic interlaminae with thin beds, or drape cross-strata foresets.

Interpretation of F13

F13 is interpreted as bay-margin laterally accreting sand bar deposition in a shallow marine embayment, dominated by tidal processes. Higher energy deposition is evident due to the increase in grain-size, presence of fluid muds,

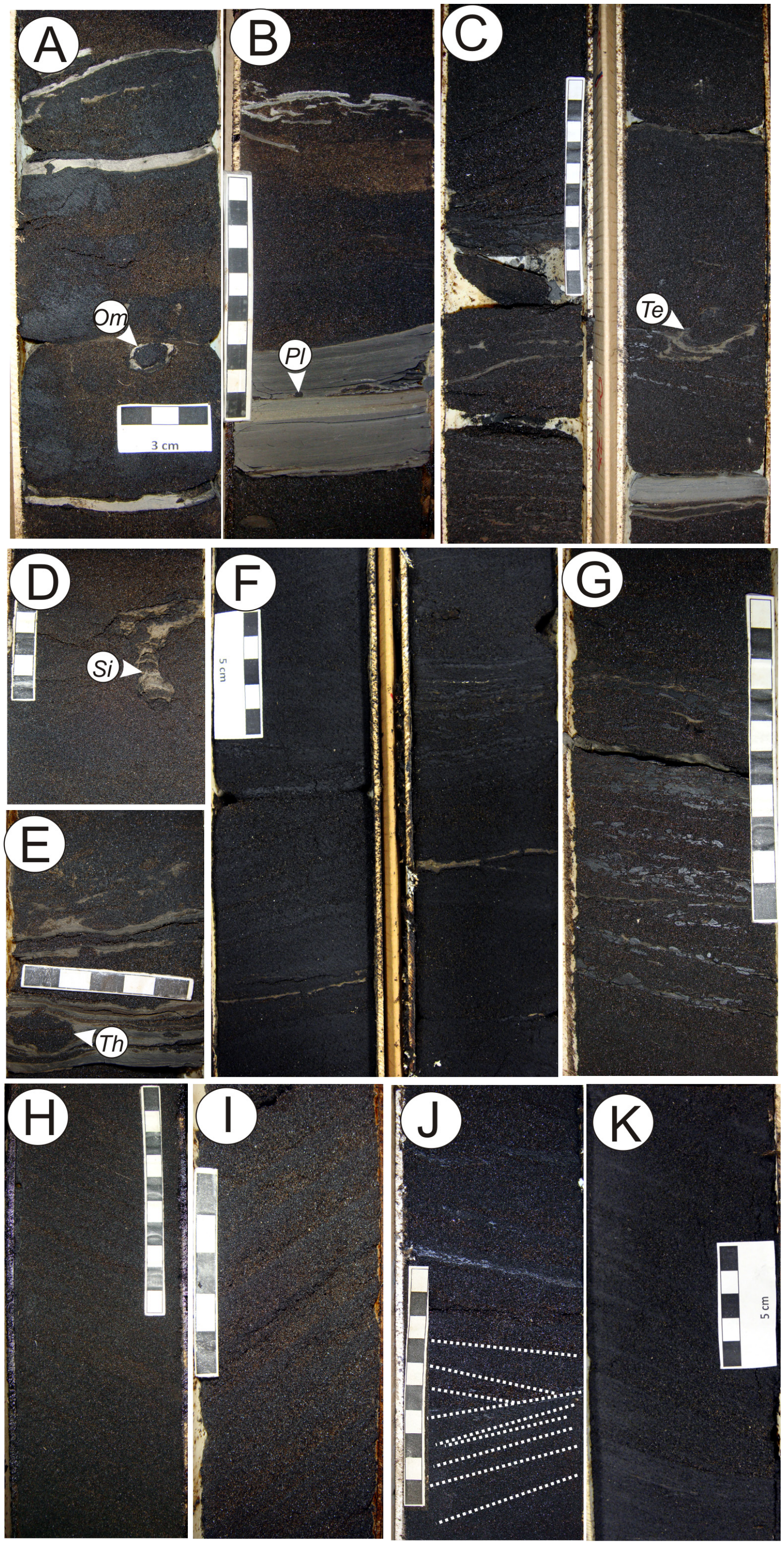

FIGURE II-15: Main reservoir facies of the upper McMurray Formation.
(A-F) Illustrate non- to weakly burrowed small-scale cross-bedded to current rippled fine- to medium-grained sands (F13). Fine-grained material is absent to rare, and dominated by starved

FIGURE II-15 CONTINUED: ripple-lamination, thin wavy mud drapes, or sharp-based fluid mud deposition. An impoverished, marine assemblage of small to moderate, simple, vertical and horizontal structures characterizes this facies and is indicative of a brackish-water ichnofacies; *Ophiomorpha (Oph), Planolites (Pl), Teichichnus (Te), Siphonichnus (Si),* and *Thalassinoides (Th).* Cross-strata foresets are also typically draped with thin mud laminae, carbonaceous debris, shell fragments, or coal laminae.(A) Well 8-12-90-14W4, depth 200.7 m, (B) well 7-19-89-13W4, depth 202.5 m, (C) well 14-12-90-14W4, depth 189.1 m, (D) well 14-12-90-14W4, depth 199.7 m, (E) well 10-22-90-14W4, depth 172.4 m, and (F) well 8-12-90-14W4, depth 190.5 m. (G-K) Illustrates medium-grained large-scale cross-bedded sands (F14). This facies is characterized by non-bioturbated, excellent bitumen saturated sands with grain-size striping, dip reversals, and carbonaceous foreset drapes. (G) Well 14-14-90-14W4, depth 181 m, (H) well 14-12-90-14W4, depth 180.8 m, (I) well 16-11-90-14W4, depth 187 m, (J) well 4-13-90-14W4, 181.2 m, and (K) well 4-13-90-14W4, depth 183 m. All scales in cms.

large consistent bedforms, tidal indicators and impoverished trace fossil suite. In a tidal system, grain-size tends to decrease in the direction of transport, with respect to energy dissipation (McLaren and Bowles, 1985). Coupled with the gradational relationship with F12, this supports a position of higher energy sand deposition.

Fluid muds in F13 are interpreted as the structureless sharp-based mud beds and indicate periods of rapid deposition during tidal slack-water periods. They are distinguished from deposition by slow suspension settling processes by thickness (>~0.5 cm), lack of structure, and lack of bioturbation except for top-down post-depositional colonization (Ichaso and Dalrymple, 2009). Fluid muds are common sedimentation processes in both modern wave- and tidally-influenced settings and form soupgrounds for fauna which would account for the impoverished, stressed ichnological suite observed (Dalrymple, *et al.,* 2003; Ichaso and Dalrymple, 2009). In these settings they form as high concentrations of near-bed suspended sediment (SSC), generated below the turbidity maximum, and are deposited by flocculation and density circulation in the mixing zone (Dalrymple, *et al.,* 2003; Ichaso and Dalrymple, 2009). Thus, deposition of F13 is interpreted to have been below the turbidity maximum where SSC are high (Dalrymple and Choi, 2007). This coupled with a coarsening-upward succession suggests the migration of tidal bars with an overprint of compound dunes in a higher energy setting, where fluid muds exist at the base of the facies, in the deepest portion of the channel.

The base of this facies also typically illustrates an erosional contact which further supports this interpretation for tidal channel deposition (Dalrymple and Choi, 2007). Tidal processes are further indicated by bidirectional cross-bedding, rhythmic lamination, mud drapes between foresets, and flaser and wavy bedding. Furthermore, the presence of mud clasts and brecciated zones near the base of cross-beds suggests erosion by tidal currents.

The ichnological signal further supports this interpretation, and that additional physico-chemical environmental stresses were present during deposition. A low diversity assemblage of simple deposit feeding and filter-feeding behaviors is consistent with a brackish-water expression (Gingras *et al.,* 1999; Pemberton *et al*., 2001; MacEachern *et al.,* 2005; Dalrymple and Choi, 2007). These opportunistic species are diminutive, simple structures and occur in a low-diversity assemblage reflecting variable and unpredictable conditions (Pemberton and MacEachern, 2006). The variable degrees of bioturbation and sporadic distribution of horizontal deposit-feeding strategies may also represent the removal of filter feeding organisms due to high SSC (Gingras *et al.,* 1999; MacEachern *et al*., 2005). The presence of equilibrium structures reflects moderate to high rates of deposition. These observations support higher energy medial to proximal tidal sand deposition.

(F14) Upper- fine to medium-grained large scale cross-stratified sand

Large-scale cross-bedded, highly bitumen saturated, moderately-well sorted sands averaging 1.5-3.5 m thick, characterizes this facies (Fig.II-15(G-K)). Lower facies contacts are sharp and erosive with F13, F10 or F9. Upper facies contacts are gradational with F15 or sharp with F16 and F17. Although not laterally extensive, F14 constitutes an important reservoir facies in the McMurray Formation in the study area. Cross-bed sets range in thickness from 5-34 cm; with an average thickness of about 10-20 cm. Dip reversals between adjacent sets are common. Rare current ripple cross-stratification and planar lamination also occurs locally between individual sets. Grain size ranges from upper- fine grained to upper- medium grained, with rare lower coarse-grained intervals. Grain size striping is common although uniform grain sizes also occur (Fig.II-15(I-J)). Individual cross-strata sets also show normal grading on a very fine scale. Mud and silt laminae make up <2% of the rock volume. Typically they comprise single, very thin laminae that drape cross-bed toe-sets and have sharp contacts with sand. Accessory features include small coal fragments, discontinuous coal laminae and organic debris which drape cross-strata sets. Rare rounded-subrounded mud clast/coal, less than 1 cm, are also observed locally and may be pyritized.

Bioturbation is sporadic in distribution exhibiting extremely rare to absent intensities (BI 0-1). Thicker, massive mud laminae are weakly burrowed with diminutive *Planolites,* and increase upward in abundance. Sands may contain diminutive *Skolithos* and fugichnia which penetrate up to 15 cm into the substrate.

Interpretation of F14

Facies 14 is interpreted as bay-margin tidal sand bar deposition. Facies 14 is dominated by deeper migration of large-scale dunes. These sands were deposited at the base of tidal channels where hydraulic reworking by tidal processes was strongest (i.e. near the tidal maximum) (Dalrymple and Choi, 2007). The abundance of large-scale cross-beds, coarser-grain size and lack of bioturbation indicates a high energy setting (Dalrymple and Choi, 2007). The low diversity, small size of traces, and sporadic distribution indicate an extremely hostile environment for organisms. The trace fossil suite is also dominated by an extremely impoverished marine suite, attributed to high sedimentation rates, salinity stress, and a fluctuating hydraulic regime (MacEachern *et al.,* 2005). Brackish water may be further supported by the presence of pyritized coal fragments and burrows (Deissel, 1992). Dip reversals in trough cross-beds reflect bidirectional currents consistent with ebb and flood tides. Grain-size striping and draping of material in strata forsets also indicates tidal sedimentation. The occurrence with F13 leads to an overall interpretation of tidally dominated sand bar deposition in a proximal subtidal nearshore marine environment.

*(***F15) Cryptobioturbated medium-grained sand**

Facies 15 is common near the top of the upper McMurray Formation and is characterized by lower- medium-grained, well-sorted, trough cross-bedded to low angle planar sands (Fig. II-16(A-C)). Local convolute laminae and dewatering structures are also observed. As a relatively thin succession, averaging ~1.5-2 m thick, it exhibits a gradational lower contact with F13, F14 and sharp to erosive upper contacts with F16 and F17 (Fig. II-16C). When F13 or F14 are not present, lower contacts are sharp with F11, F12. Grain-size striping (heavy mineral lamination) is also common and bitumen saturation is relatively low which may indicate gas saturation. Lithologic accessories include small shell fragments, coal fragments, disseminated coal laminae, and rare sharp-based mud laminae on a millimeter scale. Facies 15 is typically cryptobioturbated or thoroughly burrowed by M*acaronichnus* that retains primary sedimentary structures, resulting in a unique distortion and “fuzzy lamination” (Fig. II-16B). A low diversity assemblage of small, discrete, unlined *Skolithos*, and *Diplocraterion* were locally observed.

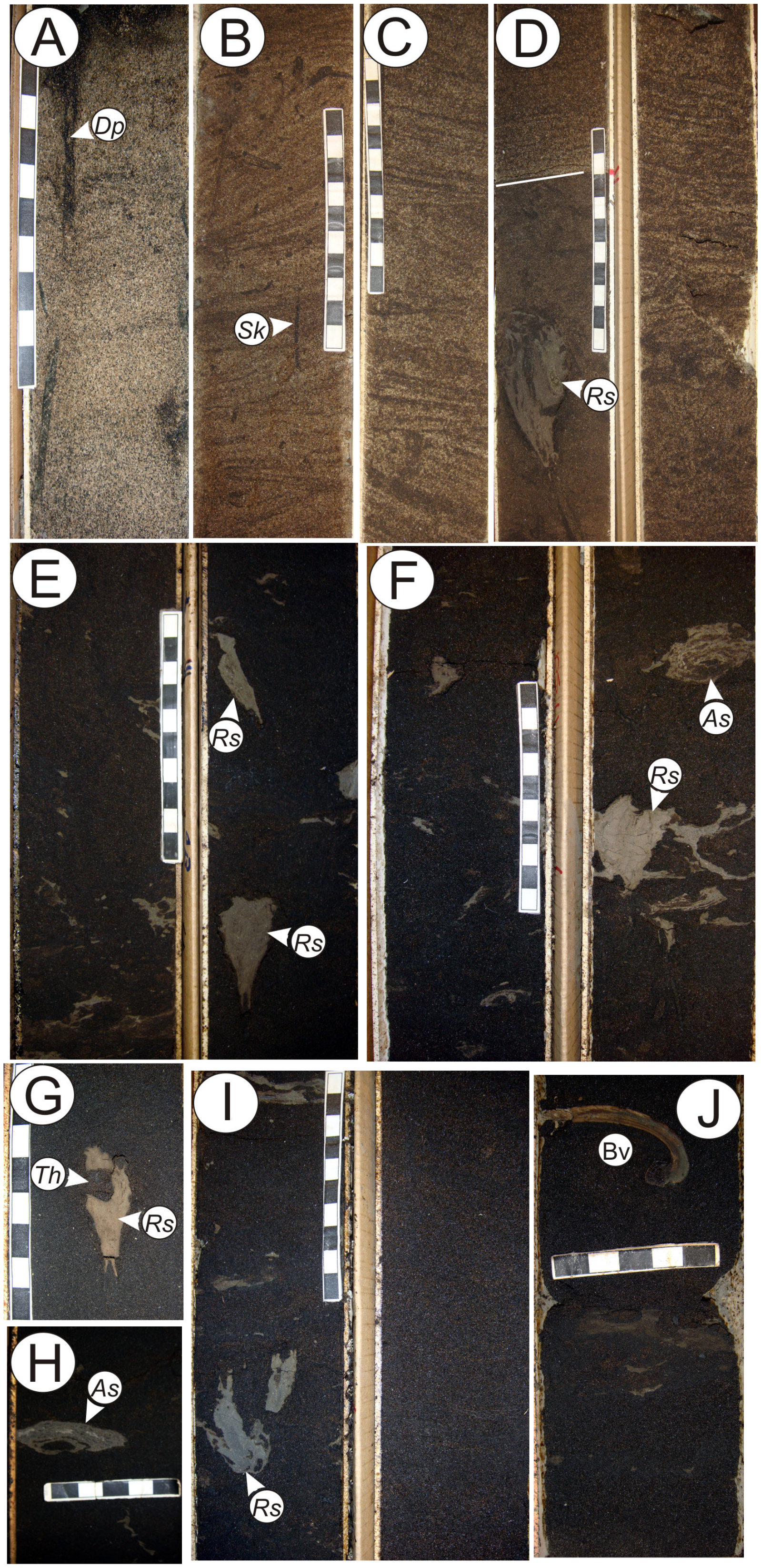

FIGURE II-16: Cryptobioturbated to weakly bioturbated sand (F15) and moderately bioturbated sand with silt and mud burrows (F16) of the upper McMurray Formation.

FIGURE II-16 CONTINUED: (A-D) Crypto-bioturbated sands exhibit trough cross-bedding to low angle planar sands. Note the grain-size striping, poor bitumen saturation, and "fuzzy" distortion of cross-laminae. (A-B) Elements of the *Skolithos* ichnofacies characterize this facies, as illustrated by discrete *Diplocraterion (Dp)* and *Skolithos (Sk*). Well 16-1-90-14W4, depth 188.3 m; well 14-12-90-14W4, depth 176.9 m, respectively (C-D) Sands are cryptobioturbated by meiofauna. This bioturbate texture and associated trace fossil assemblage reflects high energy deposition in a nearshore setting. (D) Note the sharp contact between F15 and F14. Well 16-14-90-14W4, depth 170.9 m. (D-J) Moderately bioturbated sands with silt and mud burrows illustrating a robust *Rosselia (Rs)-Asterosoma (As)* assemblage. Note that the silt and mud fraction is extremely low and there is excellent bitumen saturation. Common lithologic accessories include disseminated organic debris, coal fragments, mud clasts, and bivalve (Bv) and shell fragments. This trace fossil assemblage is characteristic of a lower to middle shoreface. (E) Well 10-07-90-13W4, depth 190.75 m; (F) Well 10-27-90-14W4, depth 172.1 m; (G) Well 12-13-90-14W4, depth 172.5 m; (H) Well 2-27-90-14W4, depth 169 m; (I) Well 14-22-88-13W4, depth 160 m; (J) Well 16-28-90-14W4, depth 175.4 m. All scales in cms.

Interpretation of F15

Facies 15 is interpreted as a shallow marine bar crest and/or an upper shoreface of an embayment. More specifically, this facies is interpreted as highly energetic deposition where there was a mix of wave and tidal processes. Cryptobioturbation represents the thorough bioturbation of interstitial meiofauna where the sediment has not been disrupted but has resulted in a subtle but fuzzy distortion to lamination (Howard and Frey, 1975; Pemberton and MacEachern, 2006). This bioturbate texture is pervasive in nearshore environments including estuarine and backshore-foreshore sands (Howard and Frey, 1975; Howard *et al.,* 1975; Dorjes and Howard, 1975). *Macaronichnus* is also known to be a useful indicator of highly energetic, oxygenated surface waters and sediments, common to a narrow range of environments, including the upper shoreface and estuary channel bars (Hubbard *et al.*, 2004). In these settings, the abundance of trough-cross stratification and low angle planar cross-bedded, well-sorted sands in response to multidirectional subaqueous dunes, are common, which is consistent with this facies (Pemberton and MacEachern, 2006).

A mixed wave-tide influenced setting is interpreted due to a dominance of wave-generated structures. Convolute and dewatering structures observed are attributed to wave-induced liquefaction (Pemberton and MacEachern, 2006). HCS is interpreted where low angle planar laminae terminate at a horizontal plane. Rhythmic heavy mineral laminations along cross-strata foresets are also common in upper shoreface settings (Howard and Frey, 1975; Pemberton and MacEachern, 2006). This facies is also dominated by elements of the *Skolithos* ichnofacies, indicating the predominance of suspension feeding behaviours, which are widespread in an upper shoreface or foreshore setting.

(F16) Moderately bioturbated fine-grained sand with silt and mud burrows

Facies 16 is common near the top of the McMurray Formation and is on a decimeter to meter scale, averaging 2 m thick. Lower contacts are gradational with F10 and F11 or more commonly sharp with F9, 12, or 13, or 18. Upper contacts are sharp with F15, F17, F18 or F19.

Facies 16 is moderately bioturbated (BI 3-4) exhibiting homogeneous ichnological distribution which has resulted in the partial destruction of primary sedimentary structures and textures, although low angle- to horizontal-lamination and rare cross-bedding may be preserved. The defining characteristic of this facies is that the majority of silt and mud material is trapped as burrows and linings of robust *Rosselia* and *Asterosoma* (Fig. II-16). Silt and mud represent a small fraction of the sediment volume, averaging ~0-5%, and laminae are extremely rare. Sand is also very-fine to fine-grained, well-sorted, and moderately to strongly saturated with bitumen. Saturation typically decreases upward, and bioturbation increases-upwards. Lithologic accessories include thin wavy beds of disseminated coal and carbonaceous material, small coal fragments, and rare mud laminae and clasts. Shell fragments are small and moderate in abundance. Pyrite and/or siderite may also replace burrows.

Well defined *Rosselia* bulbs are up to 6 cm wide with central dwelling burrows of up to 8 mm diameter. Lined or unlined dwelling tubes subtend from the mud ball and can penetrate up to 5 cm depth. *Asterosoma* mud balls are up to 5 cm wide with a central dwelling tube of up to 1.4 cm. Additional ichnogenera observed include *Skolithos, Planolites, Teichichnus, Thalassinoides, Schaubcylindrichnus, Diplocraterion* and *Scolicia*. *Diplocraterion* occurred in low density towards the top of the facies, penetrating from the overlying glauconite unit up to 50 cm. Glauconite may also be present near the top of the facies as burrow fills, when overlain by F19.

Interpretation of F16

This facies is interpreted as shallow fully marine proximal lower shoreface deposition during predominantly fair-weather conditions. The overall ichnological assemblage represents a proximal *Cruziana* ichnofacies with the dominance of deposit-feeding behaviors (e.g. *Rosselia, Asterosoma, Teichichnus, Schaubcylindrichnus, Planolites*, and *Thalassinoides*) with minor suspension-feeding behaviors (e.g. *Skolithos*, *Diplocraterion*) (Pemberton and MacEachern, 2006). This is a characteristic expression of a lower shoreface experiencing moderate- to low-energy and high sedimentation rates in a fully marine environment. Higher intensities of bioturbation with robust traces indicate that the environment was relatively stable for development of more complex specialized feeding traces. A *Rosselia-Asterosoma* assemblage is a particularly good indicator of the upper lower shoreface (Pemberton and MacEachern, 2006; Pemberton *et al.,* 2009). As bioturbation is homogeneously distributed and thus primary structures are typically destroyed, low-energy conditions are dominant.

HCS may be interpreted where low-angle planar lamination terminate into parallel-lamination, reflecting high-energy storm deposition. The lack of evident tidal sedimentation suggests that tidal currents did not have a significant impact on deposition.

(F17) Well bioturbated to planar-laminated sand

Facies 17 is defined by well-bioturbated, well-sorted, medium- to fine-grained sands that have poor bitumen saturations and fine-upwards. Facies 17 is observed at the top of the McMurray Formation and ranges from 50 cm -1.5 m thick. Lower contacts are sharp and may be bioturbated with F16, F15, F14, F12, and F11. Facies 17 may also be sharp with overlying F18 and F19.

Primary physical structures are either destroyed by biogenic reworking or include low angle planar to horizontal cross-stratification (Fig.II-17). Hummocky cross-stratification (HCS) may occur where low-angle laminae terminate into horizontal strata. Heavy mineral lamination is also commonly observed. Facies 17 contains <2 % silt/mud, predominantly as burrow fills and rarely as thin grey massive laminae. Lithologic accessories include shell fragments, disseminated organic debris, and mud intraclasts on a millimeter scale. Glauconite may also occur as isolated burrow fills and rarely as laminae at the top of the facies.

Diplocraterion hibachis are robust, in lower densities, have an irregular morphology, and can penetrate 1 m into the substrate from the overlying facies. A high diversity trace fossil assemblage with variable bioturbation intensities (BI 0-6) is also typical, where intensity increases upward. Unique to this facies are *Chondrites,* and *Schaubcylindrichnus* burrows which occur in moderate densities (Fig. II-17). The latter illustrates thin mud linings and occurs in colonial groupings. Singular forms are compacted and represent *Schaubcylindrichnus freyi. Asterosoma* are typically discrete and re-burrowed by *Chondrites*. *Rosselia* bulbs are low in occurrence and smaller in width with central tube diameters up to 5 mm. Both traces decrease in density upwards. Additional ichnogenera

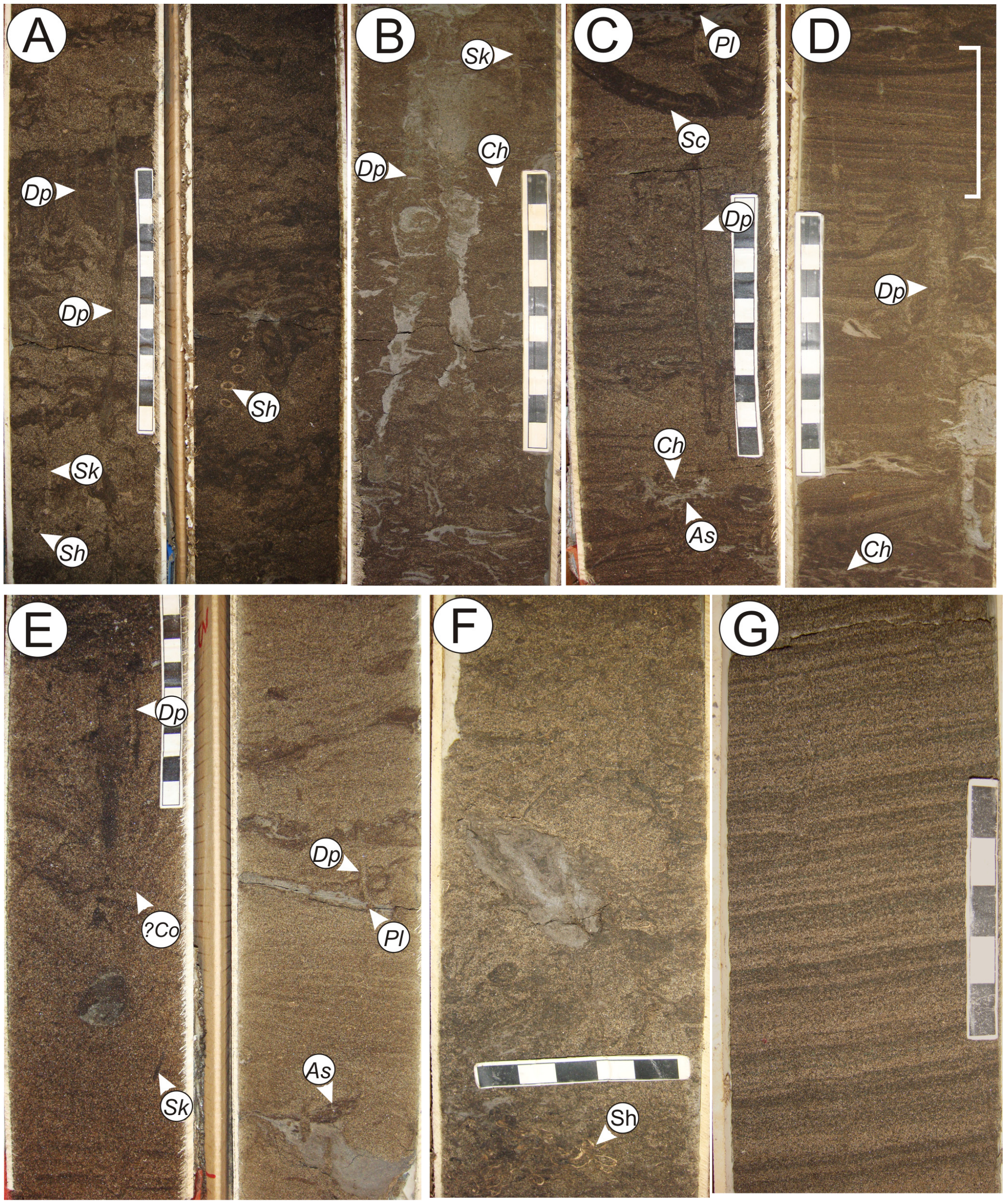

FIGURE II-17: Well burrowed to planar-laminated sand (F17) of the upper McMurray Formation.

Sands are moderate to well-sorted with poor bitumen saturations and illustrate an overall fining-upward trend. A diverse *Cruziana* ichnofacies suite representing fair-weather stable fully marine conditions is characteristic. Storm beds are characterized by the presence of non-burrowed low angle planar to HCS beds. This represents an overall lower shoreface to upper offshore environment. (A-C) Highly homogenized sands illustrating fair-weather resident trace suites. Individual ichnogenera include: *Diplocraterion (Dp), Schaubcylindrichnus (Sh), Chondrites (Ch), Scolicia (Sc), Skolithos (Sk),* and *Asterosoma (As).* (A) Indistinct mottling is common within these highly homogenized sands. Well 4-23-90-14W4, depth 171 m. (B) Note the presence of greenish-blue glauconite towards the top. Well 10-15-88-13W4, depth 156 m. (C) Planar-parallel lamination is only subtly preserved indicating burrow-reworked portions of tempestites. Well 15-14-90-14W4, 169.4 m. (D-F) The re-colonization of storm beds by opportunistic species has resulted in only the subtle preservation of low angle planar parallel lamination. Ichnogenera in

FIGURE II-17 CONTINUED: these examples include *Skolithos, Diplocraterion,* and *?Conichnus (Co)*. (D) An example in core of low angle planar lamination terminating into horizontal parallel lamination. This represents thin HCS of a preserved tempestite. Well 7-29-89-14W4, depth 178 m. (E) Fining-upward grain size is observed from the bottom left hand corner to top right hand corner. Well 3-23-90-14W4, depth 167.6 m. (E-F) Concentrated shell debris, mud-clasts and laminae are common lithologic characteristics that represent erosional lags deposited during higher energy fluxes. Well 11-31-88-13W4, Depth 179 m. (G) Low-angle planar bedding is interpreted as upper-flow regime deposition during waning storm events. Note the absence of bioturbation and heavy mineral lamination. Well 4-23-90-14W4, depth 196.25 m.

in moderate densities include *Planolites, Skolithos, Scolicia* and *Teichichnus. Thalassinoides* and *Conichnus* were locally observed.

Interpretation of F17

Facies 17 is interpreted as dominantly fair-weather deposition with thin, remnant tempestites in a fully shallow marine lower shoreface to upper offshore environment. The trace assemblage in F17 is consistent with a diverse *Cruziana* ichnofacies, where deposit-feeding strategies are widespread and suspension feeding strategies are rare (Pemberton and MacEachern, 2007). This highly diverse assemblage, coupled with the relatively uniform distribution and size of traces, and variable intensity of bioturbation, reflect a lower shoreface to upper offshore environment. In these settings, high bioturbation intensities reflect stable, fully marine conditions, and low intensities represent colonization by opportunistic organisms (e.g. *Diplocraterion, Skolithos*) post-storm deposition. HCS and planar lamination structures represent wave processes and the main storm body. Planar stratification is typically interpreted to represent upper-flow regimes and could occur during the waning-flow stages of a storm event. Shell beds and planar laminae may also have been deposited as thin erosional lags during higher energy storm deposition as they have developed amalgamated multiple-event shell concentrations. As this facies is dominated by bioturbation, and sedimentary structures are rarely preserved, storms are interpreted as infrequent events, where sand-dominated tempestites have been largely homogenized, resulting in the record of a near continuous fair-weather accumulation.

(F18) Burrowed argillaceous mud with silt and sand inter-beds

This non-reservoir facies is characterized by flat-lying inter-beds of moderate to completely bioturbated (BI 3-5) argillaceous sand, silt, and mudstone (Fig.II-18). F18 is typically mud-dominated but may contain up to 35% sand

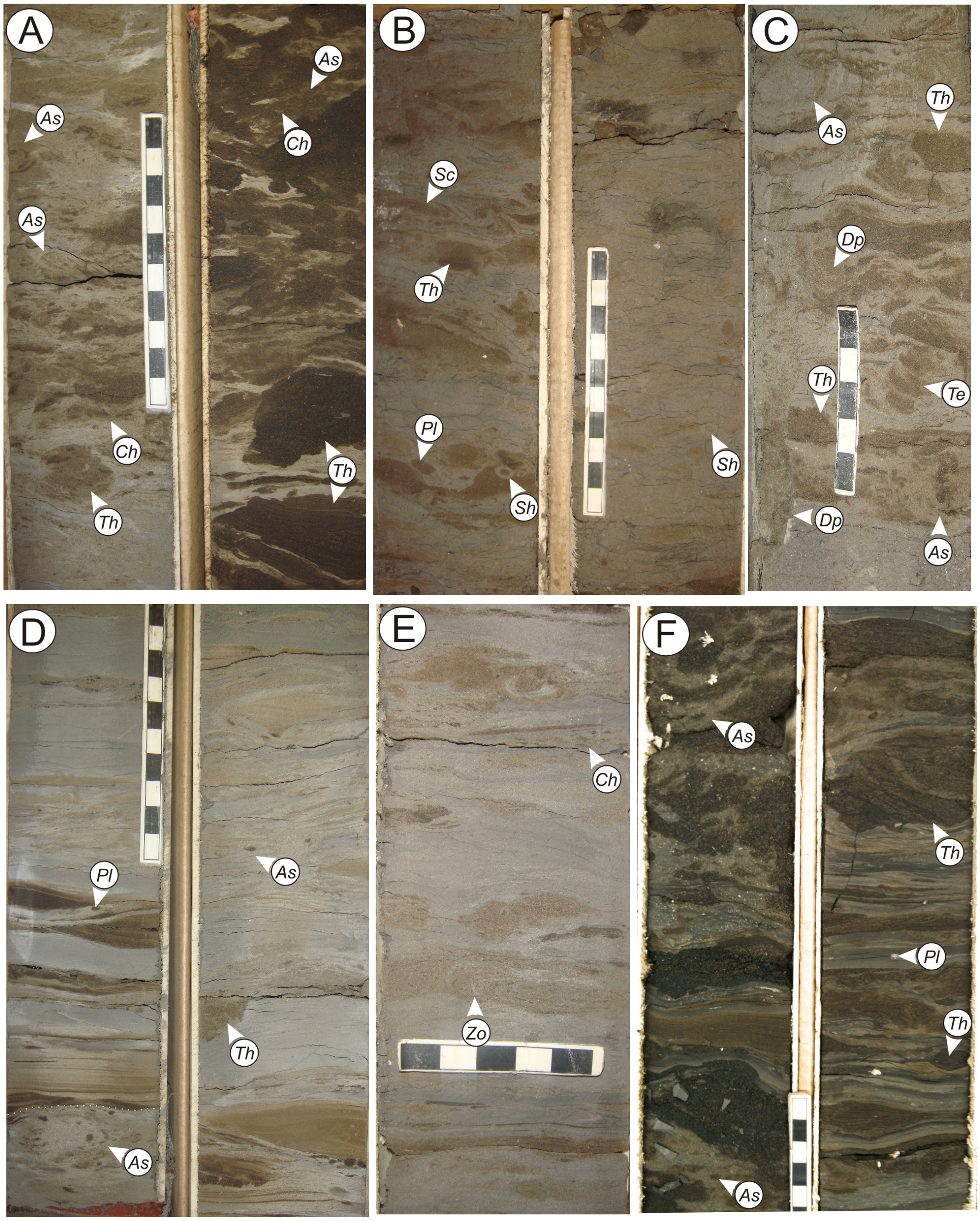

FIGURE II-18: Burrowed inter-bedded argillaceous mud, silt and sand (F18) of the upper McMurray Formation.

(A) Highly bioturbated and homogenized sand and silty mud illustrating an overall coarsening upward succession. Burrow mottling is common and large, unlined *Thalassinoides* (Th) are unique to this facies. Note the preservation of laminae in the burrow fill representing active back-filling by the tracemaker. Additional ichnogenera include *Asterosoma (As)* and *Chondrites (Ch)* which is consistent with lower shoreface to offshore deposition. Well 6-3-91-14W4, depth 171 m. (B) Well bioturbated silty mud. Sand occurs predominantly as burrow linings/fill. Ichnogenera consist of *Schaubcylindrichnus (Sh), Scolicia (Sc), Planolites (Pl),* and *Thalassinoides*. Note the colonial grouping of *Schaubcylindrichnus*. Well 10-08-89-14W4 depth 192.2 m. (C) Well burrowed silty mud and sand illustrating a fully marine, stable fair-weather *Cruziana* ichnofacies trace suite. Ichnogenera include: *Diplocraterion (Dp), Asterosoma (As), Thalassinoides (Th), Chondrites (Ch), Skolithos (Sk),* and *Teichichnus (Te*). Note the passive glauconitic infill of a *Diplocraterion*

FIGURE II-18 CONTINUED: burrow which contrasts with the surrounding matrix. Well 12-27-90-14W4, depth 172 m. (D) Weak to moderately burrowed mud and silty sand exhibiting parallel-lamination, and combined-flow ripples. Note the coarser sand infill of *Thalassinoides*. These structures indicate the increase of wave influence in the system. Note the ripple- to parallel-laminated sand truncating a burrowed interval. These are interpreted as thin tempestites. Well 10-08-90-14W4, depth 179 m. (E) *Zoophycos (Zo)* and *Chondrites (Ch)* are commonly observed in F18. Well 6-5-91-14W4, depth 167.4 m. (F) Wavy bedding and sharp to contorted contacts between sand and muds are nicely illustrated. Soft sediment deformation and ripple-lamination are common. Dark grey muds are interpreted as phytodetrital fluid muds which represent rapid sedimentation that would have resulted in soupgrounds and periods of dysoxia. This would have developed a stressful environment for benthic organisms, resulting in the impoverished suite associated with these deposits. Well 7-11-90-15W4, depth 178 m. All scales in cms.

by volume. Inter-beds are generally thin and vary in thickness on a millimeter to centimeter scale. F18 may form fining- or coarsening-upward successions, occurring at the top of the McMurray Formation. Bedding is wavy to planar and individual contacts between sand and mud are sharp to bioturbated. F18 typically illustrates sharp to bioturbated lower contacts with any facies through F9 to F17. Upper contacts are gradational or sharp with F17 or sharp with F19.

Sands in this unit are moderately- to well-sorted upper- very fine to lower-fine-grained and can be erosive in nature. Coarser sands may also occur as in localized beds and as burrow fills (Fig. II-18C). Sedimentary structures observed consist of oscillation-, combined-flow ripple-lamination, and subordinate horizontal to low angle planar stratification. Wavy-bedding with current-lamination is less commonly observed. Muds are often a distinct tan-bluish grey color, sharp-based, inter-laminated with silt/sand, and low-angle planar to parallel-laminated. Local soft sediment deformation is evident from contorted laminae and minor folding and micro-faulting. Sharp-based dark grey, non-burrowed muds are locally abundant (Fig. II-18E). Other lithological features include disseminated organic material, shell fragments, coal fragments, intraclasts and siderite/pyrite cemented zones. Glauconite from the overlying facies may also occur near upper contacts.

Trace fossils are regular heterogeneous to homogenous in distribution where moderate to robust *Thalassinoides, Asterosoma, Zoophycos, Chondrites, Teichichnus*, and *Planolites* are most common (Fig. II-18). A variety of discrete traces, in low densities, are observed in sand beds including *Teichichnus, Skolithos*, *Arenicolites* and *Diplocraterion*. Within silts and muds, traces and individual ichnogenera are often difficult to distinguish. *Scolicia, Skolithos, Fugichnia* and *Schaubcylindrichnus* are subordinate. Unique to this facies are large, unlined *Psilonichnus* sand-filled burrows containing preserved rhythmic parallel / wavy lamination. Composite traces of *Zoophycos* and *Asterosoma* were also identified. *Phycosiphon* and *Cosmoraphe* were also observed locally.

Interpretation of F18

Facies 18 is interpreted as predominantly proximal offshore fair-weather and waning flow deposition within a fully marine setting. The trace assemblage is consistent with a diverse proximal to distal *Cruziana* assemblage illustrating a mix of deposit-feeding and foraging/grazing strategies, with rare suspension-feeding strategies. This assemblage is characteristic of upper to lower offshore deposition (Pemberton and MacEachern, 2006). Dark grey mud beds are typically non-burrowed and may indicate a physico-chemical stress (i.e. decreased oxygenation).

Both tidal and wave influence are illustrated in these deposits. Preservation of wavy- rhythmic-bedding is evidence of tidal currents. Burrow fills also illustrate tidal influence where large *Psilonichnus* contain preserved passively sand-filled rhythmic laminae. These are interpreted as tubular tidalites which indicate evidence of tidal currents (Gingras and MacEachern, in press). Wave influence is reflected by oscillatory ripples. Combined- flow ripples, consisting of asymmetric profiles with smooth rounded crests, are indicative of a combination of oscillatory and unidirectional flow (Dumas *et al.,* 2005). Planar stratification is typically interpreted to represent upper-flow regime deposition. As sands are rare and reflect both biogenic homogenization and the aforementioned structures, they are interpreted as storm-generated in origin, with local preservation of waning flow deposits. Storm deposition may also be evident from coarse sand-filled burrow representing tubular tempestites (cf. Wanless *et al.,* 1988) that formed due to strong and rapid fluctuations in hydrostatic pressure operating through the burrows during intense oscillatory wave action (Webb and Theodore, 1968; Bann *et al.,* 2008). These deposits can further be interpreted as distal tempestites where thin sands represent storm beds that are intercalated with mudstone representing post-storm and fair-weather suspension fall-out (Johnston and Baldwin 1986; Pemberton and MacEachern, 2006). The high diversity, low individual density suite of traces further supports this interpretation (Pemberton and MacEachern, 2006). Trace fossils observed in the sand beds are interpreted to represent opportunistic fauna that colonized the storm sand, and traces of the fine-grained silts and muds represent the resident suite of fair-weather deposition.

Wabiskaw Member Facies

(F19) Burrowed planar-parallel glauconitic sand to sandy mud

This represents the lowermost non-reservoir facies of the Wabiskaw Member and is laterally extensive through the study area and is divided into two Subfacies.

Facies 19A is easily identified by the green-blue color (i.e. glauconitic sand), consistent thickness (from 1-3 m), and fining- and muddying-upward vertical profile (Fig. II-19). Lower contacts are typically sharp to bioturbated with underlying units and represent a major erosional bounding discontinuity. Sideritized/pyritized zones are common near contacts. Upper contacts are gradational with F19. Sands are moderately-sorted, and lower fine- to very fine-grained. Low-angle planar to horizontal stratification and wavy to lenticular inter-beds of bluish-grey silty mud and sand are locally preserved but tend to be homogenized with sand due to the high degree of biogenic reworking. Accessories include small coal fragments, thin coal laminae, disseminated organic debris, and shell fragments.

Facies 19 exhibits a high diversity, high density trace assemblage with variable bioturbation intensities (BI of 2-6) that decrease upwards. Unique to this facies is a high density *Chondrites* assemblage (Fig.II-19). Diminutive *Planolites, Skolithos* and *Teichichnus* occur in moderate densities. *Zoophycos* were locally observed. *Diplocraterion, Thalassinoides,* and small to moderate *Asterosoma* and *Rosselia* near the base decrease in size and occurrence upwards. *Phycosiphon/ Helminthopsis* were extremely rare in occurrence near the top of this facies, and typically associated with *Zoophycos*.

Facies 19B is less commonly observed and is characterized by 2-5 m thick successions of planar-parallel laminated to cross-bedded sands representing HCS (Fig.II-19C; Fig.II-24). Sands are very-fine to fine-grained, well sorted with low to moderate bitumen saturation, and are typically non-burrowed but may contain rare *Ophiomorpha* and/or fugichnia. Laminae are often enhanced by green-blue glauconitic interlaminae or thin mud drapes. The base of this subfacies truncates subfacies F19A, F18, F17, F16, or F12. Overlying contacts are sharp to gradational with F19A, or F20.

Interpretation of F19

Facies 19 is interpreted as distal offshore deposition in a mixed tide- and

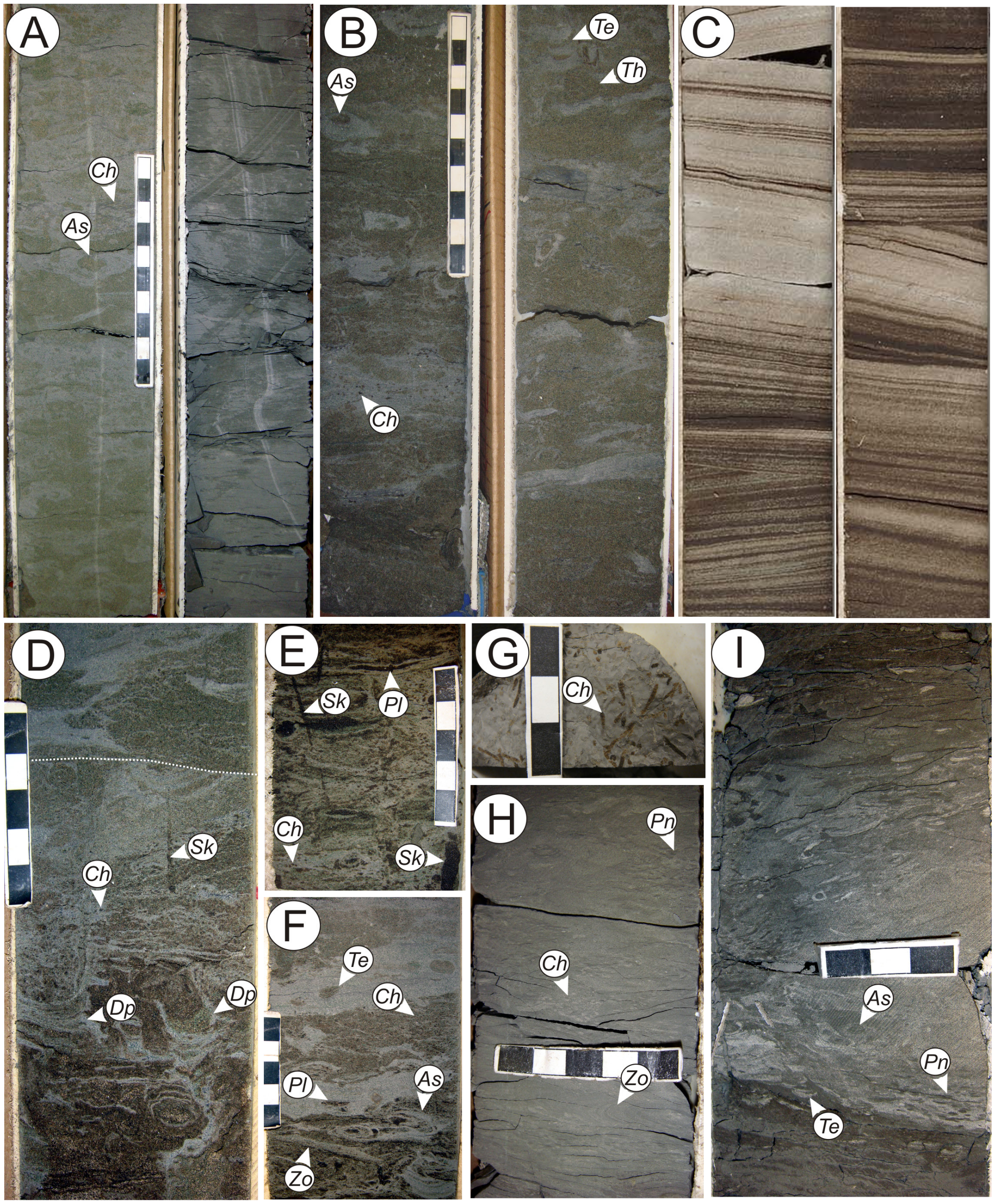

FIGURE II-19: Burrowed glauconitic muddy sand to sandy mud (F19) and silty mudstone (F20) of the Wabiskaw Member.
Facies 19 defines the base of the Wabiskaw Member and is easily recognized by a distinct green-blue color, high bioturbation intensities, and muddying-upward trend of F19A. Burrow mottling is common and individual ichnogenera are often difficult to distinguish. (A) Biogenically reworked muddy glauconitic sands of F19A. Note the muddying-upward trend into F20 from bottom left to top right. This example is dominated by *Chondrites (Ch)* and *Asterosoma (As)*. Traces are typically overprinted by deeper tiers, developing complex cross-cutting relationships and biogenic reworking of ichnogenera. Well 15-14-90-14W4, depth 169 m. (B) Silty glauconitic sands with remnant wavy bedding and disseminated organic debris. Note the abundance of *Chondrites*, which are characteristic to this facies. Well 5-36-88-14W4, depth 179 m. (C) Facies 19B illustrating parallel-planar laminated to HCS. Sands are typically non-burrowed and laminae are enhanced by glauconite. Well 11-3-92-16W4, depth 184 m. (D) Silty glauconitic sand illustrating a well developed, moderate diversity trace assemblage dominated by *Chondrites*, *Skolithos (Sk)*

FIGURE II-19 CONTINUED: and *Diplocraterion (Dp)*. Note the erosive contact within the burrowed interval. This may indicate evidence of storm influence. The lack of the main storm body suggests rapid re-colonization and reworking and is interpreted as remnant tempestite deposition. Well 10-30-88-13W4, depth 170.5 m. (E-F) Intensely bioturbated sandy glauconitic silty mud. A well developed suite of *Chondrites* and *Skolithos* represent deeper tier traces that have overprinted the primary burrow fabric resulting in a unique and complex bioturbate texture characteristic to F19A. Well 16-1-90-14W4, depth 188 m; Well 10-07-90-13W4, depth 186.8 m. (G) Complex branching pattern of *Chondrites* burrows identified in F20. Well 16-28-90-14W4, depth 169 m. (H) Weakly burrowed silty mud of F20 illustrating a *Chondrites-Phycosiphon (Pn)* trace assemblage. These grazing behaviors represent the *Zoophycos* ichnofacies, characteristic of quiet, low energy offshore conditions. Well 10-8-90-13W4, depth 196.2 m. (I) Moderately burrowed silty mud interval (F20), illustrating diminutive *Asterosoma, Teichichnus (Te), Chondrites,* and *Phycosiphon*. Well 14-12-90-14W4, depth 174 m. All scales in cms.

wave-influenced setting dominated by fair-weather deposition with remnant distal tempestites, above storm wave base. The dominance of biogenically reworked silty-mud and rare thin sand beds is evidence of a fully marine lower offshore setting. Glauconite deposits are widespread on present-day continental shelves (Odin, 1985). Thus, the presence of glauconite indicates open marine, very slow sedimentation. HCS is attributed to preserved low angle planar to horizontal stratification, indicating storm event beds. Wavy- to flaser-bedding illustrate tidal influence. A distal expression of the *Cruziana* ichnofacies is evident from the diminutive lower diversity assemblage of mixed deposit-feeding and grazing behaviors, which is characteristic of this setting (Pemberton and MacEachern, 2006). A progressive deepening is additionally illustrated in the facies, as sand content and the ichnological assemblage decreases in diversity and trace size upwards. The dominance of a very low-diversity of exceedingly small trace fossils such as *Planolites*, *Chondrites,* and *Zoophycos* may be interpreted as an oxygen-stressed environment (e.g., Ekdale and Mason, 1988; Savrda and Bottjer, 1988; Wignall, 1991). This evidence coupled with the good lateral continuity of deposition supports an offshore fully marine setting.

(F20) Bluish silty mud to moderate grey mud with sand inter-beds

This non-reservoir facies reflects regionally extensive deposition of the Wabiskaw Member. It is characterized by bluish-grey massive to lenticular bedded, and parallel- laminated muds that are consistent in thickness (3-5 m) and contain local centimeter-sized silty to lower fine-grained sand inter-beds (Fig.II-19). Sand in this facies is rare, comprising less than 5% of the volume, and may also form thin laminae and burrow fills. Muds are non- to weakly-bioturbated and form a continual fining-upward succession, where dark grey muds increase in abundance upward. Lithologic accessories include shell fragments, quartz crystals, coal fragments, pyrite nodules, and thin coal and sand interlaminae which may also be pyritized. Sideritized zones are commonly observed near the contacts of this facies and can occur up to 15 cm thick. Contacts are moderately bioturbated. Lower contacts are gradational to sharp with underlying F19. Upper contacts are sharp to erosional with F21. Muds are weakly burrowed with local moderately burrowed zones (BI 0-1; BI 2-3). *Chondrites* are the most common with subordinate *Phycosiphon/ Helminthopsis* and *Cosmoraphe* burrows (Fig. II-19). Small *Teichichnus, Thalassinoides, Skolithos, Asterosoma* and *Planolites* occur locally and are most common at both the upper and lower contacts.

Interpretation of F20

Facies 20 is interpreted as shelfal mud deposits below storm wave base. A *Zoophycos* ichnofacies is represented by an assemblage dominated by the grazing behaviors of diminutive *Chondrites, Phycosiphon/Helminthopsis* and *Cosmoraphe*. This low diversity ichnofacies has been attributed to lowered oxygen levels associated with organics in quiet-water settings (Pemberton and MacEachern, 2006). *Chondrites* dominated suites have additionally been identified as indicators of decreased oxygenation (Bromley and Ekdale, 1984). Furthermore, the massive to parallel-laminated muds indicate low energy, quiet water deposition attributed to suspension fallout. Darker muds may also be attributed to increased phytodetrital material and reducing conditions. These observations coupled with the good lateral continuity and gradational relationship with F19 support deposition in an offshore setting.

(21) Moderately burrowed fine- to medium-grained sand

This fine to medium-grained sand package of the Wabiskaw Member exhibits variable thickness on a decimeter to 10 m scale across the study area. This sand is sharp-based to gradationally inter-bedded with F19 or F20. This facies forms an overall coarsening and cleaning-upward cycle, although the top may exhibit muddier intervals when gradational contacts are present. Upper contacts are sharp to gradational and bioturbated with silts and muds of the Clearwater Formation. Sharp contacts are typically sideritized.

The base of the facies may contain wavy silty mud laminae and beds that are homogenized by burrowing. Mud inter-beds are bluish grey and interlaminated with sand and glauconite. Proportions of silt and mud decrease upward. Sands exhibit good bitumen saturation and are also characterized by thickly lined silt and mud burrows, similar to F16 (Fig.II-20). Dominant sedimentary structures consisted of wave ripple-lamination. Thin trough, and hummocky cross-stratified, beds have also been observed up to 15 cm thick.

A high diversity and high density assemblage of traces with moderate to complete bioturbation intensities is observed (BI 3-6). Individual ichnogenera include: *Chondrites, Skolithos, Asterosoma, Diplocraterion, Thalassinoides, Teichichnus, Scolicia* and *Planolites* (Fig.II-20). Sand beds are typically dominated by robust *Asterosoma, Teichichnus, Diplocraterion,* and *Scolicia. Rosselia* are subordinate and much less abundant than observed in F16. *Diplocraterion* may penetrate up to 50 cm. *Ophiomorpha* was locally observed. Muds are dominated by *Chondrites, Skolithos, Planolites* and *Thalassinoides*.

Interpretation of F21

Facies 21 exhibits a laterally extensive lobate sand geometry similar to that of a shoreface. As it is a relatively thin unit, sometimes encased in lower shoreface/Clearwater muds, it may also represent a tidal inlet or isolated amalgamated tidal bar sands. Due to the overall geometry, lateral extent, and trace assemblage, this facies is interpreted as a wave-influenced lower to middle shoreface. The trace-fossil suite predominantly reflects an archetypal *Cruziana* ichnofacies. Unbioturbated beds with HCS and oscillation ripples suggest the working of sediments by fair-weather and storm waves. Facies 21 illustrates similar characteristics (with more wave influence) to F16 but was separately designated as it is correlative to the Wabiskaw Member of the Clearwater Formation.

FACIES ASSOCIATIONS

Facies associations represent architectural elements of a particular depositional environment. They are extremely important in paleoenvironmental reconstructions as they group facies into genetically linked units, which can reveal unique physical and biological parameters of a particular environment. The relationships between units can further be analyzed which ultimately yields more accurate environmental and stratigraphic interpretations.

The previously described facies are further grouped into seven facies associations (FA) that reflect a unique environment of deposition corresponding to a particular depositional system. These FAs were subsequently subdivided into a ‘lower,’ ‘upper,’ and Wabiskaw division, corresponding to the ‘middle’

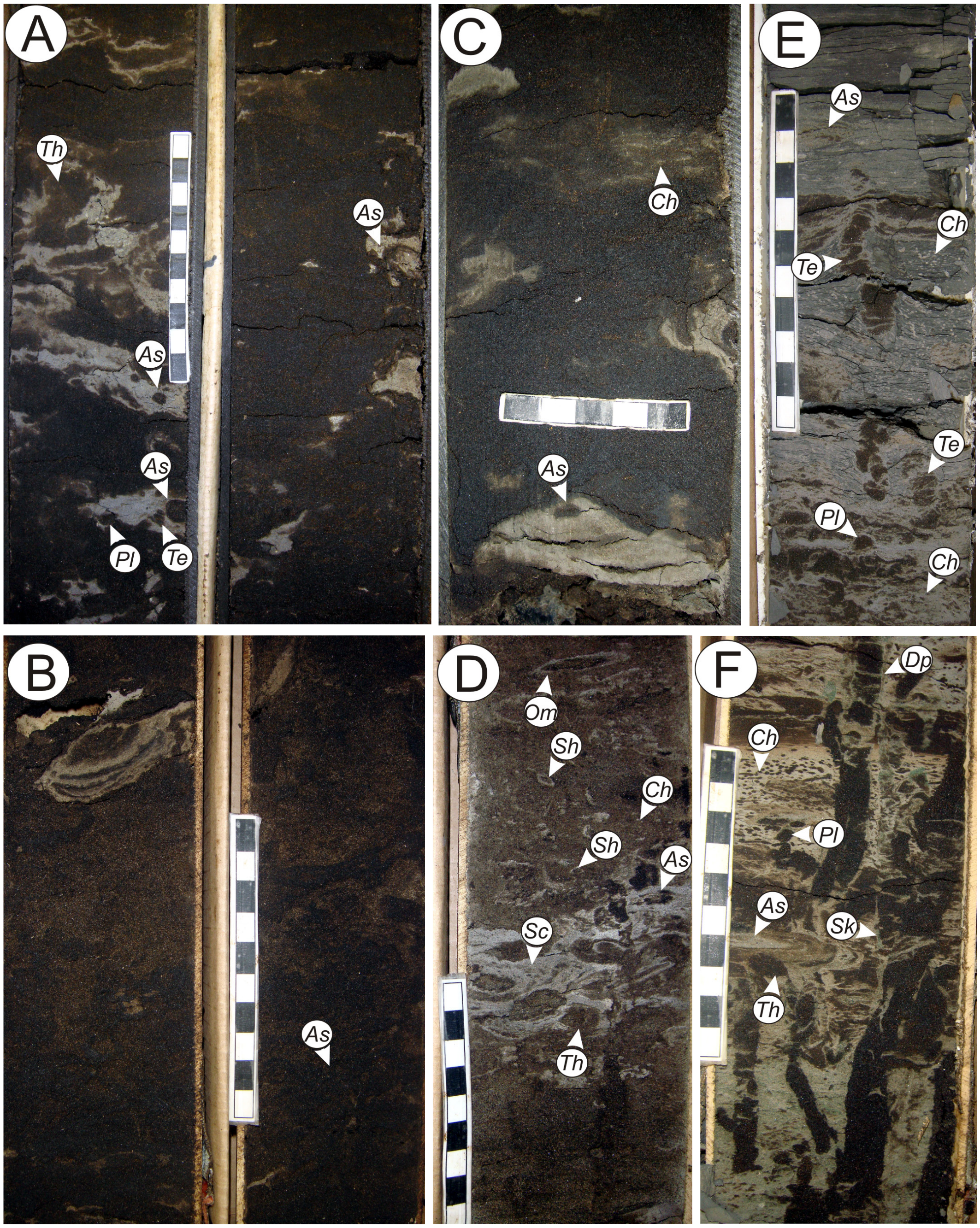

FIGURE II-20: Well burrowed fine- to medium-grained sand with silt/mud burrows (F21) of the Wabiskaw Member of the Clearwater Formation.
(A-C) Moderate to well bioturbated texture of moderately well sorted fine- to medium-grained sands (F21). Thick-lined *Asterosoma (As)* burrows are common and may be re-burrowed by *Planolites (Pl), Teichichnus (Te)* or *Chondrites (Ch)*. Note the good bitumen saturation and moderate to high bioturbation intensity which has resulted in a lack of primary sedimentary structure. (A) Well 10-8-90-14W4, depth 171 m. (B) Well 10-8-90-14W4, depth169 m. (C) Note the lack of *Rosselia* which distinguishes F21 from F16. Well 7-2+9-89-14W4, depth171.7 m. (D) A high diversity assemblage with variable bioturbation intensity is observed. This example illustrates individual ichnogenera *Chondrites (Ch), Asterosoma (As), Scolicia (Sc), Schaubcylindrichnus (Sh), Ophiomorpha (Om),* and *Thalassinoides (Th)*.Well 6-3-91-14W4, depth 162 m. (E-F) Mud and silty mud are also characteristic towards the base of F21. These zones

FIGURE II-20 CONTINUED: illustrate a unique bioturbate texture dominated by *Chondrites, Diplocraterion (Dp), Asterosoma, Thalassinoides, Skolithos (Sk), Planolites,* and *Teichichnus*. Glauconitic sands are also common as burrow fills. (E) Well 6-5-91-14W4, depth 152 m. (F) Well 7-19-89-13W4, depth187.5 m. F21 is interpreted as lower shoreface to upper offshore deposition. All scales in cms.

and 'upper' informal members of the McMurray Formation, and the overlying Wabiskaw Member, respectively. Table II-2 contains a summary of the sedimentological and ichnological characteristics of each FA. Following a discussion of the individual FA and their interpretations, a depositional setting is interpreted for the study area and a model is presented for the middle and upper McMurray Formation.

Lower FA Descriptions

Facies Association (ECP): Fine-grained Pedogenically Altered Association–Estuary Coastal Plain

The first facies association (ECP) is characterized by non-reservoir fine-grained pedogenically altered media interpreted as vertical accretion of an estuary coastal plain. Deposits of ECP are genetically related and consist of rooted muds (F1), organic muds and low-grade coals (F2), burrowed to rhizoturbated silts and sands (F3), parallel inter-laminated to inter-bedded silts and sands (F4) and thin laminated to burrowed sands (F5). More specifically, these facies correspond to eluviated deposition representing paleosols, backswamp deposits, levee-crevasse splays, and sandy intertidal flats with local distributary tidal channels. Deposits of ECP range in thickness on a decimeter to meter scale, reaching up to 10 m thick, but are rarely preserved and restricted to the lowermost stratigraphic interval of the middle McMurray Formation. They exhibit significant vertical and lateral variability and are characterized by an irregular vertical profile (Fig.II-21; II-22). This is largely due to the lateral shifting of the variable sub-environments within an estuary coastal plain.

Defining characteristics of ECP include the abundance of rooted media and rhizoturbation, thin allochthonous coal beds, convolute bedding, an abundance of coffee grounds (i.e. organic detritus), and weak pedogenesis. These features are all characteristic of deposition in the supratidal zone.

Bioturbation intensities for ECP are also characteristically absent to low, and burrowing is dominantly sporadic and heterogeneously distributed, which is common to supratidal sedimentation (BI 0-2). Unique to ECP is the identification

FA	Facies Association 1 (ECP): Fine-Grained Pedogenically Altered Association	Facies Association 2 (IME): Flat Lying to Inclined Heterolithic Association	Facies Association 3 (SMBF): Burrowed Sand, Silt and Mud Assocation	Facies Association 4 (TSB): Coarsening-Upward Sand Association	Facies Association 5 (POLS): Well-Bioturbated Coarsening-Upward Association	Facies Association 6 (DOS): Muddy Sand to Sandy Mud Association	Facies Association 7 (LSF): Burrowed Sand Association
Facies	**(F1)** Rooted white to light grey mudstone **(F2)** Organic mudstone and coal **(F3)** Chaotic, inter-bedded, rhizoturbated sand-, silt- and mudstone **(F4)** Inter-bedded to inter-laminated silty mud, silt and sand **(F5)** Laminated to burrowed very fine-grained sand	**(F6)** Cross-bedded to ripple-laminated fine-grained sand with helical- and *Cylindrichnus*-dominated silt and mud inter-beds **(F7)** Flat-lying to inclined inter-bedded to inter-laminated heterolithics **(F8)** Well bioturbated heterolithics	**(F9)** Well burrowed inter-bedded sand, silt and light grey mudstone **(F10)** Well burrowed sand with silt and mudstone-filled burrows **(F11)** Weak to moderately burrowed wavy bedded f.g. sand	**(F11) M**oderately burrowed wavy bedded f.g. sand **(F12)** Weakly burrowed f.g. sand **(F13)** Weakly burrowed rippled to small scale cross-bedded sand **(F14)** Upper fine- to medium-grained large scale cross-stratified sand **(F15)** Cryptobioturbated medium-grained sand	**(F16)** Moderately bioturbated v.f.g.-f.g. sand with silt and mudstone-filled burrows **(F17)** Well bioturbated to planar laminated sand **(F18)** Burrowed argillaceous mudstone with silt and sand inter-beds	**(F19)** Burrowed planar-parallel glauconitic sand to sandy mud **(F20)** Bluish silty mud to moderate grey mudstone with sand inter-beds	**(F21)** Moderately burrowed fine- to medium-grained sand
Occurrence	Lower FA 'middle' McMurray	Lower FA 'middle' McMurray	Upper FA 'upper' McMurray	Upper FA 'upper' McMurray	Upper FA 'upper' McMurray	Wabiskaw Member	Wabiskaw Member
Characteristic Physical Sedimentary Structures	massive to rhizoturbated; convolute bedding; low angle to parallel-lamination	IHS, large-scale trough/tabular cross beds, bi-directional small-scale cross-beds, grain-size striping, low angle planar- to horizontal-lamination, current ripple-lamination, reactivation surfaces, wavy-, flaser- and lenticular-bedding, rhythmic lamination, double mud drapes	Wavy and flaser bedding, rhythmic- to parallel-lamination, current and oscillation ripples, small scale cross-beds	Cross-beds (large and small scale), current ripple to planar-parallel lamination; oscillation and combined-flow ripples; Tidal indicators: grain size striping/ rhythmites, dip reversals, reactivation surfaces, double mud- and foreset-drapes, rhythmic laminations, reactivation surfaces, and wavy to flaser bedding	Low angle planar to horizontal cross-stratification, trough cross-beds, HCS, relict wavy bedding; parallel lamination; oscillation and combined ripple flow; "lam-scram" bedding	Low angle planar to horizontal stratification, HCS; parallel- and wave ripple-lamination; wavy interbeds	Trough cross-beds, horizontal to low angle planar stratification, HCS, wave-ripple lamination
Lithologic Characteristics	Redoximorphic features shell fragments syneresis cracks	abundant coffee grounds and mud draping foresets/toesets, coal fragments/laminae, intraclasts, syneresis cracks, pyrite/siderite zones	Massive, non-bioturbated bluish grey mud beds with sharp contacts; Shell fragments, small bivalves, passive coarse-grained burrow fills disseminated organic debris, intraclasts, coal fragments, siderite/ pyrite cemented zones	Coarsening-upward profile, clean reservoir sands with rare silt/mud partings, silt/mud burrow-linings and fills, disarticulated bivalves and shell fragments, disseminated organic debris, coal laminae, intraclasts, syneresis cracks	Coarsening-upward succession; passive glauconite and coarse-grained burrow-fills, Lam-scram bedding, siderite/pyrite cemented zones, disseminated organic debris, small interaclasts, shell fragments	Fining-upward succession; glauconite, coal fragments and laminae, disseminated organic debris and shells, pyrite and siderite	Good bitumen saturation; sand-upwards, thick clay-lined burrows, variable thickness
Ichnological Characteristics	BI 0-4 Obscure "scratchmark" burrow mottling; *Taenidium* (c) Impoverished marine assemblage: *Planolites* (m), *Skolithos* (r), *Teichichnus* (r) and *Thalassinoides* (vr) Burrow diameter size: diminutive sporadic and heterogeneous distribution	BI 0-6 *Cylindrichnus-Skolithos* association (c); Gyrolithes monospecific suites Additional Ichnogenera: *Teichichnus* (m), *Planolites* (c), *Skolithos* (m), *Arenicolites* (m), *Thalassinoides* (r), *Palaeophycus* (vr), *Chondrites* (vr), *and* fugichnia (r) Burrow diameter size: diminutive forms regular heterogeneous, sporadic, and homogeneous distribution	BI 2-6 Robust *Asterosoma* (c), *Zoophycos* (c),*Thalassinoides* (c), *Planolites* (c), *Chondrites* (c), Rosselia (m), *Skolithos (*m), *Diplocraterion* (m), *Scolicia* (m), *Rhizocorallium* (m), *Teichichnus* (m), *Spirophyton (m), Arenicolites* (r), *Palaeophycus* (vr), *Macaronichnus* (r), *Phycosiphon/ Helminthopsis* (vr), *Ophiomorpha* (r), *Monocraterion* (vr) fugichnia (vr) Burrow diameter size: moderate to robust homogeneous distribution	BI 0-2; Cryptobioturbation Ichnogenera: *Planolites* (c), *Thalassinoides (c), Teichichnus* (m), *Skolithos* (m), fugichnia (m) *Ophiomorpha* (r), *Macaronichnus* (r), *Arenicolites* (vr), *Siphonichnus* (vr), *Schaubcylindrichnus (*vr), *Scolicia (vr), Palaeophycus (vr), Diplocraterion (vr)* Burrow diameter size: Traces are moderate to robust regular to sporadic heterogeneous	BI 0-6 Ichnogenera: *Chondrites* (c), *Asterosoma* (c), *Rosselia (c), Schaubcylindrichnus (m), Diplocraterion (m), Zoophycos (m), Skolithos* (m), *Planolites* (m), *Psilonichnus (r), Scolicia* (r) *Thalassanoides* (r), *Arenicolites* (r), *Teichichnus (r), Conichnus* (vr), fugichnia (vr) *Phycosiphon/Helminthopsis* (vr), *Cosmoraphe* (vr) Tubular tidalites / tempestites Burrow diameter size: robust homogeneous distribution	BI-0-6 Ichnogenera: *Chondrites* (c), *Phycosiphon / Helminthopsis* (m), *Planolites* (m), *Zoophycos (r), Skolithos* (r), *Teichichnus* (r), *Astersoma* (r), *Diplocraterion* (r), *Thalassinoides* (r), *Rosselia* (vr), *Ophiomorpha* (vr), fugichnia (vr) Burrow diameter size: small Homogeneous distribution	BI 3-6 *Chondrites* (c), *Skolithos* (m), *Asterosoma* (c), *Diplocraterion* (m), *Thalassionides* (m), *Teichichnus* (r), *Scolicia* (m), *Planolites* (m) Burrow diameter size: robust Homogeneous distribution
Interpretation	*Scoyenia* ichnofacies and brackish-water assemblage	well developed brackish water assemblage	Proximal *Cruziana* ichnofacies	Stressed tidal-influenced marine assemblage	Archetypal *Cruziana* ichnofacies	Distal *Cruziana* to *Zoophycos* ichnofacies	Archetypal *Cruziana* Ichnofacies
	Coastal plain to intertidal sandy flats	**Brackish-water intertidal mixed flats and subtidal channel bars**	**Low energy fully marine background bay-fill / interbar sedimentation**	**Bay-margin and island tidal sand bar complex (Lateral and forward accretion)**	**Fully marine fairweather to remnant proximal tempestite sand and mud**	**Fully Marine fairweather to remnant distal tempestites and shelfal mud**	**Fully Marine sand deposition reflecting the activity of fairweather and storm waves**
	Estuary Coastal Plain	**Inner to Middle Estuary**	**Shallow Marine Bay-Fill**	**Proximal to Medial Tidal Sand Bars**	**Proximal Offshore to Lower Shoreface**	**Distal Offshore to Shelf**	**Lower Shoreface**

TABLE II-2: Summary Table of Facies Associations based on sedimentological and ichnological observations in McMurray-Wabiskaw strata in the MacKay River Area, northeast Alberta.

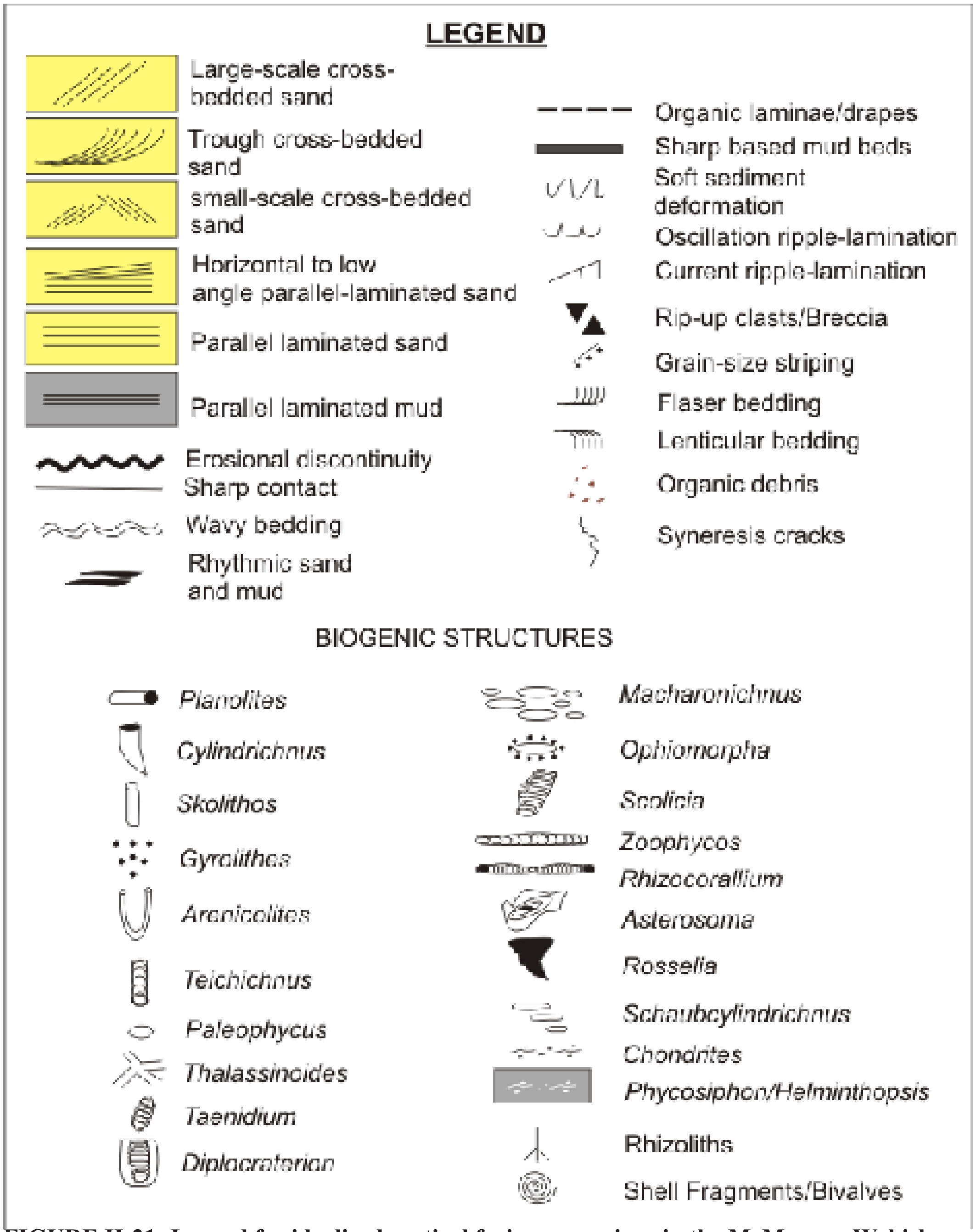

FIGURE II-21: Legend for idealized vertical facies successions in the McMurray-Wabiskaw succession. Refer to Figures 21-23.

of both a freshwater and marine ichnofabric. A continental trace fossil suite is interpreted to represent the obscure “scratchmark” like burrowing mottling with *Taenidium* burrows. More specifically, this suite is interpreted as the activity of arthropod-tracemakers (i.e. insect larvae) of the *Scoyenia* ichnofacies reflecting a freshwater environment. This assemblage coupled with the overall lack of bioturbation and sporadic distribution, abundance of roots and fine-grained nature

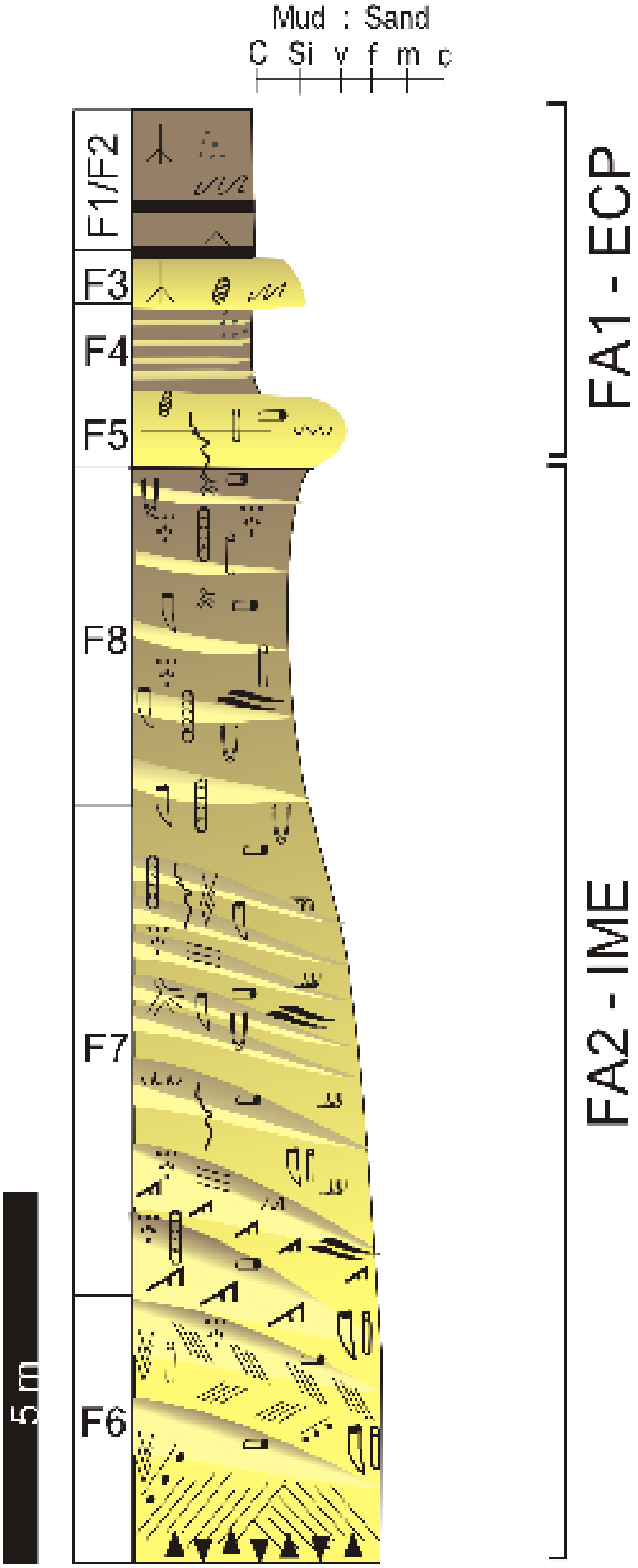

FIGURE II-22: Idealized vertical succession for tidal estuarine deposits of the middle McMurray Formation. This schematic illustrates the sedimentologic and ichnologic relationship between individual facies and facies associations. An overall irregular profile coupled with a fining- and muddying-upward succession is characteristic, with deposits of ECP overlying IME.

The large-

FIGURE II-22 CONTINUED: scale cross-beds at the base are rarely preserved, and grade into ripple cross-stratified sands and flat-lying to inclined wavy to horizontal laminated inter-bedded deposits reflecting IHS. A low diversity trace fossil assemblage characteristic of brackish-water settings is characteristic of this succession where bioturbation shows a gradational increase upwards towards the top of IME. This is overlain by a continental *Taenidium*-dominated assemblage within pedogenically altered media characteristic of supratidal deposition. This

of sediment support a continental freshwater interpretation. A low diversity mix of diminutive horizontal and vertical structures including *Planolites, Teichichnus, Skolithos*, and *Thalassinoides* was also observed in laminated sands, reflecting an impoverished marine softground trace fossil assemblage. This characteristic brackish-water trace fossil assemblage, coupled with the rare presence of syneresis cracks indicates that there was some degree of marine influence in the system. This suggests that overbank flows were both fresh- and brackish-water influenced, in an overall marginal marine environment rather than fluvial setting.

Facies Association 2 (IME): Flat-lying to Inclined Heterolithic Association– Inner to Middle Estuary

The second facies association (IME) reflects flat-lying to inclined heterolithic media interpreted as subtidal to intertidal deposition within the middle to outer estuary. Deposits of IME are characterized by cross-bedded to ripple-laminated fine-grained sands with helical- and *Cylindrichnus*-dominated silt and mud inter-beds (F6), flat-lying to inclined inter-bedded to inter-laminated heterolithics (F7), and well burrowed heterolithic media (F8). These deposits are also inter-gradational with those of ECP, and typically display sand- or mud-dominated successions that illustrate overall fining-upward cycles with a progressive increase in frequency and thickness of light tan to brownish-grey silt and mudstone beds up-section (Fig.II-21; Fig.II-22). More specifically these non-reservoir deposits reflect brackish-water deposition of lateral accreting subtidal channel bars that grade into intertidal mixed flats. Characteristic of IME is an abundance of sedimentary structures indicative of tidally-influenced sedimentation and a well-defined brackish water trace-fossil assemblage.

Evidence of tidal currents is reflected by rhythmic bedding / lamination, wavy-, flaser- and lenticular-bedding, bi-directional cross-bedding, current-ripple lamination, reactivation surfaces, cross-strata foreset mud / coal drapes, abundance of coffee grounds, grain-size striping, and double mud drapes. Evidence for marginal marine deposition within the mixing zone is reflected by the dominance of IHS, presence of syneresis cracks, and the regular to sporadic heterogeneously distributed and physico-chemically stressed ichnological signature. A low diversity assemblage of diminutive simple forms exhibits three ichnofabrics characteristic of brackish-water deposition as defined by Pemberton and Wightman (1992). Bi-specific (i.e. *Skolithos-Cylindrichnus* association), monospecific helical suites, and a general brackish-water assemblage (*Planolites, Thalassinoides, Teichichnus, Skolithos* and *Arenicolites*) are all observed. Furthermore, these low diversity suites, coupled with the ichnologic distribution and diminutive trace fossil size reflect environmental duress characteristic of salinity-stressed deposition in a marginal marine tidal setting (Gingras and MacEachern, in press).

When preserved, IME forms the basal portion of the McMurray Formation and are restricted to the middle McMurray stratigraphic interval. Deposits are typically erosional into Devonian carbonates range from 0 to 25 m thick, and are common in the axis of topographic lows where higher accommodation allowed channels to amalgamate. In an ideal vertical succession, large scale cross-bedded tidal channel sands (F6) representing deeper flow accommodation and higher energy channel deposition, form erosional based sands that transition into ripple-laminated IHS lateral accretion bedding of channel point bars (F6 and F7), and grade into well bioturbated tidal flat heterolithics (F8). As facies of IME are genetically related and represent laterally equivalent environments, any combination of facies can occur and partial successions are the norm. These cycles also illustrate increasing bioturbation upwards and typically form stacked successions that are decimeters to 10 m thick. Localized *Glossifungites* suites may also develop between stacked successions, at the base of subtidal deposits. This is characteristic for lower contacts of subtidal channel / bar deposits (Gingras and MacEachern, in press). This relationship illustrates a preserved succession of subtidal to supratidal deposition. Stacking of these deposits reflect the lateral shifting of the tidal complex.

Upper FA Descriptions

Facies Association 3 (SMBF): Burrowed Sand, Silt and Mud Association-Shallow Marine Bay-Fill

The third facies association (SMBF) is characterized by well burrowed media interpreted as background bay-fill and/or interbar sedimentation of a fully marine shallow embayment. Facies association 3 is the first association of the upper McMurray stratigraphic interval and illustrates extremely different character than deposits of ECP or IME, in terms of sediment caliber and ichnological signature. A mix of non-reservoir and reservoir facies characterize SMBF, with well-burrowed inter-bedded sand, silt, and mudstone (F9), well-burrowed sand with silt and mud-filled burrows (F10), and weak- to moderately-burrowed wavy-bedded fine-grained sands (F11). Compared to middle McMurray associations, SMBF sands exhibit a larger grain-size and muds have a light bluish-grey color. Deposits of SMBF illustrate both fining- and coarsening-upward vertical successions ranging from approximately 7-15 m thick (Fig. II-21; Fig.II-23). Idealized coarsening-upward successions are floored by well bioturbated inter-bedded sand and mudstone (F9) and transition into sand with mudstone-filled burrows (F10) and then wavy bedded moderately burrowed sands (F11).

Unique to SMBF is the homogeneous distribution of a highly bioturbated, high diversity assemblage of large softground marine trace fossils. Structures are dominated by robust and pervasive horizontal deposit-feeding forms (e.g. *Asterosoma, Rosselia, Rhizocorallium*), horizontal grazing structures (e.g. *Phycosiphon*), deep-tiered mining structures (e.g. *Chondrites and Zoophycos*), and a variety of simple deposit-feeding structures (e.g. *Planolites, Teichichnus, Thalassinoides*), indicating a marine dominant source of sedimentation and non-diluted marine waters. This assemblage is characteristic of an overall proximal *Cruziana* ichnofacies and the extensive reworking of larger complex structures by smaller ichnogenera reflect stable, well oxygenated, fully marine conditions with abundant deposited food (Bann *et al.,* 2008). Such intense bioturbation (BI 4-6) also indicates slow, continuous rates of deposition indicating low energy and shelter from storm and fair-weather wave processes.

SMBF illustrates an overall low degree of hydraulic reworking and coupled with an abundance of silt and mud in the system, suggests that the tidal prism was not large during deposition. Variations in the ichnological signature, where bioturbation becomes sporadic in distribution and intensity levels and diversities are reduced (BI 1-3), indicate areas of higher physico-chemical stresses that are likely related to soupground and dysoxic/anoxic bottom water conditions (reflected by phytodetrital fluid muds) in more distal areas of sedimentation. In more proximal areas of sedimentation, decreased intensities are more likely attributed to the higher energy conditions and a greater impact of tidal energy resulting in fluctuating sedimentation rates, water turbidity, and water energy.

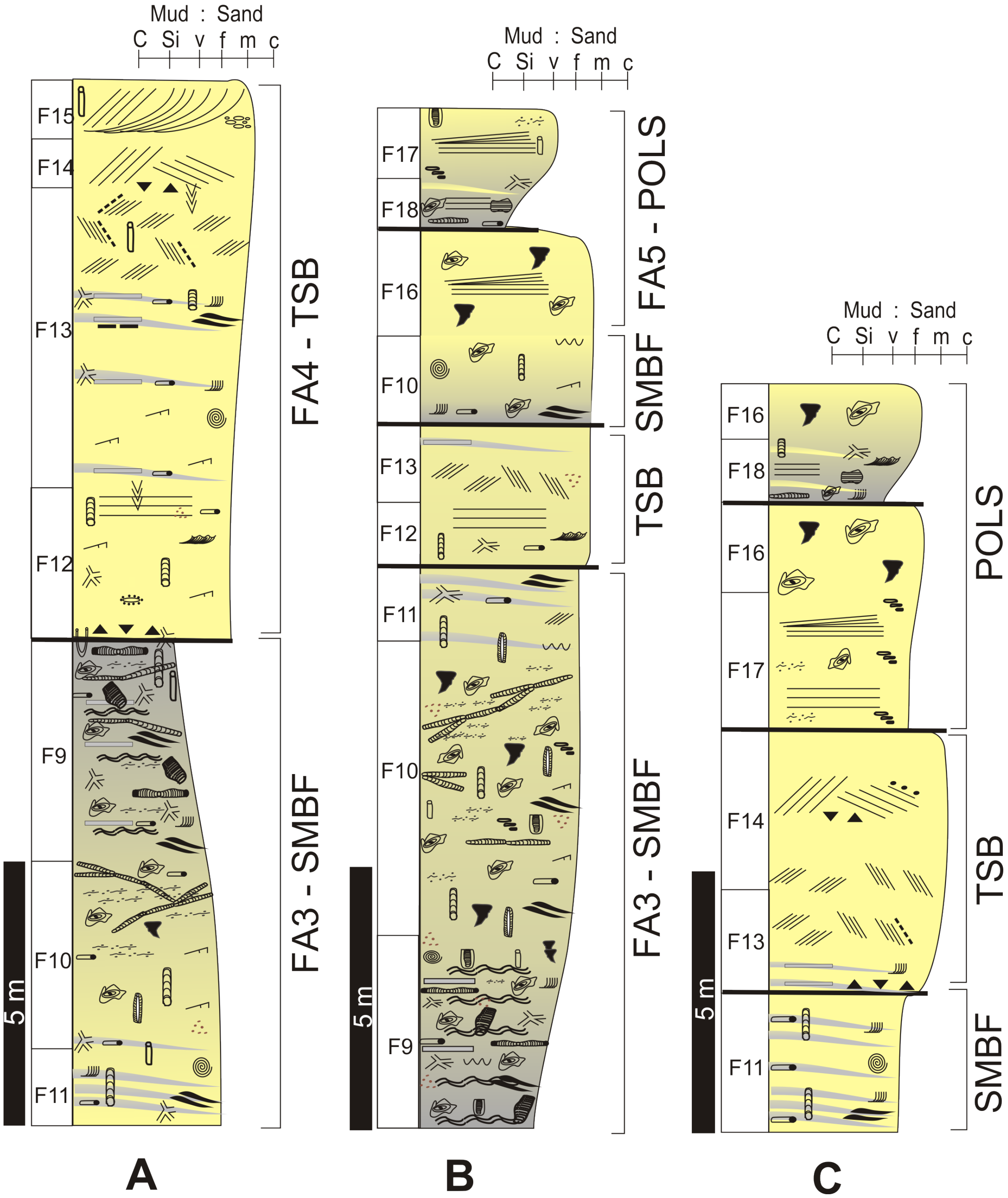

FIGURE II-23: Idealized vertical successions illustrating the sedimentologic and ichnologic characteristics and dominant stacking relationships of facies and facies associations (SMBF-TSB-POLS) in the upper McMurray Formation. Deposits are characterized by stacked coarsening- and sandier-upward successions that reflect the complex amalgamation of tidal bar complexes overlain by lower shoreface to proximal offshore deposits in a shallow marine embayment. Stacking patterns vary due to the complex relationship between lateral and forward accretion (refer to Fig.II-30). Stacked successions increase in frequency but decrease in thickness to the north (basinward). They also illustrate a basinward-fining, increase in relative wave versus tidal sedimentation, and a systematic increase in overall bioturbation intensity and diversity. Successions of SMBF and TSB illustrate a decrease in frequency and thickness to the northwest. Successions of SMBF and POLS increase in frequency and thickness to the northwest. Successions A to C reflect overall proximal to distal relationships.

Tidal influence is interpreted as the dominant energy process based on the dominance of current-generated stratification, wavy- and flaser-bedding, and rhythmic inter-lamination, when primary structures are preserved. Wave action is evident from local oscillation ripples. Infrequent storm events may also be preserved via local, coarser-grained passively sand-filled burrows, associated with opportunistic species. The fully marine ichnological assemblage coupled with evidence of tidal energy and minor wave action, strongly support deposition in a fully marine embayment devoid of fluvial input.

This succession shows a decrease in bioturbation intensity and diversity up-section indicating an increase in physico-chemical stress in the system (when there are environmental stresses related to decreased oxygenation or soupy substrates at the base of the succession). When bioturbation is near absent at the base of these successions, it can show an opposite trend, with increasing intensity and diversity upwards, corresponding to a change in environmental stress related instead to fluctuations in energy conditions. Thus, tidal influence illustrates a corresponding increase upwards where higher energy sedimentation results in the preservation of sedimentary structures. This succession reflects a transition from distal to more proximal bay-fill and/or interbar sedimentation. Coarsening-upward successions may exhibit gradational or sharp contacts with TSB and POLS. The same ichnological and sedimentologic vertical trends are observed in fining-upward successions but in the opposite positions as they represent proximal interbar / bay-fill to more distal sedimentation. Fining-upward successions are also typically in erosive / sharp contact with deposits of TSB or POLS. When deposits of SMBF are gradational with TSB, deposits represent the transition from interbar to bar deposition reflecting the most distal position, or toe-sets, of tidal sand bar sedimentation. When gradational with POLS, deposits represent a slow transition from bay-fill to lower shoreface sedimentation.

Facies Association 4 (TSB):Coarsening-Upward Sand Association-Proximal to Medial Tidal Sand Bars

Facies association 4 (TSB) reflects the main reservoir interval and comprises clean coarsening-upward successions interpreted as proximal to medial tidal sand bars that are laterally accreting to the bay-margin and islands within a shallow marine embayment. Successions of TSB consist of moderately burrowed wavy bedded fine-grained sands (F11), weakly burrowed fine-grained sands (F12), weakly burrowed rippled to small-scale cross-bedded sands (F13), upper-fine to medium-grained large-scale cross-bedded sands (F14), and cryptobioturbated medium-grained sands (F15). Sands of TSB reflect variable positions of proximal to distal positions of tidal sand bar deposits, with F15 reflecting a proximal subtidal channel position, and F11 reflecting most distal subtidal channel deposition, respectively. Tidal sand bars are also likely overprinted by compound sand dunes due to the abundance of migrating mega-ripple and dune bedforms, in a coarsening- and cleaning-upward profile (Mutti *et al.,* 1985; Dalrymple and Choi, 2007). Thus, these deposits likely represent both forward and lateral accretion.

Important characteristics of TSB include the abundance of tidal indicators, evidence of wave-influence, and complete lack of river-induced structures. A tidal setting is interpreted based on the abundance of bi-directional cross-beds with grain-size striping, reactivation surfaces, dominance of current-generated stratification, rhythmites, double mud drapes, material draping cross-strata foresets, rare fluid muds, and flaser- and wavy bedding. A small degree of wave-reworking is evidenced through oscillatory ripple-lamination and combined ripple-flow. The complete lack of river-generated structures suggests limited freshwater input into the system.

The ichnological signature is also quite stressed compared to the ichnological baseline of SMBF, with low bioturbation intensities (BI 0-2) and a regular heterogeneous to sporadic distribution of trace fossils. The assemblage also comprises a mix of vertical and horizontal forms dominated by robust to moderate-sized *Thalassinoides, Planolites, Teichichnus, Skolithos, Ophiomorpha,* and *Fugichnia* burrows. This ichnological assemblage resembles characteristics of a tidally-influenced trace fossil suite of a tidal marine setting where overall diversities are low with more normal sized burrows (Gingras and MacEachern, in press). Stresses imparted on the environment are likely a combination of elements including fluctuations in water turbidity, sedimentation rates, and water energy. Salinity fluctuations are less likely to be a substantial stress as there lacks a fluvial source to the marine bay, but the presence of rare syneresis cracks gives evidence for some influence (i.e. via storm/weather conditions).

Deposits of TSB are dominated by coarsening- and cleaning-upward successions that range from approximately 3 to 20 m thick and reflect amalgamated tidal sand bars. Idealized successions are based by wavy-bedded moderately- to weakly-bioturbated sands (F11-F12) that transition into rippled and parallel-bedded to cross-bedded sands (F13-F14) illustrating a vertical increase in energy (i.e. vertical transition from lower to higher flow regime structures) (Fig.II-21; II-23). The base of these successions reflect toe-set deposits that exhibit higher bioturbation intensities (BI 1-3) and the transition zone to low energy marine interbar / bay-fill sedimentation.

These deposits then show a decrease in bioturbation intensity (BI 0-2) and diversity upwards into medial positioned rippled and parallel-laminated sediments with an ichnological distribution becoming less homogeneous to sparsely heterogeneous. This transition then continues upward where bioturbation becomes absent to extremely sporadic, within large-scale cross-bedded sands (F14). These sands are either gradational or erosive within the succession and reflect deeper migration of large-scale dunes deposited at the base of subtidal channels where hydraulic reworking by tidal processes was strongest. The tops of these successions may also be capped by cryptobioturbated sands that exhibit high energy trough cross-bedding, low angle to planar lamination, and or HCS, reflecting the effects of wave-reworking in a proximal subtidal setting. As these represent the lateral accretion, coupled with forward migration of subtidal channels, partial successions and rarely even fining-upward successions are also observed. This reflects the complexity of tidal sand bar migration and amalgamation. These successions may develop a gradational and continuous succession with deposits of SMBF, but most commonly sharply overlies SMBF. In turn TSB can be sharply overlain by deposits of SMBF, POLS or DOS.

Facies Association 5 (POLS): Well Bioturbated Coarsening-Upward Association-Proximal Offshore to Lower Shoreface

Successions of Facies Association 5 (POLS) range in thickness from less than 2 m to 10 m thick and are in sharp or gradational contact with SMBF, or abruptly overlie those of TSB. When gradational with SMBF, *Rosselia* and *Asterosoma* sands of POLS are occur at the top of the coarsening-upward succession or argillaceous muds occur at the base of the coarsening-upward succession. When abruptly overlying SMBF or TSB, successions coarsen- and clean-upward and exhibit a corresponding increase in relative energy and ichnological diversity upward. In turn, successions of SMBF and TSB can sharply overlie deposits of POLS. Stacked successions of POLS also become more common, and thicker, to the northwest of the study area. This reflects a more basinward direction, where stacked successions of SMBF and POLS are dominant and reach up to 10 m thick. Facies association 5 almost always occurs at the top of the McMurray Formation where deposits of DOS have an erosional contact.

Facies association 5 (POLS) is characterized by well bioturbated coarsening- and sanding-upward successions interpreted as fully marine proximal offshore to proximal lower shoreface deposition. Deposits include a mix of reservoir and non-reservoir facies. Reservoir facies correspond to moderately bioturbated fine-grained sands with silt- and mud-filled burrows (F16). Non-reservoir facies consist of burrowed argillaceous mudstone with silt and sand inter-beds (F18) and well bioturbated to planar laminated sands (F17). More specifically, these deposits reflect dominantly fair-weather sedimentation with remnant tempestites, where the proximal lower shoreface represents more proximal higher energy conditions (F16), and the proximal offshore reflects muddier, more distal lower energy conditions (F18).

Unique to POLS is the finer-grained nature of well-sorted sands compared to those observed in SMBF and TSB. Sands also exhibit a unique ichnological assemblage dominated by *Rosselia* and *Asterosoma*. This bi-specific association is a significant indicator of proximal lower shoreface conditions and high sedimentation rates in western Cretaceous sedimentary strata (Fig.II-24) (Pemberton *et al.,* 2009). The abundance of *Schaubcylindrichnus* further supports this interpretation as it is most common seaward of high-energy shoreface conditions but well landward of quiet, low-energy offshore conditions (Pemberton et al., 2009). The overall ichnological signature reflects an archetypal *Cruziana* ichnofacies with homogeneous bioturbation distributions and high bioturbation intensities (4-6) of a high diversity assemblage dominated by horizontal deposit-feeding behaviors. This is characteristic of lower shoreface to offshore conditions reflecting continuous fair-weather deposition and a stable marine environment for benthic communities to flourish.

Most significant to POLS is the marked change in dominant energy processes. The grain-size and sorting of sands reflects the higher degree of winnowing and wave-reworking. POLS also contains evidence of storm- and fair-weather waves, indicated by low-angle planar to horizontal cross-stratification, HCS, trough cross-beds, oscillation- to combined- flow ripples, and 'lam-scram' bedding. HCS sand beds are typically thin, sharp-based, and non-burrowed to containing sporadic *Skolithos* and fugichnia*,* and gradationally burrowed tops. These are interpreted as the main storm body of the event. Intercalated burrowed intervals are inferred as post-storm, fair-weather sedimentation during suspension fallout, developing lam-scram bedding. The preservation of these beds is also

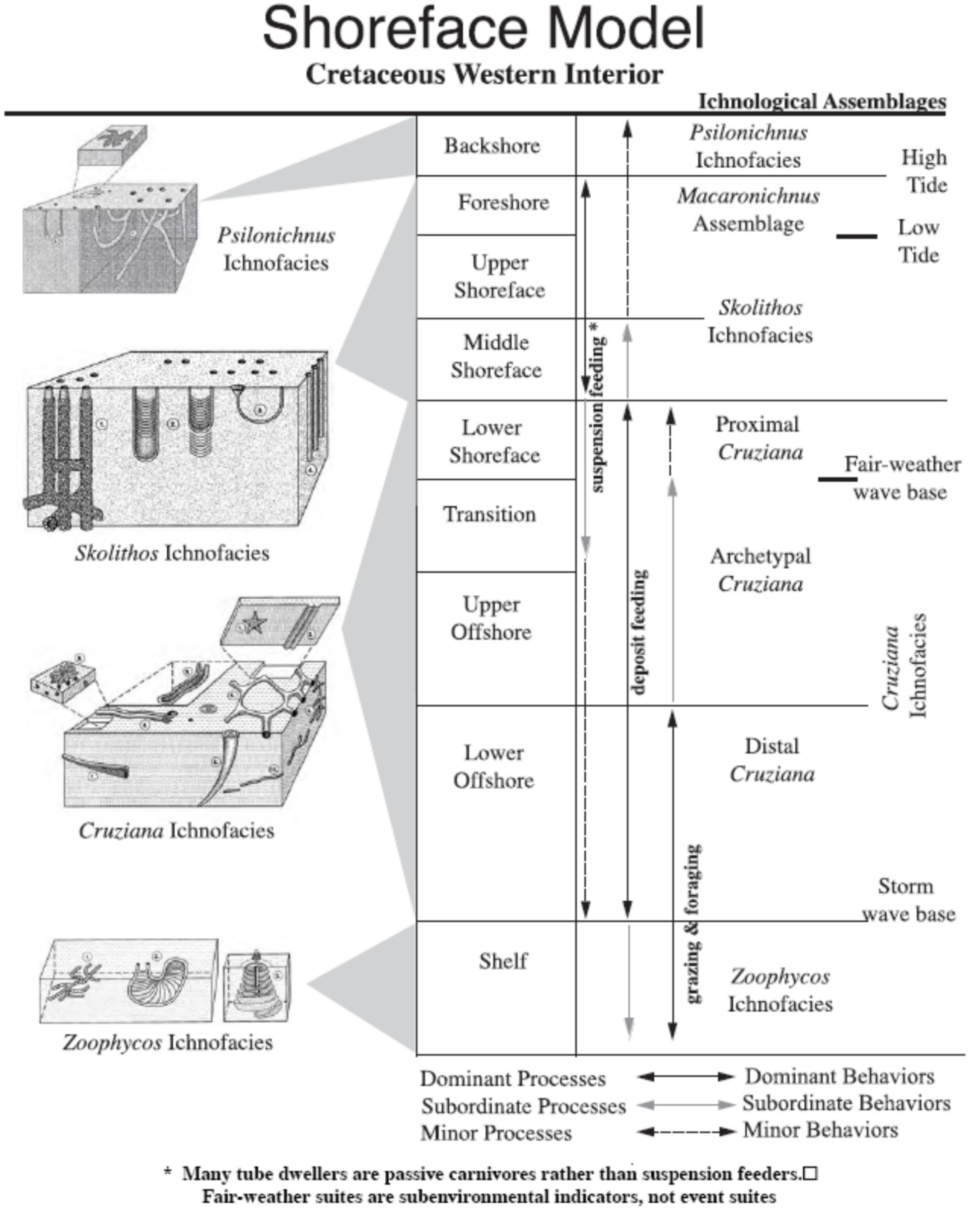

FIGURE II-24: Ichnological distribution within a shoreface for strata of the Cretaceous Western Interior. This model was utilized to compare the ichnological signature of lower shoreface and offshore facies associations of the McMurray-Wabiskaw succession (from Pemberton and MacEachern, 2006).

most abundant in deposits reflecting lower shoreface conditions and become thinner in more muddy wavy-bedded distal facies. These features coupled with proximal-distal trends are all characteristic traits of tempestite deposits (Pemberton and MacEachern, 2006). Further evidence of storm-influence is reflected through coarse-grained sand-filled burrows within a very fine-grained sand matrix and is interpreted to represent tubular tempestites. Burrow fills also illustrate tidal influence where large *Thalassinoides* or *Psilonichnus* contain preserved passively sand-filled rhythmic laminae. These are interpreted as tubular tidalites which indicate evidence of tidal currents (Gingras and MacEachern, in press).

Wabiskaw FA Descriptions

Facies Association 6 (DOS): Muddy Sand to Sandy Mud Association-Distal Offshore to Shelf

Facies association 6 (DOS) represent non-reservoir facies of the Wabiskaw Member and is interpreted as distal offshore to shelf sedimentation. Deposits are characterized by fining-upward successions of burrowed planar-parallel glauconitic sand to sandy mud (F19) and bluish silty mud to moderate grey mudstone with sand inter-beds (F20). More specifically, these deposits are interpreted as the progressive deepening of remnant distal tempestite to fair-weather deposition above storm wave base and shelfal mud deposits below storm wave base (i.e. offshore to shelf transition). This is strongly reflected by the ichnological signature where bioturbation intensities, diversities, and trace fossil size progressively decrease upwards. A transition from distal *Cruziana* to *Zoophycos* ichnofacies is also observed upwards, interpreted based on the dominance of deposit-feeding and deep-tiered mining structures that transition to a dominance of grazing behaviors (Fig.II-24). Remnant storm activity is preserved by thin, non-burrowed low-angle planar to horizontal laminated sands and HCS (Fig.II-25). The dominance of wave-influence is also evident based on the abundance of oscillation ripple-stratification. Lenticular- and wavy-beds are less commonly observed. Distinguishing features of DOS is the high density of *Chondrites* burrows as well as the bluish steel-grey colour of the muds. Facies Association 6 is regionally extensive across the study area and exhibits a relatively consistent thickness ranging from 2-5 m thick (Fig.II-21; II-26). The base of these successions is dominated by glauconite, indicating very slow marine sedimentation. Alternatively, successions are based by HCS sands that exhibit glauconitic concentrated as cross-laminae (Fig.II-25; II-21; II-26). This reflects the storm event and the erosion of underlying- fair-weather glauconitic sands. Lower contacts exhibit an erosive and regional bounding discontinuity that illustrate robust *Diplocraterion* burrows subtending into underlying deposits of POLS, TSB, or IME. Overlying contacts are sharp to gradational with LSF. Both underlying and overlying contacts may illustrate a *Glossifungites* ichnofacies.

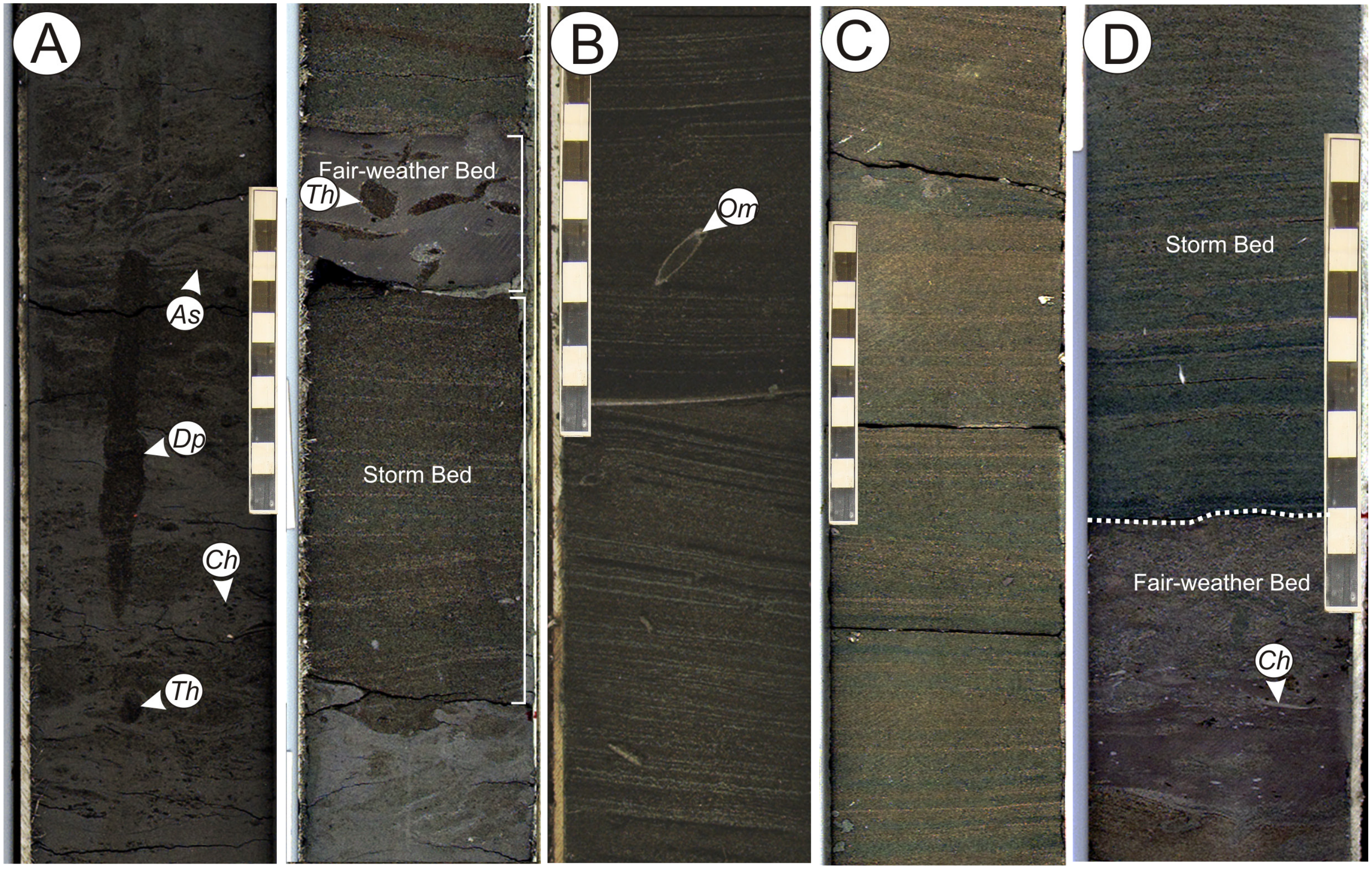

FIGURE II-25: Storm deposits (F19B) of the Wabiskaw Member.
(A) *Glossifungites* surface within Wabiskaw deposits. The fair-weather succession is dominated by a diverse trace fossil suite. Identified ichnogenera include *Chondrites (Ch), Thalassinoides (Th), Diplocraterion (Dp)*, and *Asterosoma (As)*. Well 10-3-92-15W4, depth 160.5 m. (B) Example of low angle planar- to horizontal-parallel laminated glauconitic sands interpreted as HCS. Note the lack of burrowing in sands, representing HCS of the storm event. Burrowing is

FIGURE II-25 CONTINUED: extremely rare with sporadically distributed *Ophiomorpha (Om).* Well 6-5-92-15W4, depth 177.2 m. (C) Low angle-planar to horizontal-parallel laminated glauconitic sands. Undulatory lamination towards the top of the photo, coupled with the absence of ripple-lamination supports the interpretation of HCS. Well 6-10-92-15W4, depth 155 m. (D) Note the erosive contact of F19B over the *Chondrites*-dominated, sideritized sandy mud of F19A. This is interpreted as truncation of fair-weather deposition by the main HCS storm body. Well 16-4-92-15W4, depth 158.8 m. All scales are in cms.

Facies Association 7 (LSF): Burrowed Sand Association-Lower Shoreface

Facies Association 7 exhibits one or two regionally extensive lobate sand bodies that ranges in thickness from less than 1 m to 10 m thick across the study area (Fig.II-21; II-26). LSF regionally overlies and inter-fingers with deposits of DOS, and is overlain by silts and muds of the Clearwater Formation.

Facies Association 7 (LSF) comprises bitumen-saturated sands of the Wabiskaw Member that are interpreted as lower shoreface deposition. These deposits consist of gradational to sharp-based, cleaning-and coarsening-upward, moderately-burrowed, fine-grained to medium-grained sands (F21). Deposits are dominated by wave-generated structures and exhibit trough cross-beds, oscillatory ripples, and HCS that represent the dominance of fair-weather and storm wave activity. Sands exhibit moderate to high bioturbation intensities (BI 3-6) and exhibit homogeneously distributed trace fossils dominated by thick *Asterosoma* mud-filled burrows. Gradationally-based successions may contain thin muddy intervals dominated by *Chondrites, Teichichnus,* and the opportunistic species *Diplocraterion* and *Skolithos,* reflecting a *Glossifungites* ichnofacies. The overall ichnological signature reflects a moderate diversity assemblage of robust marine ichnoforms, interpreted to reflect a *Cruziana* ichnofacies.

Middle McMurray, Upper McMurray, and Wabiskaw Member Stratigraphic Boundaries

Major regional bounding discontinuities reflect the contacts between major divisions of the McMurray-Wabiskaw succession and were identified based on sedimentological and ichnological relationships (Table II-2). Lower ECP-IME of the middle McMurray Formation, represent the lower associations in the stratal package. Upper SMBF-POLS, represent the upper McMurray Formation and are stratigraphically higher in the succession. DOS-LSF of the Wabiskaw Member represents deposits at the top of the stratigraphic interval.

Between the lower (ECP-IME) and upper (SMBF-POLS) subdivisions, a

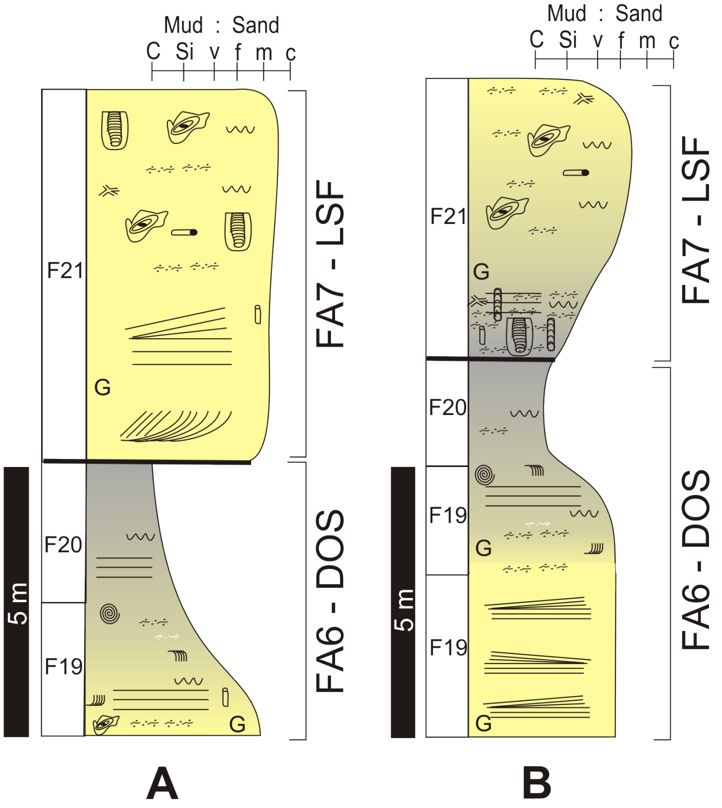

FIGURE II-26: Idealized vertical successions for deposits of the Wabiskaw Member of the Clearwater Formation (DOS-LSF). Example A illustrates the typical fining- and muddying-upward FA6 succession corresponding to progressive marine deepening of the offshore to shelf transition. This is reflected by a decrease in glauconitic sand, burrow diversity and size upwards, and bioturbation intensity. Trace fossil assemblages also illustrate a gradational change from a distal *Cruziana* to *Zoophycos* ichnofacies. A sharp-based coarsening-upward shoreface is also typical of the overlying Wabiskaw sand and can range in thickness from 0-10 m. Example B illustrates the alternative succession which is based by erosive HCS and planar-parallel laminated sands interpreted as storm deposits. The Wabiskaw shoreface sand may also illustrate a gradational coarsening-upward succession with higher proportions of mud at the base. Wabiskaw sands are dominated by an *Asterosoma-Rosselia* trace fossil assemblage characteristic of lower shoreface conditions.

widespread erosive contact is evident and in many occurrences, is marked by a *Glossifungites* firmground (Fig.II-27). This is a structurally-controlled ichnofacies that represents erosionally exhumed substrates (Ekdale *et al.,* 1984; Pemberton *et al.,* 1992). This surface is characterized by passively-filled *Diplocraterion, Arenicolites,* and / or *Teichichnus* burrows, that cross-cut the non-bioturbated to brackish-water trace fossil assemblage of the lower FA subdivision. Burrows are typically filled with fine- to coarse-grained sands from overlying FA, which comprises any of the upper subdivision FA (SMBF-POLS). Thus, the overlying assemblage may represent anything from a stressed tidally-influenced marine assemblage to an archetypal *Cruziana* facies. When not marked by a

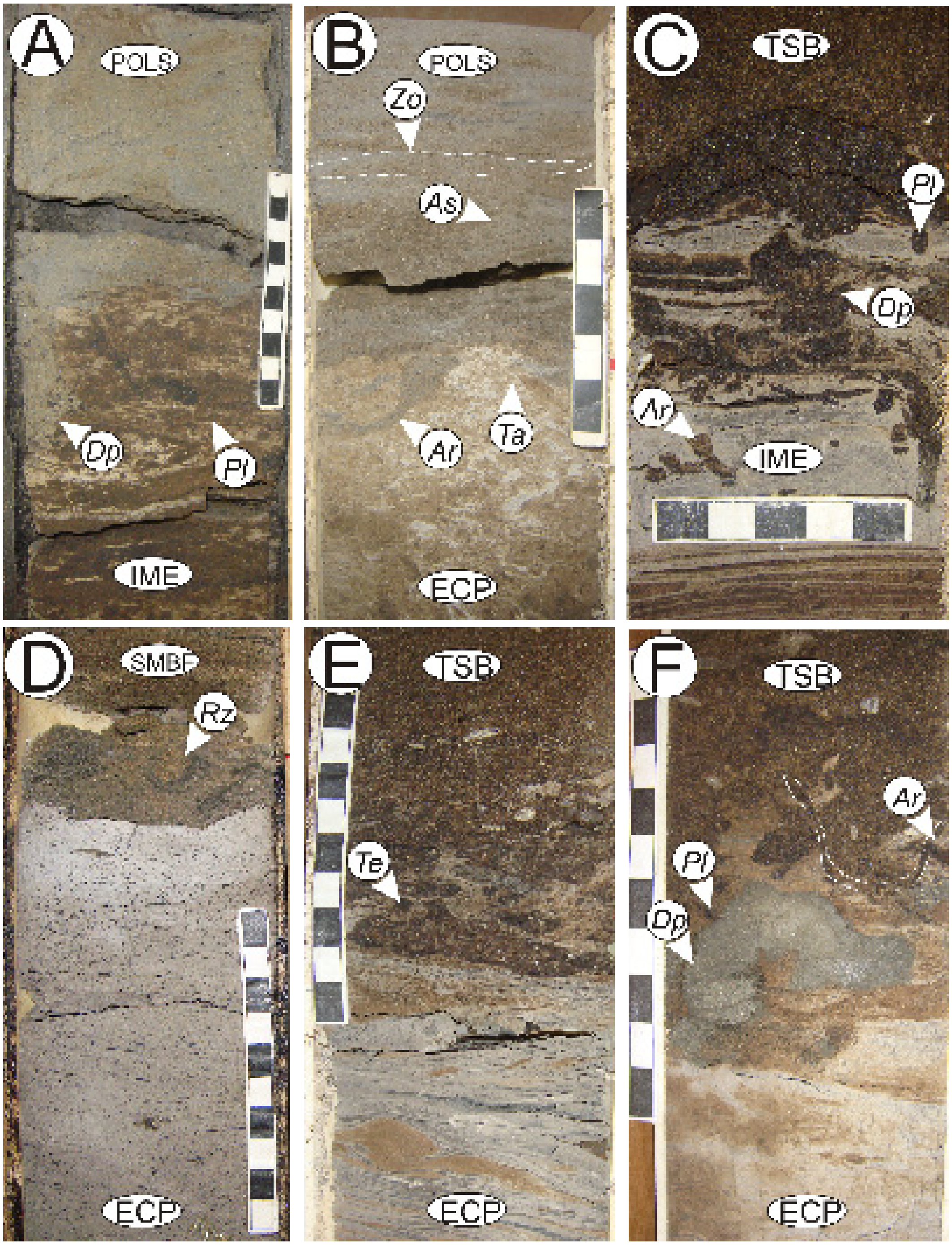

FIGURE II-27: Core examples illustrating the erosional contact between deposits of the middle and upper McMurray Formation.

This surface often illustrates a *Glossifungites* firmground. (A) Note the sharp contrast between overlying sediments and a passively in-filled *Diplocraterion (Dp)* burrow from POLS cross-cutting the brackish trace assemblage of MOE. Well 10-26-89-14W4, depth 178 m. (B) The underlying continental trace fossil assemblage of ECP consists of intense burrow mottling by arthropods. Individual ichnogenera include *Taenidium (Ta)*. ECP is sharply overlain by an assemblage dominated by elements of the *Cruziana* ichnofacies including *Zoophycos (Zo), Asterosoma (As),* and *Chondrites (Ch)*. The *Glossifungites* firmground consists of passively-filled *Arenicolites (Ar)* burrows. Well 7-29-89-14W4, depth 183.2 m. (C) *Diplocraterion* and

Arenicolites burrows are passively filled with upper fine-grained sand from overlying TSB. **FIGURE II-27 CONTINUED:** This contrasts with the the very fine- to fine-grained sand characteristic of F7 in MOE. Well 10-22-90- 14W4, depth 191.4 m. (D) Medial/distal, fully marine trace assemblage of SMBF directly overlies an erosive contact with terrestrial muds of ECP. Under-lying muds are non-burrowed and represent the development of a paleosol, creating an inhospitable environment for ichnofauna. Well 11-6-90-13W4, depth 217.8 m. (E) A thin erosional lag with quartz pebbles and rip-up clasts characterizes the base of TSB which is in sharp contact with underlying silty muds of ECP. Note the preservation of diminutive *Teichichnus (Te)* and *Planolites (Pl)* burrows above this contact. Well 14-14-90-14W4, depth 193.4 m. (F) Pervasive siderite and pyrite replacement of burrows is common at this surface. Note the erosive nature of this contact illustrated by rip-up clasts and a pebble lag. Well 4-13-90-14W4, depth 197 m. All scales in cms.

Glossifungites suite, this surface is marked by a sharp, erosive contact with rip-up clasts and/or a thin pebble lag, and overlying deposits can comprise both tidal- or wave-generated sedimentary structures. This, coupled with the position of marine facies overlying marginal-marine facies allows for an interpretation for a transgressive surface of erosion developed via both tidal and wave ravinement.

A second widespread *Glossifungites* firmground occurs between the upper (SMBF-POLS) subdivision and the Wabiskaw (DOS-LSF) subdivision (Fig. II-28). This surface is characterized by robust *Diplocraterion* and *Arenicolites* burrows that are passively filled with glauconitic sands from the overlying FA (DOS). This trace suite may penetrate up to 2 m into the underlying upper subdivision (SMBF-POLS). When this surface lacks bioturbation, an erosionally truncated surface is present. This surface is overlain by sharp-based, non-burrowed, HCS storm-bed deposits (Fig.II-25). In rare occurrences, the upper McMurray subdivision was completely exhumed. From the regional flat nature of the surface and position of distal marine facies above more proximal marine facies, a transgressive surface of erosion is interpreted to have developed through wave ravinement. The stratigraphic significance of these bounding discontinuities is further discussed in Chapter 3.

DISCUSSION

Deposits of the McMurray-Wabiskaw succession in the MacKay River area are interpreted as marginal marine tide-dominated, to shallow marine mixed wave- and tide-influenced sedimentation. In contrast to wave-dominated settings, the proximal-distal changes in processes and facies occurring in tide-dominated to mixed energy (i.e. tide-wave) settings are poorly understood (Dalrymple and Choi, 2007). In particular, tide-dominated and tide-influenced settings are extremely difficult to interpret with confidence in the ancient record, as tidally-

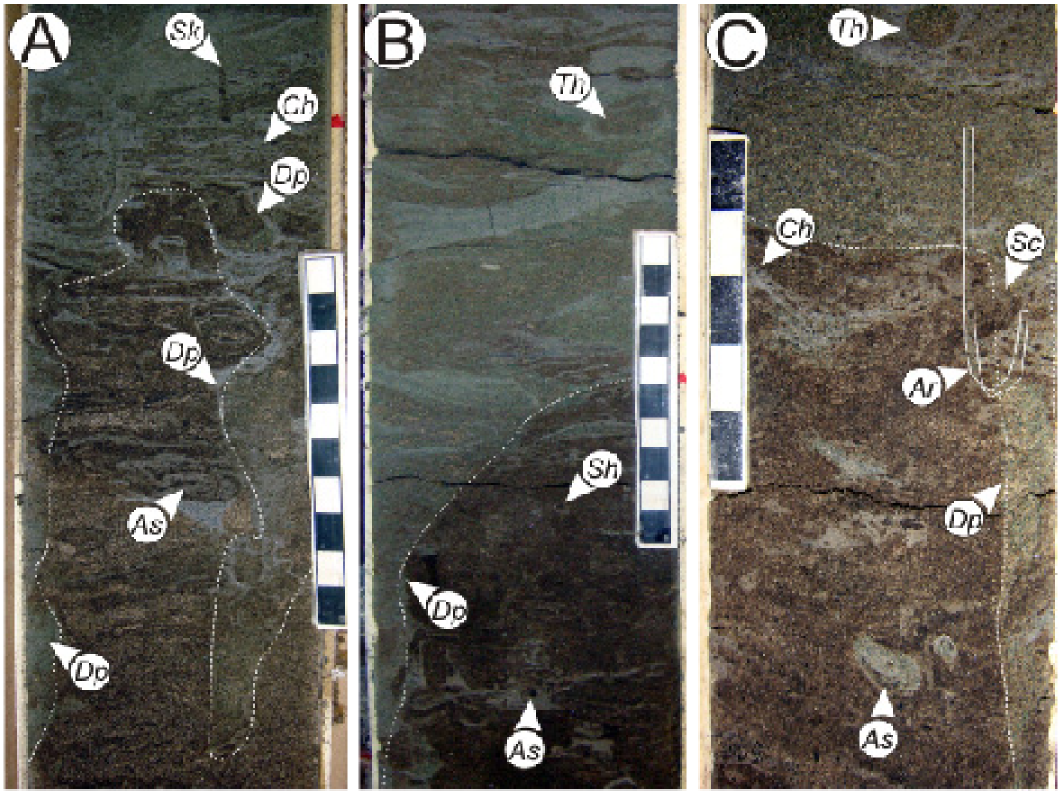

FIGURE II-28: Core examples illustrating a *Glossifungites* firm-ground between the upper McMurray and overlying Wabiskaw Member.
This contact is characterized by robust *Diplocraterion (Dp)* and *Arenicolites (Ar)* burrows that subtend into the underlying facies of the upper McMurray (SMBF-POLS) and are passively-filled with glauconitic sands from DOS. Burrows can subtend up to 2 m into the underlying sediment. (A) The underlying trace fossil assemblage of FA5 illustrates *Asterosoma (As)* and *Chondrites (Ch)* that are cross-cut by numerous *Diplocraterion*. The overlying assemblage of DOS illustrates an abundance of *Asterosoma* that have been re-burrowed by deeper tier traces including *Chondrites* and *Skolithos (Sk).* Well 10-30-88-13W4, depth 170.5 m. (B) Robust *Diplocraterion* subtending into the underlying POLS association consisting of *Asterosoma, Chondrites,* and *Schaubcylindrichnus (Sh). Thalassinoides (Th), Asterosoma*, and *Chondrites* are observed in the overlying DOS assemblage. Well 12-27-90-14W4, depth 171.2 m. (C) *Diplocraterion* and *Arenicolites* burrows cross-cut *Asterosoma* and *Chondrites* of POLS. Note the passive glauconitic fill. Well 7-29-89-14W4, depth 176.5 m. All scales are in cms.

derived facies can represent the preferred preservation of a variety of sub-environments within an overall system dominated by wave or river processes. Thus, the dominance of tidal sedimentation and lack of river- and wave-influence is not enough to classify a system as tide-dominated. Alternatively, identifying a marginal-marine versus a shallow fully-marine system, coupled with determining the type of shallow-marine system is more of a challenge, as the majority of facies may occur in more than one depositional system. Depositional models for marginal- to shallow marine, tide-dominated to tide-influenced, systems have been broadly categorized as representing five main settings: tidal flats, estuaries, deltas, lagoons and continental shelves. This is often limiting, making it difficult to think outside the box, or not to force-fit tidally-influenced interpretations to these models. Moreover, these systems are the least understood in the geological record and thus there is a limited amount of data and analogues to compare and contrast.

The distinction between estuary and embayment is not typically identified in literature. The majority of coastal depressions in the modern are simply referred to as bays or embayments, without being classified as either estuary or embayment. Often, many tide-dominated or open-mouth bays are classified as both, where researchers use the terms estuary and embayment interchangeably. This difficulty is reflected by the fact that these environments are commonly gradational, and contain both estuary and marine embayment parts with varying proportions. However, most sequence stratigraphers define an estuary as incised valleys undergoing transgression and filled with sediments deposited under the mix of marine and fluvial processes (e.g., Dalrymple, 1992; Dalrymple *et al.,* 1992; Dalrymple, 2006). An embayment however, should be identified as a separate entity. It is best defined as a coastal shallow marine setting with no fluvial-input and a completely marine source of sedimentation (Ke *et al.,* 1996). This definition of embayment is also very similar to environments referred to as salt marsh estuaries in literature. Salt marsh estuaries are large, backbarrier bodies of water, with a lack of a noteworthy freshwater connection and a dominance of tidal waters (cf. Redfield, 1967; Howard and Frey, 1985). A delta differs from an embayment or salt marsh estuary, as it is applied to depositional systems that prograde at the mouth of a river, formed by sediment supplied by the river, and containing fluvially-influenced deposits (Dalrymple *et al.,* 1992; Dalrymple, 1999; Dalrymple *et al.,* 2003).

Tide-dominated estuarine deposits are relatively well studied as they are dominant in modern coastal settings and thus, provide good analogues for recognizing ancient deposits. On the contrary, there are very few well documented modern (Dalrymple *et al*., 2003) or ancient (Mutti *et al.,* 1985; Martinius *et al.,* 2001) tide-dominated or mixed wave and tide-influenced deltaic systems, and thus, are relatively unstudied from both a sedimentological and ichnological perspective. Moreover, there is an extremely limited record of ancient embayment or salt marsh estuary systems (Yoshida *et al*., 2004), and very few documented modern systems (Howard and Frey, 1985; Ke *et al.,* 1996). As there is a lack of overall analogues for such shallow marine systems, their recognition and differentiation in the ancient record is complicated, and must be interpreted based on comparing and contrasting elements from all models (Fig. II-29; Fig. II-30) (Dalrymple *et al.,* 1992; Zaitlin *et al*., 1994; Mutti *et al.,* 1985; Martinius *et al.,* 2001; Dalrymple *et al*., 2003).

In the MacKay area, the McMurray-Wabiskaw succession reflects a period of complex marginal-marine to fully marine deposition, dominated by coarsening-upward sand successions. The integration of ichnological and sedimentological characteristics of facies associations and their corresponding stacking patterns were utilized to develop a greater understanding of the physical and chemical environmental parameters influencing deposition, which led to a refined paleoenvironmental interpretation. The McMurray Formation is interpreted to reflect a shift in depositional system, with two stacked, unique settings that are separated by a regionally widespread bounding discontinuity (Fig. II-27). The middle McMurray is interpreted as a tide-dominated estuarine setting. The upper McMurray is interpreted as a mixed energy shallow marine embayment system, infrequently affected by storms. Tidal sand bars of the upper McMurray show similarities to deposits of estuarine mouth bars or deltaic distributary mouth bars. The apparent progradational nature of these sand bodies in the upper McMurray argues towards deltaic deposition. However, the transgressive nature of these deposits, coupled with the relationship of tidal sand bar complexes erosionally overlying middle McMurray estuarine facies is more characteristic of an estuarine setting. The combination of these elements coupled with the lack of a fluvial source, distribution of facies associations, stacking patterns, and widespread ravinement surface favor an alternative setting; a shallow marine embayment.

Depositional Setting

Middle McMurray Formation

The environment of middle McMurray deposition in the MacKay River area is interpreted as marginal-marine tide-dominated estuaries, constrained within valleys undergoing transgression (Fig.II-29). An estuary is characteristically funnel-shaped, illustrating a "straight-meandering-straight geometry" where deposits comprise laterally accreting elongate tidal bars in the seaward portion with tidal flat and salt marsh deposits along the margins (Dalrymple *et al.,* 1992). It is also broadly divided into four distinct facies zones: fluvial-tidal transition, middle estuary, outer estuary, and tide-dominated shelf (Dalrymple and Choi, 2007) (Fig.II-29).

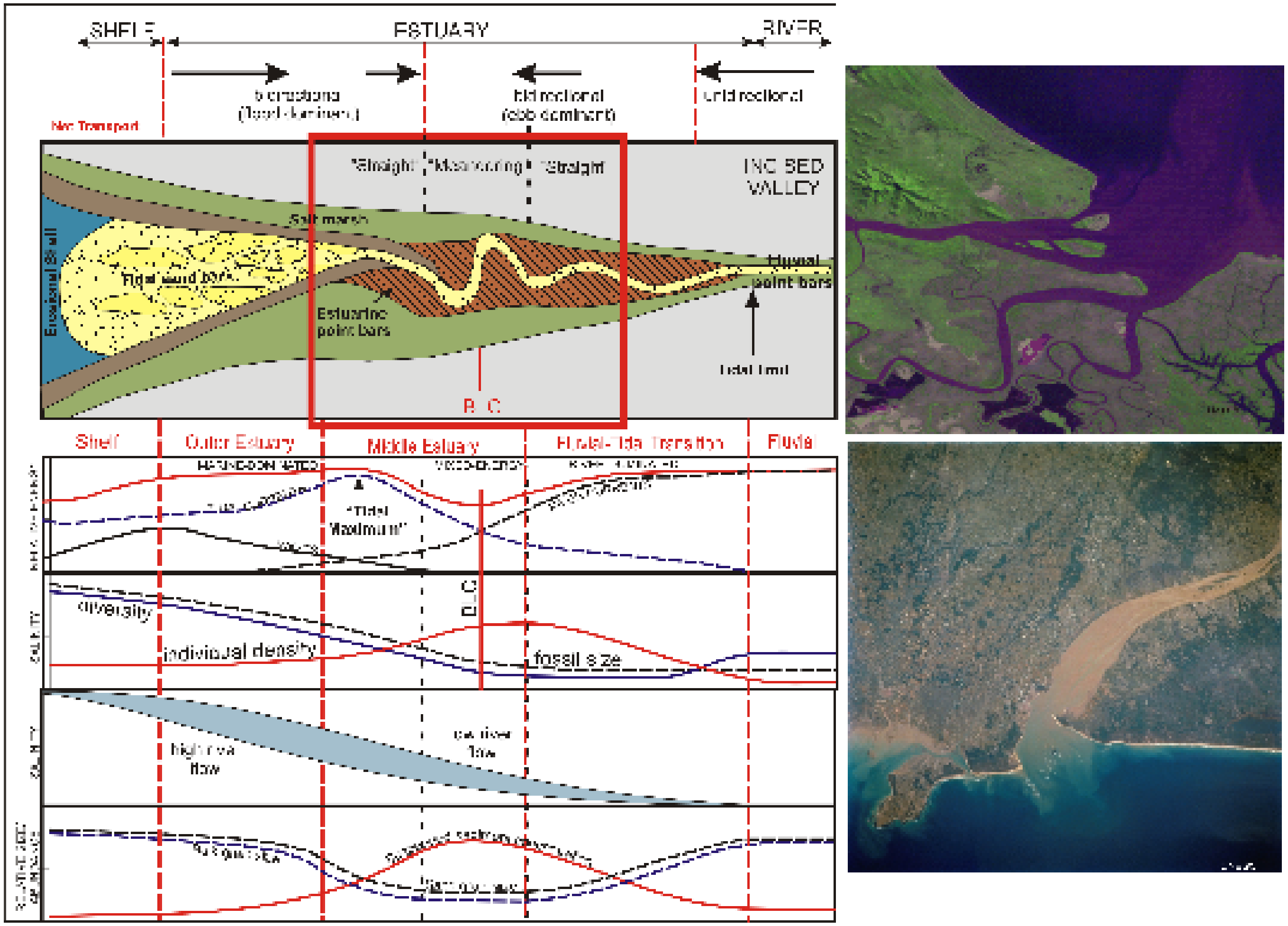

FIGURE II-29: Depositional model and modern analogues for a tide-dominated incised valley estuary. This figure illustrates the longitudinal relationship of net sediment transport, relative energy, bioturbation, salinity, and bulk grain-size through the zones that characterize a tide-dominated estuary. The middle

FIGURE II-29 CONTINUED: McMurray reflects deposition in the inner to middle estuary where sedimentation is bi-directional and dominated by tidal processes. This setting is also characterized by high SSCs and is dominated by the finest material in the system (modified from Dalrymple *et al.*, 1992; Dalrymple and Choi, 2007). Modern analogues for this setting include the Fitzroy Estuary, Australia (top) and Gironde Estuary, France (bottom) (Photos courtesy of NASA).

Preserved deposits in the MacKay River area reflect sedimentation in a channelized middle to outer estuarine setting, corresponding to subtidal channels and associated intertidal flat (IME) and supratidal estuary coastal plain sub-environments (ECP). The middle estuarine setting reflects deposition from bedload convergence at the tidal limit (fluvial/tidal transition) to the estuary mouth and is characterized by strong tidal currents, with sediment transported in a net landward direction (Dalrymple and Choi, 2007). In this setting, bulk grain size decreases in a seaward direction and there is a lack of fluvial evidence in sedimentary structures due to the dominance of tidal processes (Dalrymple and Choi, 2007). The middle estuary is also often dominated by high suspended sediment concentrations due to mixing of fresh- and seawater and development of a salt wedge and density-driven circulation resulting in the “tidal maximum” (Dalrymple *et al.,* 2003). This results in a dominance of IHS within lateral-accretion bedding reflecting the migration of tidal point bars. Fluid muds may also develop in this high SSC setting, typically at channel bottoms (Dalrymple *et al.,* 2003). Waters are characteristically brackish in the middle estuary, resulting in a stressed physico-chemical environment for benthic organisms and a resulting impoverished marine trace fossil suite of small, simple, dominantly vertical structures that may occur in high density bi-specific or mono-specific suites (Gingras *et al.,* 1999; Pemberton *et al.,* 2001; Gingras *et al.,* 2002; Pearson and Gingras, 2006). Overall, bioturbation reflects sporadic to regular heterogeneous distributions (Dalrymple and Choi, 2007; Gingras and MacEachern, in press).

The outer estuary is dominated by elongate tidal sand bars which are constantly reworked by strong waves and tides. These deposits are also clean, coarse, and contain very few mud drapes as sediment is predominantly marine sourced and SSC are relatively low. Salinities are approaching more normal marine in this setting however stresses related to energy, and constantly moving sediment inhibit benthic colonization (Dalrymple and Choi, 2007). Deposits of the middle McMurray do not comprise any of these characteristics and are therefore interpreted as a inner to middle estuary setting.

Modern analogues that reflect a similar geomorphology and setting include the Gironde Estuary of France, or the Fitzroy Estuary of Australia (Fig.

II-29). Both of these examples exhibit mesotidal estuaries dominated by brackish-water conditions and tidal current energy. Note the funnel-shaped geometry and the seaward widening and straightening of channels.

Successions of the middle McMurray are characteristic of a mesotidal channelized tidal estuarine setting. A generalized succession for the sedimentological and ichnological characteristics observed in middle McMurray deposits is presented in figure II-22. Deposits are characterized by a classical landward fining-upward succession based by subtidal channels / bars, which grade into intertidal flats, and are capped by supratidal deposits, which exhibit an increase in ichnological intensity upwards. This tidal channel to flat succession and ichnological signature has been repeatedly identified in the modern setting (i.e. Willapa bay and Shepody River; Gingras *et al.,* 1999; Pearson and Gingras, 2006), ancient record (Weimer *et al*., 1982; Dalrymple, 1992; Gingras and MacEachern, in press) and is also consistently identified in middle McMurray deposits of the main valley trend (Mossop and Flach, 1985; Ranger and Pemberton, 1992; Ranger and Gingras, 2003; Lettley, 2004). Subtidal channel successions of F6 and F7 are common in the main valley, where thick cross-bedded medium-grained sands and breccias are overlain by flat-lying to inclined current-rippled sands with monospecific *Cylindrichnus-Gyrolithes* burrowed sand / mud couplets. These deposits also inter-digitate with flat-lying to inclined, inter-bedded to inter-laminated sands and muds that exhibit an abundance of tidally derived structures. These successions are largely consistent with the thick bedded sand facies and epsilon cross strata of Mossop and Flach (1983), that are widely regarded as tidal channels and IHS of laterally accreting point bars (Mossop and Flach, 1983; Ranger and Pemberton, 1992; Ranger, 1994; Ranger and Gingras, 2003; Lettley, 2004). Furthermore, these deposits illustrate similar brackish-water ichnofacies, consisting of *Planolites, Arenicolites*, *Teichichnus*, *Cylindrichnus, Skolithos* and *Gyrolithes* structures, dominated by bi-specific and monospecific suites (Mattison, 1999; Gingras *et al.,* 1999; Pemberton *et al.,* 2001; Buatois *et al*., 2002; Lettley, 2004; MacEachern *et al.,* 2005; Pearson and Gingras, 2006). These similarities, coupled with the close association of supratidal deposits (ECP), have led to the overall interpretation as deposition in a channelized estuarine environment.

Although middle McMurray deposits in the MacKay River area are similar to those in the main valley, important differences are also observed. This primarily concerns the lack of thick channel sand bar deposits that comprise the main reservoirs of the main valley. Instead, the middle McMurray is dominated by muddier, non-reservoir deposits of mud-dominated IHS (F7), and tidal flats (F8). Tidal flat deposits of the MacKay River area also exhibit a higher degree of wave action evidenced through oscillatory ripple-flow. This suggests that there was more exposure to wave energy compared to tidal flats deposited in completely protected areas (Thompson, 1968; Larsonneur, 1975; Dalrymple, 1992). There is also a complete lack of fluvial facies in the MacKay River area, indicating that deposition occurred further from the fluvial/tidal transition. Middle McMurray deposits are also variably preserved in the study area and comprise a relatively thin basal portion of the succession, with thickest deposits reaching only up to 25 m. For these reasons, smaller, secondary, estuary tributaries compared to the main valley fluvio-estuarine system are interpreted, reflecting an overall middle estuary position where salt marsh areas and tidal flats would have been more abundant, and there was more mud in the tidal channel system.

Evidence for Tide-Dominated Estuarine Deposition

Several lines of evidence suggest that strong tide-dominated estuarine deposition is reflected by lower facies associations of the middle McMurray Formation. Firstly, these deposits illustrate an overall back-stepping pattern typical of a transgressive system, which is essential in the definition of an estuarine coastline. Estuaries are further subdivided based on of relative dominance of marine processes on sedimentation, into wave-dominated or tide-dominated end-members (Dalrymple *et al.,* 1992). Each system comprises a contrasting tripartite zonation of facies associations and ichnological suites. Facies in the MacKay River area are consistent with a tide-dominated setting. All tidal environments are characterized by channelization with a preponderance of laterally accreting channel margins and vertically accreting ‘overbank’ (i.e. tidal flat and coastal plain) areas (Dalrymple and Choi, 2007) (Fig.II-29). As the middle McMurray facies exhibit the classical fining-upward succession, an estuarine interpretation is favored. The stacking, sedimentological and ichnological relationships between middle and overlying upper McMurray deposits also favors an estuary over a delta plain environment. A tidal environment is further supported by the overwhelming lack of river- and wave-generated sedimentary structures and corresponding preponderance of tidally-generated sedimentation. Oppositely dipping ripple- and dune cross-stratification are common in these facies associations, and reflect flood and ebb tidal flows. The abundance of mud drapes and “coffee grounds” mantling stratification foresets also reflects current velocity fluctuations and mud fallout during slack water.

Heterolithic deposits of IHS represent processes in the mixing zone and have been interpreted in many deposits as lateral accretion bedding of tidal point bars (Thomas *et al.,* 1987; Dalrymple *et al*., 1992; Fenies and Tastet, 1998; Gingras *et al.,* 1999; Choi *et al*., 2004; Gingras *et al.,* 2002; Dalrymple *et al.,* 2003; Lettley, 2004; Pearson and Gingras, 2006). Additional tide-generated structures include flasers, double mud drapes, and wavy- and lenticular-bedding, which indicate alternations between traction sedimentation and suspension fallout. The presence of fluid muds are also common in tidally-influenced systems, and represent deposition beneath the turbidity maximum where SSC were high (Dalrymple and Choi, 2007; Ichaso and Dalrymple, 2009). Furthermore, sporadic and localized brecciated zones of rip-up mud clasts within cross-stratified sands represent overbank erosion and are typical in tide-influenced settings, particularly in the middle estuary where suspended sediment concentrations are highest (Dalrymple and Choi, 2007). Only minor indications of river- and wave-influence are present in the lower facies associations. Syneresis cracks indicate the influence of river processes as they represent fluctuations in fluid salt concentrations and mixing between fresh and saltwater (Foster *et al*., 1955). Wave processes are illustrated through the occurrence of wave- and combined-flow ripples. Gastropods and bivalves were also observed in salt marsh deposits (ECP) in the MacKay area, and represent the most common body fossils in a stressed, brackish-influenced, fluvial-marine transition of an estuary (Dalrymple and Choi, 2007). The ichnological trace assemblage also illustrates sound evidence of stressed conditions, typical of a brackish-water setting. This is supported by the presence of a low diversity mix of vertical and horizontal structures of an impoverished, marine trace fossil assemblage dominated by infaunal, opportunistic species in bi-specific and mono-specific suites. Overall, distribution of ichnofossils appears to be largely controlled by the salinity gradient and SSC, with other parameters such as sedimentation rate, substrate, and energy, acting at a more local scale. Coupled with the great similarity of tidally-dominated estuarine deposits recorded in the main valley system, this strongly supports a tidally-dominated middle estuarine setting.

Upper McMurray Formation

Open-marine shelf deposits are typically considered to directly overlie estuarine valley-fill deposits without any intervening transitional phase (Dalrymple *et al*., 1992; Zaitlin *et al.,* 2004) (Fig.II-29; II-30). The upper McMurray represents an overall transgressive system but does not conform to either estuarine or open-marine shelf facies models. Instead, it illustrates an intermediate setting that is underrepresented in current facies models. This depositional setting is interpreted as a broad, sheltered, shallow marine embayment.

An embayment is defined as a bedrock-lined coastal indentation that forms a large and unconstructed opening to the ocean with free exchange of fully marine waters (Fig.II-31). It is also characterized by a very small river input volume with localized headlands and offshore islands that form environments that are transitional between true estuarine and marine conditions. This definition of embayment is also very similar to environments referred to as salt marsh estuaries in literature. Salt marsh estuaries are large, backbarrier bodies of water, with a lack of a noteworthy freshwater connection and a dominance of tidal waters (cf. Redfield, 1967; Howard and Frey, 1985). Modern coastal embayments are also typically designated based on their geomorphology and are classified under a variety of terms including oceanic embayments, drowned river valleys, sound, inlet, firth, rias, and or fjords. These settings are typically tide-dominated as they lack fluvial input and are slightly sheltered from ocean waves. Modern examples of embayment settings include Cascade Bay, Bellingham Bay, the Firth of Thames, the Cook Inlet, and West Inlet of Tasmania. Modern salt marsh estuarine environments include Wassaw, St. Catherines, Sapelo, Doboy, Ogeechee River-Ossabaw and St. Simons Sounds (Frey and Howard, 1986). An embayment forms a precursor to an estuarine or deltaic depositional environment, and for this reason contains a mix of similar elements from both settings.

The Upper McMurray embayment is interpreted as tide-influenced and is characterized by elongate tidal bar sedimentation dominated by tidal and wave-generated features. Bar formation in the upper McMurray is interpreted as the lateral accretion in shallow water, of large, elongate sub-tidal channel bars which were attached to bedrock of the bay-margin and bay islands (Fig.II-31). Tidal bars are characteristic features of estuarine and deltaic systems and have been described in both systems through modern (Nio and Yang, 1991; Fenies and Tastet, 1998; Gingras *et al.,* 1999; Dalrymple *et a*l., 2003; Choi *et al*., 2004;

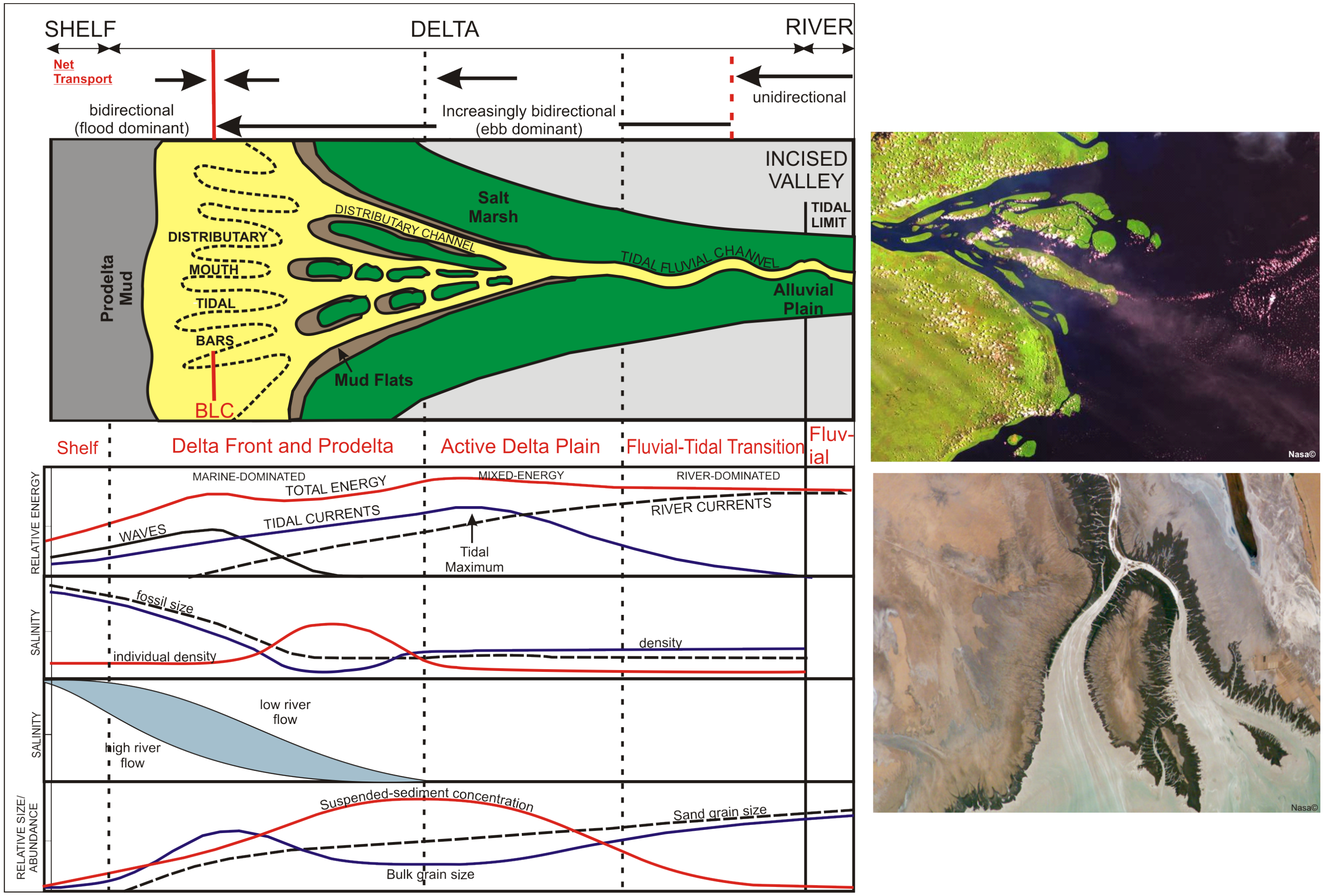

FIGURE II-30: Depositional model and modern analogues for a tide-dominated delta.
The longitudinal relationship of net sediment transport, relative energy, bioturbation, salinity, and bulk grain-size through the zones that characterize a tide-

FIGURE II-30 CONTINUED: dominated delta are illustrated. Modern analogues of tide-dominated deltas include the Fly River delta, Papua New Guinea (top) and the Colorado River Delta, Mexico (bottom) (photos courtesy of NASA). The upper McMurray Formation does not reflect elements of a tide-dominated delta but of a shallow marine embayment.

Yoshida *et al.,* 2004) and ancient examples (Mutti *et al.,* 1985; Dalrymple *et al.,* 1990; Dalrymple and Rhodes, 1995; Willis *et al.,* 1999; Martineau *et al*., 2001; Bhattacharya and Willis, 2001; McCrimmon and Arnott, 2002; Lettley, 2004; McIllroy, 2004; Ponten and Plink-Bjorklund, 2009). All tidal bars migrate laterally, oblique to flow direction, and their internal architecture is strongly controlled by tidal currents (Dalrymple, 1992; Ponten and Plink-Bjorklund, 2009) (Fig.II-31). In both systems, bars are elongate, can exhibit abundant tidal features, and may be several kilometers long (Fenies and Tastet, 1998; Lui *et al.,* 2007). Sediment source differs for each setting; Sediment is supplied dominantly from a marine source in estuarine settings, whereas a fluvial source plays a significant role in deltaic settings (Boyd *et al.,* 1992; Dalrymple *et al.,* 1992) (Fig.II-29; II-30). Lateral accretion of tidal point bars and elongate tidal bars are differentiated based on the amount of curvature, where moderately- to highly-curved lateral accretion reflect point bars, and elongate bars generate straighter lateral-accretion bedding (Dalrymple and Choi, 2007). These types of bars also reflect the position within the system, where straighter elongate bars are generally located further seaward in both settings (i.e. estuary or delta front) (Dalrymple *et al.,* 1992; Dalrymple and Choi, 2007) (Fig.II-29; II-30). The vertical growth of elongate tidal bars is also controlled by water depth, where deposition of shallow water results in laterally expanding bars with broad tops (Harris, 1988). Bi-directional cross-stratification and reactivation surfaces are common to these deposits and reflect tidal flow current reversals. The position of these bedforms is typically at the crestline, separating mutually evasive tidal channels, and/or within compound dunes (Dalrymple, 1984).

The upper McMurray is extremely complicated as bar complexes do not illustrate the characteristic fining-upward profile of laterally accreting bars (Dalrymple, 1984; Dalrymple and Choi, 2007). Deposits comprise stacked, coarsening-upward sand packages that are sharp-based, to gradationally based or overlain by well bioturbated silts and muds of SMBF or POLS (Fig.II-23). This coarsening-upward profile can be attributed to progradation or foreward accretion of compound dunes. This is illustrated along with the sedimentologic features of tidal bar development in figure II-31. This schematic illustrates the lateral and vertical facies relationships between bar development and fair-weather bay-fill

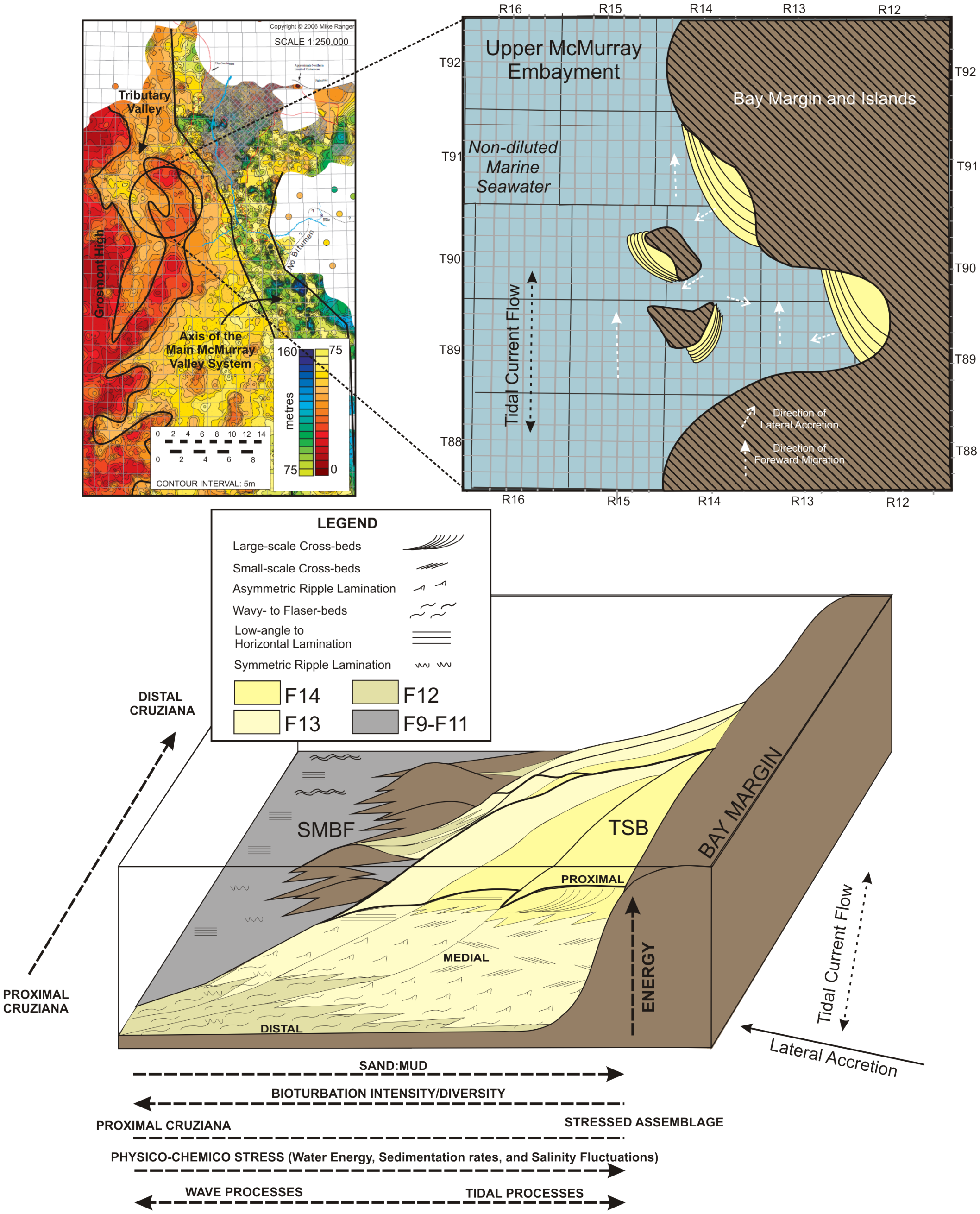

FIGURE II-31: Generalized conceptual depositional and facies model for tidal sand bars within a broad embayment of the upper McMurray Formation.
This model illustrates the idealized vertical and lateral relationship between facies, sedimentary structures, and ichnologic trends observed between SMBF and TSB of the upper McMurray tidal sand bar complex. The depositional environment is a broad sheltered shallow marine embayment, dominated by marine processes, normal marine seawater, and a lack of fluvial influence. Sedimentation in this environment reflects an energetic tidal sand bar complex with intervening low energy, fair-weather shallow marine bay-fill. Overall successions are complex as SMBF and TSB can exhibit both gradational and erosive relationships based on tidal bar migration. Deposits of SMBF may develop fining- or coarsening-upward successions. Tidal bars are interpreted to have been attached to the bay margin and bay-islands via subtidal channels. Tidal bars are large and elongate, with an overall upward-coarsening and sanding succession, 5-25 m thick. Ideally, successions are floored by distal wavy-bedded sand deposition that grade into medial ripple-

FIGURE II-31 CONTINUED: laminated and cross-bedded sands and proximal cross-bedded sands that cap the succession. In a seaward direction from the bay-margin, bioturbation intensity and diversity show an increase, as relative energy decreases resulting in less physico-chemical stress on benthic communities. Tidal energy also becomes weaker and wave-generated structures are more apparent. As energy decreases, the sand and mud ratio also decreases until and bar toe-sets become gradational with deposits of SMBF. This relationship becomes much more complex due to the superimposition of compound dunes on tidal bars, coupled with the lateral accretion of tidal bars, and overall direction of bar migration. The position of tidal bars was predominantly controlled by the location of sediment supply, coupled with available accommodation space, and orientation of the bay-margin and bay-islands. The overall ichnological signature illustrates a progressive change from a proximal to distal *Cruziana* ichnofacies, seaward of the bay margin.

deposition in the upper McMurray embayment. Deposits exhibit a coarsening- and sanding-upward profile corresponding to an increase in energy upwards, representing vertical successions of approximately 5-25 m thick. This is indicated by the change in tidal sedimentary structures from lower energy ripple- and wavy-bedding at the base to small-scale cross-beds, transitioning up into parallel-lamination or large-scale cross-beds. Bioturbation also decreases in intensity and diversity upwards. This corresponds largely to the increase in physico-chemical stresses such as water energy, sedimentation rates, and salinity fluctuations as deposits are subjected to stronger tidal currents and greater variability in sedimentation rates. This is interpreted as a distal to proximal facies relationship and is observed throughout the study area. Bar tops are also eroded reflecting the reworking of bars by tides and waves. Tidal bar complexes are much larger in lateral extent than estuarine tidal bars and extend up to several kilometers across the study area. Fair-weather bay-fill deposits (SMBF) are illustrated and represent the vertical accretion between tidal bars (interbar sedimentation) and in a low energy marine setting (Fig.II-31).

These deposits illustrate high bioturbation intensities and homogenous bioturbation of a diverse suite of large marine ichnogenera indicating a stable shallow marine setting. Bay-fill deposits also illustrate a basinward decrease in sand bed thickness and frequency, coupled with a progressive increase in mudstone beds, and a change from proximal to distal *Cruziana* ichnofacies. Bioturbation intensities also increase from proximal to distal bay-fill. These characteristics reflect a decrease in energy basinward.

Sedimentary structures also show a transition from current and oscillation rippled-, and wavy-bedded sand to biogenically homogenized sand and mud. Wave-generated structures are more apparent than in tidal bar deposits and reflect wave reworking. The complexity of bar migration is captured in figure II-31 illustrating the lateral accretion of tidal bar deposits transverse to tidal flow, where individual bars are separated by interbar bay-fill sedimentation. Moreover, the migration and amalgamation of bars forms complex stacking patterns. Stacking can result in gradational or erosional relationships with separate individual bars and/or bay-fill deposits reflecting the complexity within the system (Fig.II-23).

Sand bar complexes result from overall progradation caused by the combination of lateral accretion and foreward migration. This is attributed to the NW-SE direction of tidal currents and/or longshore drift coupled with the orientation of the bay-margin (Fig.II-31). The location of deposition and lateral accretion of tidal bars was largely controlled by the structural placement of Devonian lows, creating the necessary accommodation space, coupled with the location of sediment supply during deposition. Sediment deposited in this system was derived from erosion of deposits in the main valley and transported following a breach in basin topography, via tidal currents and waves (Fig.II-31).

Ancient examples of deposition within a broad marine embayment are extremely rare. Both tidal bars and dune complexes have been described from modern environments, but have not been widely used as analogs for ancient deposits. The Lower Cretaceous Woburn Sands of southern England are the closest analogue to deposits of the upper McMurray Formation in MacKay River (Yoshida *et al.,* 2004). This succession is interpreted as a tide-dominated marine embayment and represents a change from narrow estuarine to broad embayment, containing normal marine seawaters and sediment derived from a marine source (Yoshida *et al.,* 2004).

Yoshida et al. (2004) demonstrated the modification of a coast from a narrow incised-valley estuary fill to a broad, non-confined embayment during transgression, compared with the normal transgression of an estuary (Fig.II-32). This serves as a good analogue for deposition for the upper McMurray Formation. In this succession, large tidal sand bar and sand wave complexes migrate laterally and in the direction of dominant (ebb) flow, and were comparable to the lateral accretion of large tidal sand bars (10-40 m thick and 2-10 km long) in a modern Wash in eastern England (Yoshida *et al.,* 2004). This scale is also comparable to those of the McMurray Formation in the MacKay River area. A strong marine ichnological signature was also observed in both these modern and ancient examples with a high diversity trace fossil assemblage of large marine ichnoforms (Yoshida *et al*., 2004). The modern Holocene Wash of eastern England also illustrates distinctly different sediment transport patterns compared to estuarine valley fill models (Yoshida *et al.,* 2004). Sediment is sourced from outside of

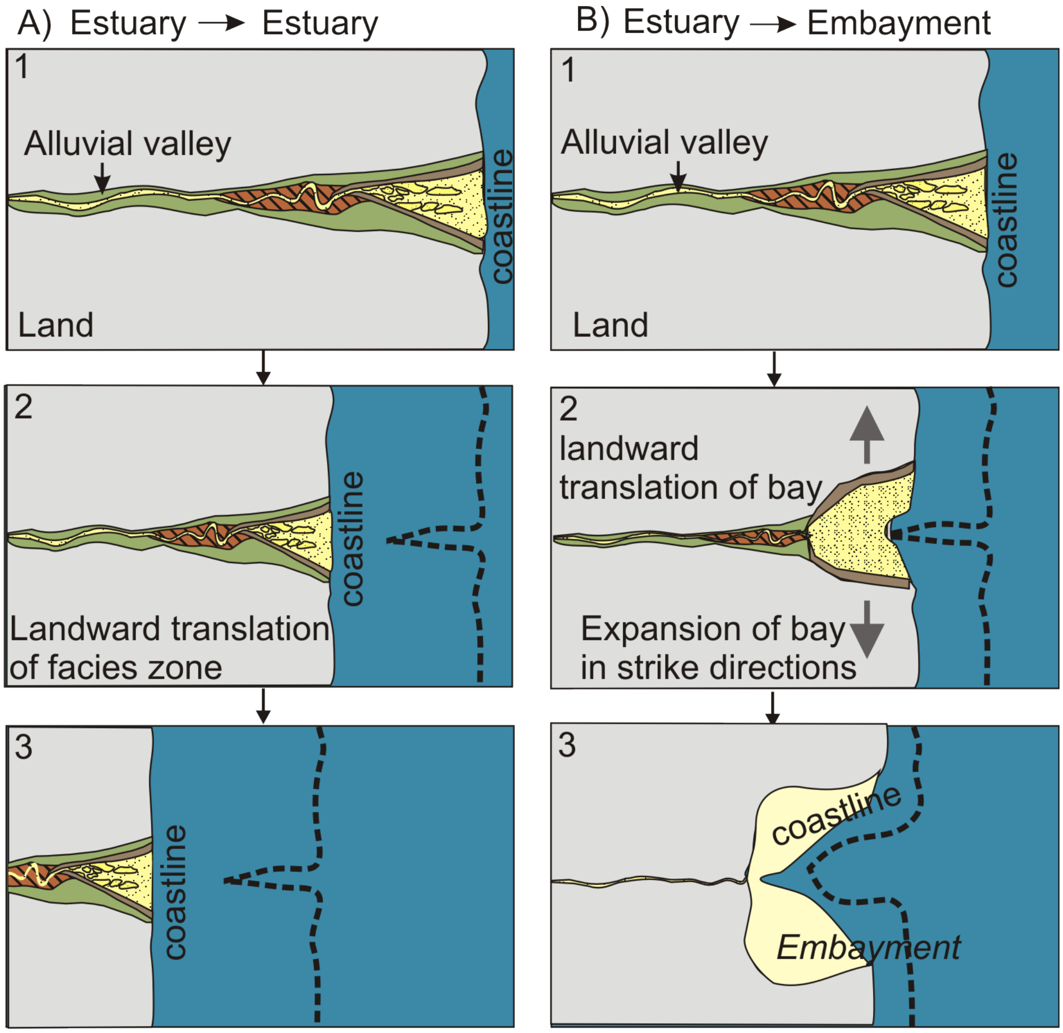

FIGURE II-32: Translation of a coast from a narrow estuary constricted to an alluvial valley to a broad unrestricted embayment. A) Transgression of an estuary that is confined to an alluvial valley. The classical back-stepping pattern of an estuary is illustrated in column A (1-3). B) Transgression of an estuary confined to an alluvial valley that expands into a broad, unconfined bay. Note the decrease in fluvial input and widening of the coastal margins from column B (1-3) (modified from Yoshida, 2004).

the bay and is dominated by marine sediments and saltwater (Ke *et al.,* 1996). Currents also do not illustrate the vertical and lateral heterogeneities typical of an estuary salt wedge, but are typically homogeneous and emphasize tidal processes (Ke *et al.,* 1996). Tidal ravinement in this setting has been attributed to lateral accretion of few relatively deep channels, flanked by large, laterally accreting tidal sands that are commonly covered with large sand dunes (Ke *et al.*, 1996; Yoshida *et al.,* 2004). All of these characteristics are comparable to embayment deposits of the upper McMurray Formation.

Ancient deposits form the North Sea may also contain analogous

FIGURE II-33: Modern Ogeechee Inlet, Georgia, USA. This locality works as a modern depositional analogue for the mixed-energy embayment setting interpreted for deposits of the upper McMurray Formation.

transgressive embayments. One example is the Middle Jurassic Bruce Group in the Bruce field, which evolved from a tidal estuary to marine embayment (Beryl Formation) (e.g., Dixon *et al*., 1997; Yoshida *et al.,* 2004). A modern analogue for upper McMurray embayment deposition could be the salt marsh estuary Ogeechee Inlet, situated on the Atlantic coast of Georgia, USA (Fig.II-33), or the Rio De La Plata on the coastal boundary of Argentina and Uruguay. These systems comprise almost fully marine sedimentation that is influenced by both tide and wave processes. They also illustrate a classic embayment geomorphology with a broad and expansive bedrock-lined coast that has free exchange of fully marine waters with the open ocean.

Lower shoreface to offshore deposits of POLS overlie embayment deposits of TSB and SMBF, and are often gradational with SMBF. This reflects the transition to a more mixed energy to wave- and storm-dominated embayment or shelf setting. These deposits contain finer-grained sand to argillaceous muds that are dominated by wave processes and episodic storm processes and illustrate an archetypal *Cruziana* to *Zoophycos* ichnofacies. The finer-grained nature and sorting of these deposits reflects the continual reworking by wave and tidal currents. Lower shoreface to offshore deposition reflect distal marine conditions and the back-stepping/transgressive nature of the basin. Successions of POLS display a basinward increase in frequency and thickness and fining. The basinward cessation of high-energy conditions reflects deepening of the basin in a lower energy environment such as a broad, open-mouthed embayment or a more open shallow-marine environment close to the shoreline.

Evidence for Tide-influenced Embayment

Evidence for deposition in a shallow marine embayment versus an estuarine or deltaic environment is based on a number of factors including: the lateral extent of facies, paleotopography of the Devonian surface, vertical stratigraphic configuration, ichnological signature, and no evidence of fluvial input.

The intensity of bioturbation coupled with the highly diverse suite of fully marine ichnoforms reflecting an overall *Cruziana* ichnofacies gives indisputable evidence for deposition in non-diluted marine waters. This also indicates a stable environment and good availability of food in quiet water, low energy conditions suitable for benthic communities to flourish. This assemblage can only be observed in normal marine waters. The only other plausible setting to explain this assemblage is the seaward portion of some delta front deposits in a deltaic system (Dalrymple and Choi, 2007) (Fig.II-30). Most delta fronts and prodelta areas, as well as estuarine environments, would exhibit too many stresses (i.e. high suspended-sediment, high current speeds, etc.) and environmental variability that would result in an impoverished, low diversity marine assemblage. These settings are typically characterized by assemblages similar to brackish-water trace fossil suites as observed in the modern Fly River Delta (Dalrymple et al., 2003) (Fig.II-29), ancient Frewens Sandstone (Frontier Formation) and Jurassic Tilje Formation of Norway (Willis *et al.,* 1999; Martinius *et al*., 2001).

A deltaic example with similarities in terms of scale and sedimentological characteristics and stacking to the upper McMurray succession is the tide-influenced Caleta Olivia succession of the Lower Miocene Chenque Formation

(Carmona *et al.,* 2009). Differences exist in the ichnological assemblage, where the Caleta Olivia succession exhibits a variety of stresses in the environment related to influences of fluvial discharge that develop fluctuating salinity, energy levels, water turbidity, flocculated muds, and sedimentation rates, ultimately developing a different suite of traces and an impoverished *Cruziana* ichnofacies. This supports the interpretation that McMurray tidal sands were deposited in less stressful conditions and experienced less variability typical of a deltaic system due to the inherent lack in fluvial input.

Overall, the fact that an abundant and diverse array of species was able to colonize these deposits indicates that there was increased input via marine tide and wave processes, and that the system was somewhat sheltered, protecting these communities from the majority of high energy activity.

This setting is further supported by the complex ridge and valley paleo-topography, where the highs and lows of Devonian carbonates would have acted as the resistant bedrock coast and headlands/islands necessary for this setting. Hard rocky coasts do not provide significant sediment at the coast in an embayment, but in sediment starved environments bar formation is associated with headlands/islands, developed by ebb and flood currents (Dyer and Huntley; 1999).

A setting dominated by a mix of tidal and wave processes and a lack of fluvial influence provides further evidence of an embayed setting. Tidal sedimentation is supported through the abundance of tidal indicators including bi-directional cross-bedding, current-generated stratification, rhythmic interlaminations of coal fragments and organic debris, fluid muds, and rhythmic mud drapes. Sediment supply was sourced via marine processes and transported primarily through tidal, wave and wind-generated currents. Sand was likely mobilized via storm processes and in motion throughout the tidal cycle, directed towards the coast by tidal currents and minor longshore drift from erosion of deposits in the main valley system to the east. Sand transport mechanisms identified in an embayed coast of New Zealand may act as an analogue. In this microtidal embayment experiencing low littoral drift, the Okura estuary is filling with marine sands that were mobilized dominantly by storms, and transported from outside of the bay by wind-generated waves coupled with tides (Green and MacDonald, 2001).

Tidal channel sand bars are interpreted based on the elongate geometry of sand bodies in the MacKay River area. Furthermore, the sedimentological and ichnological characteristics strongly support large-scale tidal sand bar sedimentation. Mud drapes within tidal bars are attributed to strong tidal energy where slack-water periods between cross-bed and or/ripple cross-lamination allow for fines to settle out. The abundance of mud drapes, shell debris and "coffee grounds" mantling stratification foresets also reflects current velocity fluctuations and suspension fallout during slack water. The thin nature of these drapes is attributed to low suspended-sediment concentrations resulting from a lack of fluvial discharge within tidal channels of the embayment (Dalrymple and Choi, 2007).

The cross-bedding is more likely tidally-generated rather than fluvial, based on a variety of criteria. First, there is a lack of deep scouring at cross-bed sets. Cross-beds are also more planar-tabular and are relatively similar in dimension, the opposite of what occurs in fluvial cross-bedding (Dalrymple and Choi, 2007). Current reversals are also common resulting in bi-directional cross-stratification, reactivation surfaces, and a regular formation of similar bedforms over time (Dalrymple and Rhodes, 1995). Tidal bars also display a number of features characteristic of compound dune formation. These include upward-coarsening grain size, upward decrease in mud and bioturbation, upward increase in set thickness, and correspond to an upward transition in energy levels (Allen, 1980; Dalrymple, 1984; Dalrymple and Rhodes, 1995). This supports an interpretation that upper McMurray tidal bars are superimposed with compound dunes.

To date, relatively few studies have been conducted on the internal architecture and on modeling the vertical succession of facies generated by the progradation of tidal sand bars or compound dune deposits (formerly called "sandwaves"). Instead, the vast majority have focused on bar morphologies, hydrodynamic contexts and associated facies (Dalrymple, *et al.,* 1978; Dalrymple *et al*., 1992). Elongate tidal bars and compound dunes are both common in tidal environments, where the former represent lateral migration and the latter represent forward accretion (Dalrymple and Choi, 2007). Elongate tidal bars are similar to point bar deposition and exhibit a fining-upward succession and set thickness, and may exhibit IHS where suspended sediment concentrations are high (Dalrymple and Choi, 2007). Compound dunes may be from <1m to >10 m thick and have opposing features, including a coarsening-upward grain size, increasing set thickness, decrease in the abundance of mud and bioturbation upwards, and increasing energy levels upward (Dalrymple and Choi, 2007). This increase in energy level upwards corresponds to a higher current strength at the crest than in the trough.

Tidal deposits of the Eocene Ager Basin of northern Spain are similar in scale and illustrate similar sedimentologic features to those of the upper McMurray Formation. These deposits also illustrate an archetypal *Cruziana* ichnofacies of a strandplain succession. Initial interpretations by Mutti et al. (1985) supported deposition of a tidal bar succession of a tide-dominated estuary but was later re-interpreted to be a compound dune or deltaic deposit due to the coarsening-upward succession illustrating forward accretion (Dalrymple, 1992; Dalrymple and Choi, 2007). More recently, Olariu et al. (2008) interpreted these deposits as subtidal compound dunes within a strait or seaway.

The upper McMurray embayment displays a progressive basin-ward fining of grain size, and thinning/fining of sandy beds. It also progressively increases in bioturbation intensity and diversity, where salinities are normal marine. This is more characteristic of deltaic deposits than estuarine (fig.II-30) (Dalrymple and Choi, 2007). However, the lack of fluvial input favors an embayment rather than deltaic setting. In modern tide-influenced estuaries and deltas, tidal flat deposits also occur at the top of bar deposits, or give evidence of subaerial exposures. These deposits typically have a low preservation potential due to erosion during transgressive ravinement (Bhattacharya and Willis, 2001). The lack of bar top facies further supports an embayment fill interpretation, where supratidal deposits were not preserved and/or bay deposition in the study area was generated much further seaward from supratidal deposition.

SUMMARY AND CONCLUSIONS

In the MacKay area, the McMurray-Wabiskaw succession reflects a period of overall transgression that is marked by complex marginal-marine to fully marine deposition, dominated by coarsening-upward sand successions. By integrating ichnological and sedimentological characteristics, a greater understanding on the physical and chemical environmental parameters influencing deposition has led to a refined paleoenvironmental interpretation for both the middle and upper McMurray members. The middle McMurray is interpreted as a tide-dominated estuary, where deposits in-filled valley-lows in the Devonian paleo-surface. The middle and upper McMurray are separated by a regional bounding discontinuity, marked by a *Glossifungites* firmground surface caused by ravinement processes. The upper McMurray reflects a transitional phase between a confined estuary system (middle McMurray) and open marine-shelf setting (Wabiskaw Member), interpreted as a broad, shallow-marine, tide-influenced embayment. Furthermore, it reflects a mixed energy system, infrequently affected by storms, and dominated by amalgamated laterally accreting tidal sand bars with intervening fair-weather bay-fill sedimentation.

The refined model of the McMurray-Wabiskaw succession contrasts with the traditional depositional framework common to the main bitumen fairway. It completely lacks fluvial deposition of the lower McMurray member, and comprises only a thin middle member fluvio-estuarine package (ECP-IME) dominated by tidal processes. This is overlain by a much thicker upper member sand bar complex under the influence of wave and tidal processes within a broad sheltered embayment (SMBF-POLS). Contrary to the main valley system, middle McMurray estuarine sands are also not the main reservoir sands, as this interval is typically thin and of non-reservoir quality. Clean sands are relatively sparse and exhibit extreme lateral and vertical compartmentalization. Instead, mixed tidal flat and channel heterolithics dominate and the overall succession exhibits greater heterogeneity with variable bitumen saturations. The main reservoir interval in the MacKay area comprises laterally continuous, northwest-trending, coarsening-upward, and elongate tidal sand bar complexes of a mixed energy embayment that exhibit excellent reservoir quality.

The identification of an overall open marine trace fossil assemblage was instrumental in the recognition of fully marine deposition in the upper McMurray and classification of embayment versus deltaic deposition. These observations further address the relationship between 'middle' and 'upper' informal members. The identification of a substrate-controlled *Glossifungites* surface represents a significant marker surface of allostratigraphic significance. Identification of a regional erosional discontinuity indicates that deposits are not genetic in the study area, and that the upper McMurray reflects a change in the depositional system. A major allostratigraphic marker also characterizes the upper McMurray-Wabiskaw transition. These results ultimately enhance the sedimentological and ichnological knowledge of upper McMurray deposition for the AOSA, and lead to an overall, improved understanding of the McMurray-Wabiskaw succession at both a local and sub-regional scale.

In recent years, much progress has been made towards understanding the sedimentologic and ichnologic responses in tidally active settings, and this case study provides an ancient example of a tidally-influenced embayment setting. It illustrates that the recognition of these processes is vital for a better interpretation as they have great effects on the ichnofauna within the environment, as well as the sedimentary structures preserved in the rock record. Due to the vast variation and complexity of lateral accretion and migration, the internal architecture of tidal sands is difficult to map at the core scale. The proposed generalized model for upper McMurray coarsening-upward sand cycles illustrates, and to some degree simplifies, the facies architecture for these complex deposits. This sedimentological and ichnological model further aids in facies mapping and stratigraphic correlation techniques, necessary to recognize the variability within these sands and to identify unique depositional packages.

This detailed facies work has developed a better understanding and strong foundation for stratigraphic interpretation for the McMurray Wabiskaw succession in the MacKay River area. This will ultimately aid in refining the geological model for the MacKay River area to enhance reservoir identification and prediction. As tide-dominated systems are becoming increasingly important with regards to petroleum reservoirs, this case study may also prove to be a valuable analogue for similar deposits within the Athabasca Oil Sands, and elsewhere.

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CHAPTER III – STRATIGRAPHIC ANALYSIS OF THE LOWER CRETACEOUS MCMURRAY-WABISKAW SUCCESSION IN THE MACKAY RIVER AREA OF THE ATHABASCA OIL SANDS, NORTHEASTERN ALBERTA

INTRODUCTION

The McMurray-Wabiskaw succession is a widely recognized stratigraphic interval within the Athabasca oil sands area (AOSA) in north-eastern Alberta, Canada. Although data has been collected and studied for the past 50 years, there is little agreement on the regional stratigraphic relationships within this interval. This is largely due to the high degree of difficulty in correlating lithostratigraphic and chronostratigraphic units and surfaces across any significant distance in the subsurface, resulting in an inadequate stratigraphic understanding and lack of sub-regional perspective. The majority of sedimentological, ichnological and stratigraphical studies have also been confined to the main valley system of the McMurray Formation, as it is the most densely drilled area. Secondary tributary valley systems remain relatively unstudied and the age-equivalency of McMurray-Wabiskaw strata, particularly for the upper McMurray and Wabiskaw Member, has yet to be demonstrated in literature. With the recent discoveries of significant bitumen reservoirs within these discrete tributary valley trends, an improvement in the understanding of the sedimentological and stratigraphic relationships within the McMurray-Wabiskaw succession is essential for the most efficient exploitation of these reservoirs.

Detailed sedimentological and stratigraphic studies were initially carried out by Carrigy (1959) who was responsible for the development of the informal three-fold stratigraphy of the McMurray Formation (i.e. lower, middle and upper members) (Fig. III-1). Since then, these informal units have become broadly characterized as continental fluvial, marginal marine estuarine and marine deposition, respectively (Carrigy, 1971; Stewart and MacCallum, 1978; Nelson and Glaister, 1978; Mossop and Flach, 1983; Hein and Cotterill, 2006). This nomenclature has remained the preferred stratigraphic framework of the McMurray Formation for the entire Athabasca basin but has more recently become subject to debate. Although these informal members are consistently supported in the main valley system, this traditonal framework does not adhere to the stratigraphy observed in adjacent valley trends (Broughton, 2009; Mathison, 2003). This has further complicated matters as there is now a disagreement upon

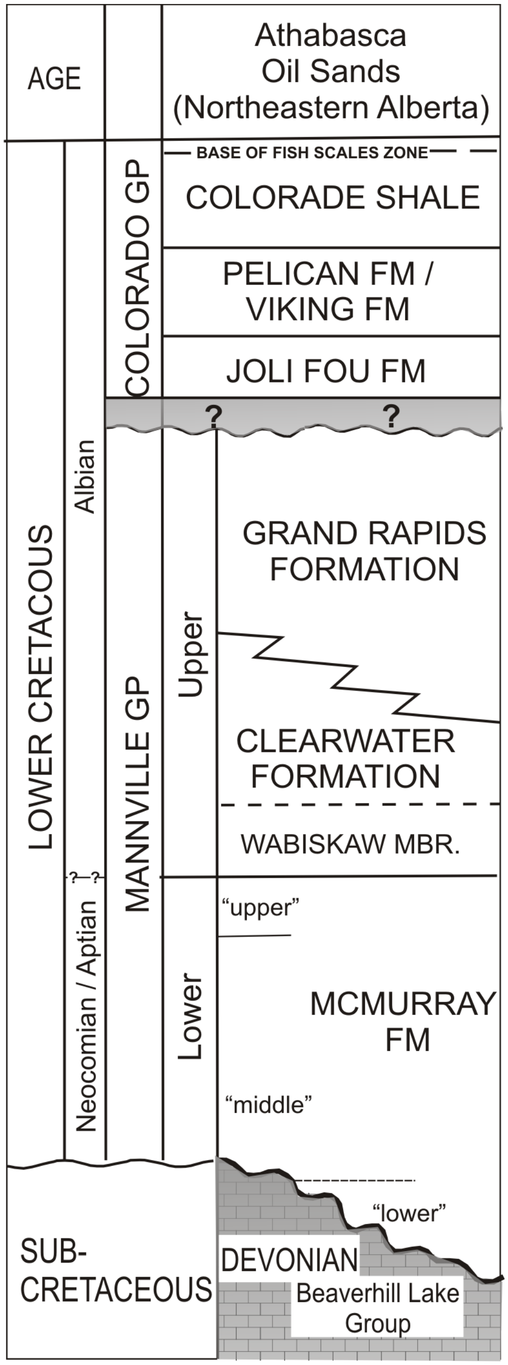

FIGURE III-1: Stratigraphic column for the lower Cretaceous in the Athabasca Oil Sands Area of northeastern Alberta. An informal tripartite stratigraphy consisting of lower, middle and upper members, characterizes the McMurray Formation (modified from Ranger and Gingras; 2003).

the nature of bounding surfaces between members, particularly between the upper McMurray and Wabiskaw Member. Badgley (1952) initially defined this as the first occurrence of glauconite, but this was later thought too difficult to identify on well-log signatures (Flach, 1984). This has resulted in a transition zone of facies that has been attributed to either McMurray or Wabiskaw sedimentation. These conflicting analyses have major significance as each infer different stratigraphic interpretations (Mossop and Flach, 1983; Keith *et al.,* 1988; MacGillivray *et al.,* 1989; Ranger and Pemberton, 1997; Hein and Cotterill, 2001; Crerar and Arnott, 2007; Broughton, 2009; Ranger and Gingras, 2007; Langenberg *et al.,* 2002; Ranger and Gingras, 2003; Ranger *et al.,* 2007).

Ichnologic analysis has been demonstrated as a useful tool in sedimentologic studies and it is equally significant in stratigraphic studies, particularly in the recognition of allostratigraphic surfaces (MacEachern and Pemberton, 1992; MacEachern and Pemberton, 1994; MacEachern *et al.,* 1999). Ichnological research regarding the reconstruction of depositional conditions and relative sea-level has only been carried out for the McMurray Formation in recent years. Most work has resulted in the identification of a strong marine signature for both the middle and upper McMurray members. The McMurray Formation in the main valley system has typically been described as exhibiting environmentally stressed trace fossil suites for both middle and upper informal members. Suites attributed to brackish-water conditions are common to the middle McMurray, where low diversity and low density suites containing fully marine ichnogenera are often identified in the upper McMurray. Ichnological and sedimentological studies have also identified that significant differences exist between members, although distinct bounding surfaces are rarely described in detail, in literature.

Recent work on tide-influenced systems have tested and refined previous tide-dominated models by comparing modern and ancient examples. This has led to some significant sedimentological observations that can be used to better identify and differentiate between tide-dominated systems in the rock record (Dalrymple, 1999, Dalrymple *et al.,* 2003; Yang *et al.,* 2006; Yang *et al.,* 2008).

In this paper, ichnology is integrated with other lines of evidence as part of a multidisciplinary approach to stratigraphic interpretation. A combination of litho- and sequence-stratigraphic methodologies is utilized to highlight the spatial and temporal significance of the sedimentological and ichnological interpretations discussed in Chapter II. Together, this study supports a transition from a tide-dominated estuary to tide-influenced embayment in the study area. It also demonstrates that depositional environments of the middle and upper McMurray members are not genetic as they are separated by a regional bounding discontinuity. These members may also not be contemporaneous to middle and upper McMurray deposition in the main valley system. The aim of this paper is to (1) document the two-dimensional and three-dimensional facies architecture and internal stratigraphy, (2) to discuss the possible controls on stratigraphic architecture, and (3) to discuss the significance of ichnofossils as an aid to stratigraphic characterization of the McMurray-Wabiskaw succession. As there is very little published on the McMurray Formation in this region, this study may act as a local to sub-regional stratigraphic foundation that will enhance reservoir predictability, distribution, and overall geological understanding of the McMurray-Wabiskaw succession. Development of a stratigraphic framework for the MacKay River area may also aid in the prediction of facies architecture and rock quality distribution in similar reservoirs within analogous environments.

Regional Setting

During the Mesozoic, the North American continental margin underwent a major transition from a passive margin to an active margin. This tectonic transition resulted from the opening of the North Atlantic Ocean, which initiated westward drift of the North American Plate. During the late Jurassic, as the continental North American Plate collided with the oceanic Pacific domain, subduction was initiated. This led to the development of the Cordilleran orogenic belt, which extends for more than 6,000 km from southern Mexico to Alaska, forming a major segment of the Circum-Pacific orogenic belt (Decelles, 2004).

Contemporaneous to the development of the Cordilleran belt was the development of an adjacent and immense foreland basin that formed in response to flexural subsidence of the uplifting mountains. A portion of this foreland basin formed the Western Canadian Sedimentary Basin (WCSB), which was subsequently filled with thick successions of Mesozoic to Tertiary sedimentary strata that unconformably overlie crystalline rocks of the Precambrian basement (Decelles, 2004) (Fig.III-2). These sedimentary successions form a northeasterly tapering wedge that is more than 6 km thick to the west, reflecting the long and complex history of foreland basin development. This asymmetrical trough covers a distance of ~600-1200 km, the thickest portion of which underlies Alberta and southern Saskatchewan. The WCSB thins eastward to exposed Precambrian crystalline rocks that form the core of the North American craton.

The McMurray-Wabiskaw stratigraphic interval is a clastic succession that comprises the basal portion of the lower Cretaceous Mannville Group (Fig. III-1). The Mannville was deposited during Aptian to Albian time prior to, and during, the initial stages of marine sedimentation. This clastic succession ranges

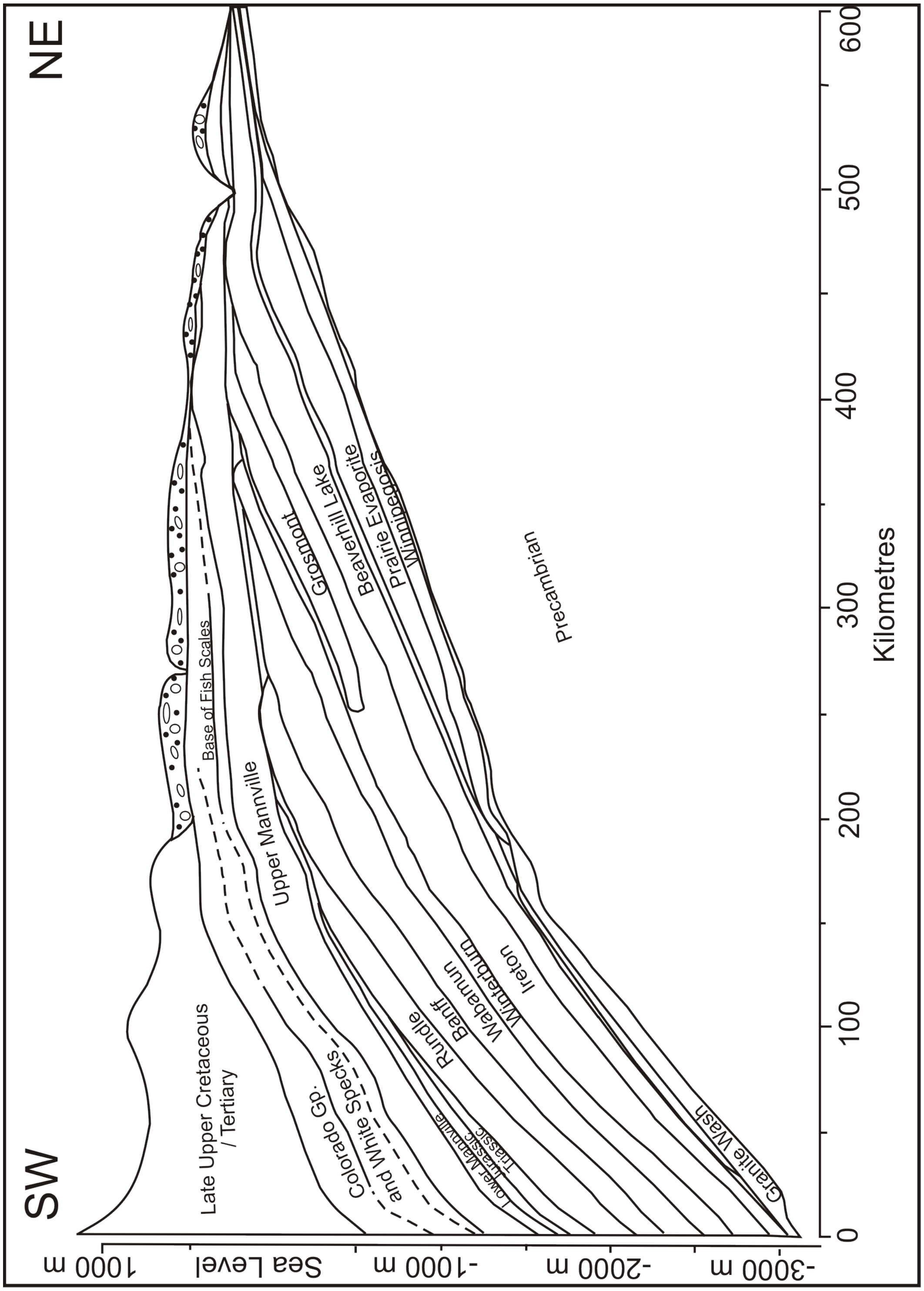

FIGURE III-2: Geologic cross-section of the WCSB showing the major stratigraphic units and their position (modified from Ranger and Pemberton, 1997; Wickert, 1992).

in thickness from 180 to 280 m and is divided into the McMurray, Clearwater, and Grand Rapids formations.

The McMurray Formation overlies a variety of different carbonate formations and is separated by the sub-Cretaceous unconformity. Underlying formations that subcrop from east to west include: the Beaverhill Lake Formation, Cooking Lake Formation, Ireton Formation, Grosmont Formation, the Winterburn Group, the Wabamun Group, and in some locations the Elk Point Group (Fig. III-2). These carbonate platforms (and minor shales represeted by the Ireton Formation) largely controlled McMurray deposition as they were formerly subject to differential erosion. This resulted in a complex ridge and valley paleo-topography, characterized by a main trunk valley system with a variety of secondary tributary valleys and sub-basins that are bound by the Precambrian Shield to the east (Fig.III-3). This intricate arrangement of basins and sub-basins acted as clastic catchments for McMurray and Clearwater sediments and strongly influenced the distribution of depositional environments. The McMurray Formation comprises a wide variety of marginal-marine and shallow-marine strata that were deposited during overall transgression of the Boreal Sea within the WCSB. The lower McMurray Formation is characterized primarily by continental sedimentation sourced mainly from the eastern Cordillera (Jackson, 1984). Lower McMurray sediments were then transported and deposited via major channel systems, and paleo-flow was primarily to the north (Keith *et al.,* 1989). By the mid-Aptian, the Boreal Sea had transgressed into north-eastern Alberta which began to influence upper McMurray sedimentation. By the end of the McMurray, the Boreal Sea transgression developed a marine shelf setting. This resulted in the deposition of fully marine, glauconitic sediments of the Wabiskaw Member in an offshore, shallow marine environment (Outtrim and Evan, 1977; Ranger *et al.,* 1988; Wightman *et al.,* 1991). The McMurray Formation is coeval to the Dina Formation in the Lloydminster area of east-central Alberta, the Gething Member of the Bullhead Group in the Peace River area of northwest Alberta, and the Ellerslie interval of the lower Mannville Group in southern Alberta (Mossop, 1980; Wightman *et al.,* 1991). The Wabiskaw Member is contemporaneous to the Bluesky Formation of northwestern Alberta, the Glauconitic sandstone of southern Alberta, and the Cummings Formation of eastern Alberta (Kramers, 1974).

Deposition of the overlying Clearwater Formation marked an increase in sediment supply to the WCSB due to a phase of more pronounced tectonism and uplift in the eastern Cordillera (Jackson, 1984). This resulted in the deposition of a series of progradational pulses into a shallow marine deltaic setting at the edge of the Boreal Sea. Continued progradation during the Albian produced

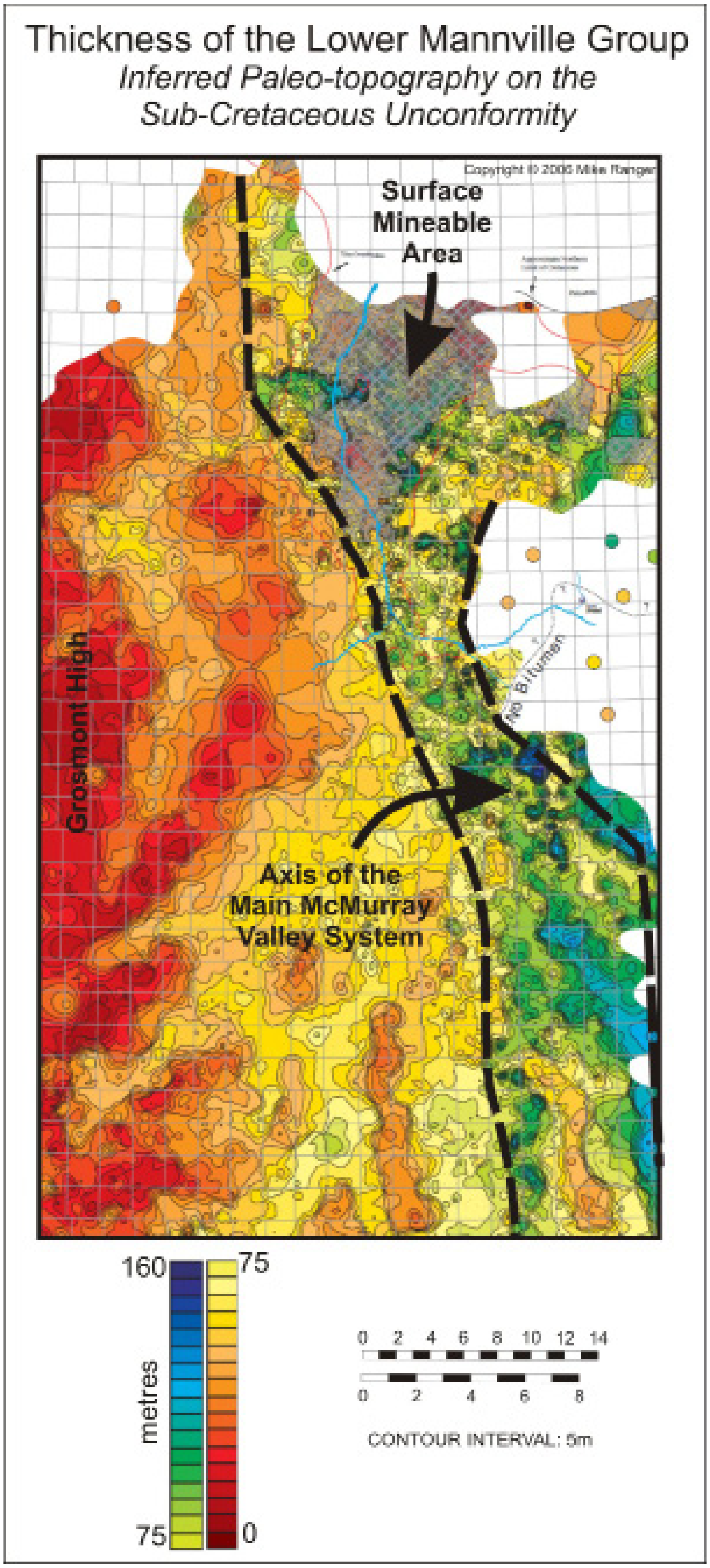

FIGURE III-3: Inferred paleotopography of the sub-Cretaceous unconformity surface expressed by the thickness of the McMurray Formation and its stratigraphic equivalents. Note the axis of the main valley system and surface mineable area (main bitumen fairway), bound by the Precambrian shield to the west and the Grosmont High to the east (modified from Mike the Upper and Lower Grand Rapids Formations. These formations represent an overall shallowing of nearshore marine conditions as an overall regression occurred during deposition. Following Grand Rapids deposition, the Boreal Sea underwent a second major transgression. This continued into the late Cretaceous (Cenemonian) where maximum flooding connected the Boreal Sea (Arctic Ocean) with the Tethys Ocean (Gulf of Mexico), developing a broad, shallow marine seaway (Cretaceous Western Interior Seaway) (Gill and Coban, 1973). During this time, marine muds of the Colorado Group were deposited over Manville Group sediments in northeastern Alberta.

Local Setting

The MacKay River area comprises a significant bitumen resource within the McMurray Formation in the AOSA of north-eastern Alberta. Located west of the main valley trend in Townships 88-92 and Ranges 12-16 West of the 4th Meridian, the study area covers a combined surface area of 684 sections (1771.55 km2) (Fig.III-4). This position is also located on a paleo-high towards the edge of a secondary northwest-trending valley, bound to the west by the Grosmont High, and to the east by the main valley trunk system. A total of 214 wells comprise the dataset for this study, with 100 representing cored intervals (Fig.III-4). Of these, 72 represent those cored by Dover Operating Corporation (OPCO), and 28 from Petro-Canada (Suncor) and Southern Pacific Resources lease areas, comprising a total of ~4500 m of logged McMurray-Wabiskaw section. The remaining wells reflect data derived from wire-line log suites. A high-resolution log suite was available for wells only in the OPCO lease areas. Other areas were limited to an assortment of well data typically comprising gamma-ray, neutron- and density-porosity, and/or resistivity logs.

In the MacKay River area, the McMurray Formation is sub-divided into the 'traditional' middle and upper informal members, although deposition may not be contemporaneous with the same intervals of the main valley trend. The reason for this division was based primarily on the similarities observed in lithofacies characteristics and resulting depositional interpretations, coupled with the apparent equivalency on well-logs and stratigraphic position. Sedimentation of the middle member reflects estuarine valley-fill deposits. Facies associations include inner to middle estuarine (IME) subtidal channels and intertidal flats, and estuary coastal plain (ECP) deposition. In contrast with the main valley, middle McMurray sands do not constitute the main McMurray reservoir and clean middle

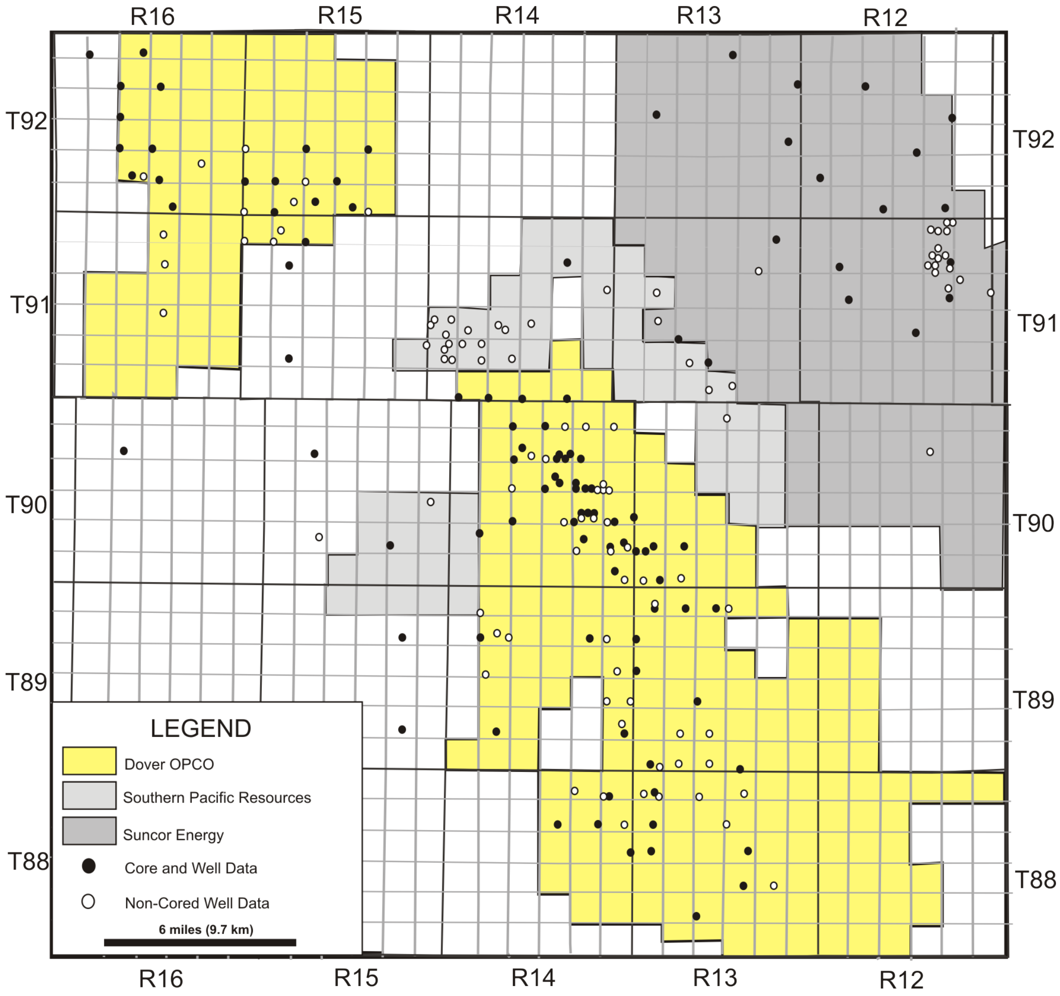

FIGURE III-4: Study area map of the MacKay River area illustrating the dataset and well control used within the three main oil sand lease holders.

McMurray channel sands are not common. Instead, mixed tidal flat and channel heterolithics are dominant and demonstrate greater lateral heterogeneity and variable bitumen saturations.

Upper member deposition reflects the transition between estuarine and open-marine shelf sedimentation, within a broad sheltered embayment. Reservoir facies in the MacKay River area are restricted to upper McMurray deposits, which are dominated by coarsening-upward cycles reflecting amalgamated bay-margin tidal sand bars (TSB), separated by shallow marine bay-fill (SMBF) and lower shoreface to offshore sands and muds (POLS) (discussed below). Upper McMurray sand bodies are of excellent reservoir quality and are clean, laterally continuous, and are typically northwest-southeast oriented. These deposits are interpreted as mixed wave- and tide-influenced sedimentation within a broad sheltered embayment. Overlying facies associations of the Wabiskaw Member of the Clearwater Formation illustrate a regionally widespread upward-fining succession and comprise distal offshore to shelfal muds (DOS) with an overlying gradational to sharp-based shoreface (LSF). Sands clean-upwards and exhibit moderate to excellent reservoir quality with high bitumen saturations. They are also laterally correlative across the entire study area, however, can vary significantly in thickness and occurrence. For a more detailed description of the sedimentology and ichnology of individual facies associations and depositional interpretations, refer to table III-1.

Structure and isopach maps show that the McMurray-Wabiskaw succession ranges in thickness from 10-50 m, with the thinnest deposits in the center of the study area along a northwest-trend (Fig.III-5A). The middle McMurray isopach are thickest within the deepest depressions of the sub-Cretaceous unconformity surface and thins towards structural highs (Fig.III-5B: III-6A; III-7A). These middle McMurray strata (which are the lowest McMurray strata in the study area) represents the initial transgression and filling of paleo-valleys, and has limited preservation potential, ranging in thickness from 0-35 m across the project area (Fig.III-5A).

The upper McMurray isopach illustrates that the thickness of the upper McMurray is variable across the MacKay River project area, ranging from 0-30 m, with an average of 15 m (Fig.III-5C). Thick sand deposition preferentially occurs along lows in the middle McMurray (Fig.III-6B). Cleanest sands are aligned in a NW-SE orientation within middle McMurray lows indicating that bar migration was, to some degree, structurally controlled. This is further illustrated by a comparison of the net sand thickness map for the upper McMurray with the middle McMurray structure map (Fig.III-6B; III-7B). Interpretations for this preferential sand bar orientation are attributed to a mixed tidal and wave ravinement surface, which is described in more detail in the litho- and sequence-stratigraphic sections of this paper. Wabiskaw Member shales are relatively uniform in thickness across the project area (approx. 5 m thick) and drape deposits of the upper McMurray. The Wabiskaw sand ranges from <1 m to 10 m (Fig.III-5D). Sands are thickest in lows of the upper McMurray structure to the northwest along a northeast-trend, and exhibit a continual thinning to the southeast in response to a marine transgression of the shoreface (Fig.III-6C).

METHODS AND STRATIGRAPHIC APPROACH

All available wire-line logs and facies analysis data for the MacKay River

FA	**Facies Association 1 (ECP): Fine-Grained Pedogenically Altered Association**	**Facies Association 2 (IME): Flat Lying to Inclined Heterolithic Association**	**Facies Association 3 (SMBF): Burrowed Sand, Silt and Mud Assocation**	**Facies Association 4 (TSB): Coarsening-Upward Sand Association**	**Facies Association 5 (POLS): Well-Bioturbated Coarsening-Upward Association**	**Facies Association 6 (DOS): Muddy Sand to Sandy Mud Association**	**Facies Association 7 (LSF): Burrowed Sand Association**
Facies	**(F1)** Rooted white to light grey mudstone **(F2)** Organic mudstone and coal **(F3)** Chaotic, inter-bedded, rhizoturbated sand-, silt- and mudstone **(F4)** Inter-bedded to inter-laminated silty mud, silt and sand **(F5)** Laminated to burrowed very fine-grained sand	**(F6)** Cross-bedded to ripple-laminated fine-grained sand with helical- and *Cylindrichnus*-dominated silt and mud inter-beds **(F7)** Flat-lying to inclined inter-bedded to inter-laminated heterolithics **(F8)** Well bioturbated heterolithics	**(F9)** Well burrowed inter-bedded sand, silt and light grey mudstone **(F10)** Well burrowed sand with silt and mudstone-filled burrows **(F11)** Weak to moderately burrowed wavy bedded f.g. sand	**(F11) M**oderately burrowed wavy bedded f.g. sand **(F12)** Weakly burrowed f.g. sand **(F13)** Weakly burrowed rippled to small scale cross-bedded sand **(F14)** Upper fine- to medium-grained large scale cross-stratified sand **(F15)** Cryptobioturbated medium-grained sand	**(F16)** Moderately bioturbated v.f.g.-f.g. sand with silt and mudstone-filled burrows **(F17)** Well bioturbated to planar laminated sand **(F18)** Burrowed argillaceous mudstone with silt and sand inter-beds	**(F19)** Burrowed planar-parallel glauconitic sand to sandy mud **(F20)** Bluish silty mud to moderate grey mudstone with sand inter-beds	**(F21)** Moderately burrowed fine- to medium-grained sand
Occurrence	Lower FA ‘middle’ McMurray	Lower FA ‘middle’ McMurray	Upper FA ‘upper’ McMurray	Upper FA ‘upper’ McMurray	Upper FA ‘upper’ McMurray	Wabiskaw Member	Wabiskaw Member
Characteristic Physical Sedimentary Structures	massive to rhizoturbated; convolute bedding; low angle to parallel-lamination	IHS, large-scale trough/tabular cross beds, bi-directional small-scale cross-beds, grain-size striping, low angle planar- to horizontal-lamination, current ripple-lamination, reactivation surfaces, wavy-, flaser- and lenticular-bedding, rhythmic lamination, double mud drapes	Wavy and flaser bedding, rhythmic- to parallel-lamination, current and oscillation ripples, small scale cross-beds	Cross-beds (large and small scale), current ripple to planar-parallel lamination; oscillation and combined-flow ripples; Tidal indicators: grain size striping/ rhythmites, dip reversals, reactivation surfaces, double mud- and foreset-drapes, rhythmic laminations, reactivation surfaces, and wavy to flaser bedding	Low angle planar to horizontal cross-stratification, trough cross-beds, HCS, relict wavy bedding; parallel lamination; oscillation and combined ripple flow; “lam-scram” bedding	Low angle planar to horizontal stratification, HCS; parallel- and wave ripple-lamination; wavy interbeds	Trough cross-beds, horizontal to low angle planar stratification, HCS, wave-ripple lamination
Lithologic Characteristics	Redoximorphic features shell fragments syneresis cracks	abundant coffee grounds and mud draping foresets/toesets, coal fragments/laminae, intraclasts, syneresis cracks, pyrite/siderite zones	Massive, non-bioturbated bluish grey mud beds with sharp contacts; Shell fragments, small bivalves, passive coarse-grained burrow fills disseminated organic debris, intraclasts, coal fragments, siderite/ pyrite cemented zones	Coarsening-upward profile, clean reservoir sands with rare silt/mud partings, silt/mud burrow-linings and fills, disarticulated bivalves and shell fragments, disseminated organic debris, coal laminae, intraclasts, syneresis cracks	Coarsening-upward succession; passive glauconite and coarse-grained burrow-fills, Lam-scram bedding, siderite/pyrite cemented zones, disseminated organic debris, small interaclasts, shell fragments	Fining-upward succession; glauconite, coal fragments and laminae, disseminated organic debris and shells, pyrite and siderite	Good bitumen saturation; sand-upwards, thick clay-lined burrows, variable thickness
Ichnological Characteristics	BI 0-4 Obscure “scratchmark” burrow mottling; *Taenidium* (c) Impoverished marine assemblage: *Planolites* (m), *Skolithos* (r), *Teichichnus* (r) and *Thalassinoides* (vr) Burrow diameter size: diminutive sporadic and heterogeneous distribution	BI 0-6 *Cylindrichnus-Skolithos* association (c); Gyrolithes monospecific suites Additional Ichnogenera: *Teichichnus* (m), *Planolites* (c), *Skolithos* (m), *Arenicolites* (m), *Thalassinoides* (r), *Palaeophycus* (vr), *Chondrites* (vr), *and* fugichnia (r) Burrow diameter size: diminutive forms regular heterogeneous, sporadic, and homogeneous distribution	BI 2-6 Robust *Asterosoma* (c), *Zoophycos* (c),*Thalassinoides* (c), *Planolites* (c), *Chondrites* (c), Rosselia (m), *Skolithos* (m), *Diplocraterion* (m), *Scolicia* (m), *Rhizocorallium* (m), *Teichichnus* (m), *Spirophyton (m), Arenicolites* (r), *Palaeophycus* (vr), *Macaronichnus* (r), *Phycosiphon/ Helminthopsis* (vr), *Ophiomorpha* (r), *Monocraterion* (vr) fugichnia (vr) Burrow diameter size: moderate to robust homogeneous distribution	BI 0-2; Cryptobioturbation Ichnogenera: *Planolites* (c), *Thalassinoides (c), Teichichnus* (m), *Skolithos* (m), fugichnia (m) *Ophiomorpha* (r), *Macaronichnus* (r), *Arenicolites* (vr), *Siphonichnus* (vr), *Schaubcylindrichnus* (vr), *Scolicia (vr), Palaeophycus (vr), Diplocraterion (vr)* Burrow diameter size: Traces are moderate to robust regular to sporadic heterogeneous	BI 0-6 Ichnogenera: *Chondrites* (c), *Asterosoma* (c), *Rosselia (c), Schaubcylindrichnus (m), Diplocraterion (m), Zoophycos (m), Skolithos* (m), *Planolites* (m), *Psilonichnus (r), Scolicia* (r) *Thalassanoides* (r), *Arenicolites* (r), *Teichichnus (r), Conichnus* (vr), fugichnia (vr) *Phycosiphon/Helminthopsis* (vr), *Cosmoraphe* (vr) Tubular tidalites / tempestites Burrow diameter size: robust homogeneous distribution	BI-0-6 Ichnogenera: *Chondrites* (c), *Phycosiphon / Helminthopsis* (m), *Planolites* (m), *Zoophycos (r), Skolithos* (r), *Teichichnus* (r), *Astersoma* (r), *Diplocraterion* (r), *Thalassinoides* (r), *Rosselia* (vr), *Ophiomorpha* (vr), fugichnia (vr) Burrow diameter size: small Homogeneous distribution	BI 3-6 *Chondrites* (c), *Skolithos* (m), *Asterosoma* (c), *Diplocraterion* (m), *Thalassionides* (m), *Teichichnus* (r), *Scolicia* (m), *Planolites* (m) Burrow diameter size: robust Homogeneous distribution
Interpretation	*Scoyenia* ichnofacies and brackish-water assemblage	well developed brackish water assemblage	Proximal *Cruziana* ichnofacies	Stressed tidal-influenced marine assemblage	Archetypal *Cruziana* ichnofacies	Distal *Cruziana* to *Zoophycos* ichnofacies	Archetypal *Cruziana* Ichnofacies
	Coastal plain to intertidal sandy flats	**Brackish-water intertidal mixed flats and subtidal channel bars**	**Low energy fully marine background bay-fill / interbar sedimentation**	**Bay-margin and island tidal sand bar complex (Lateral and forward accretion)**	**Fully marine fairweather to remnant proximal tempestite sand and mud**	**Fully Marine fairweather to remnant distal tempestites and shelfal mud**	**Fully Marine sand deposition reflecting the activity of fairweather and storm waves**
	Estuary Coastal Plain	**Inner to Middle Estuary**	**Shallow Marine Bay-Fill**	**Proximal to Medial Tidal Sand Bars**	**Proximal Offshore to Lower Shoreface**	**Distal Offshore to Shelf**	**Lower Shoreface**

TABLE III-1: Summary Table of Facies Associations based on sedimentological and ichnological observations in McMurray-Wabiskaw strata in the MacKay River Area, northeast Alberta.

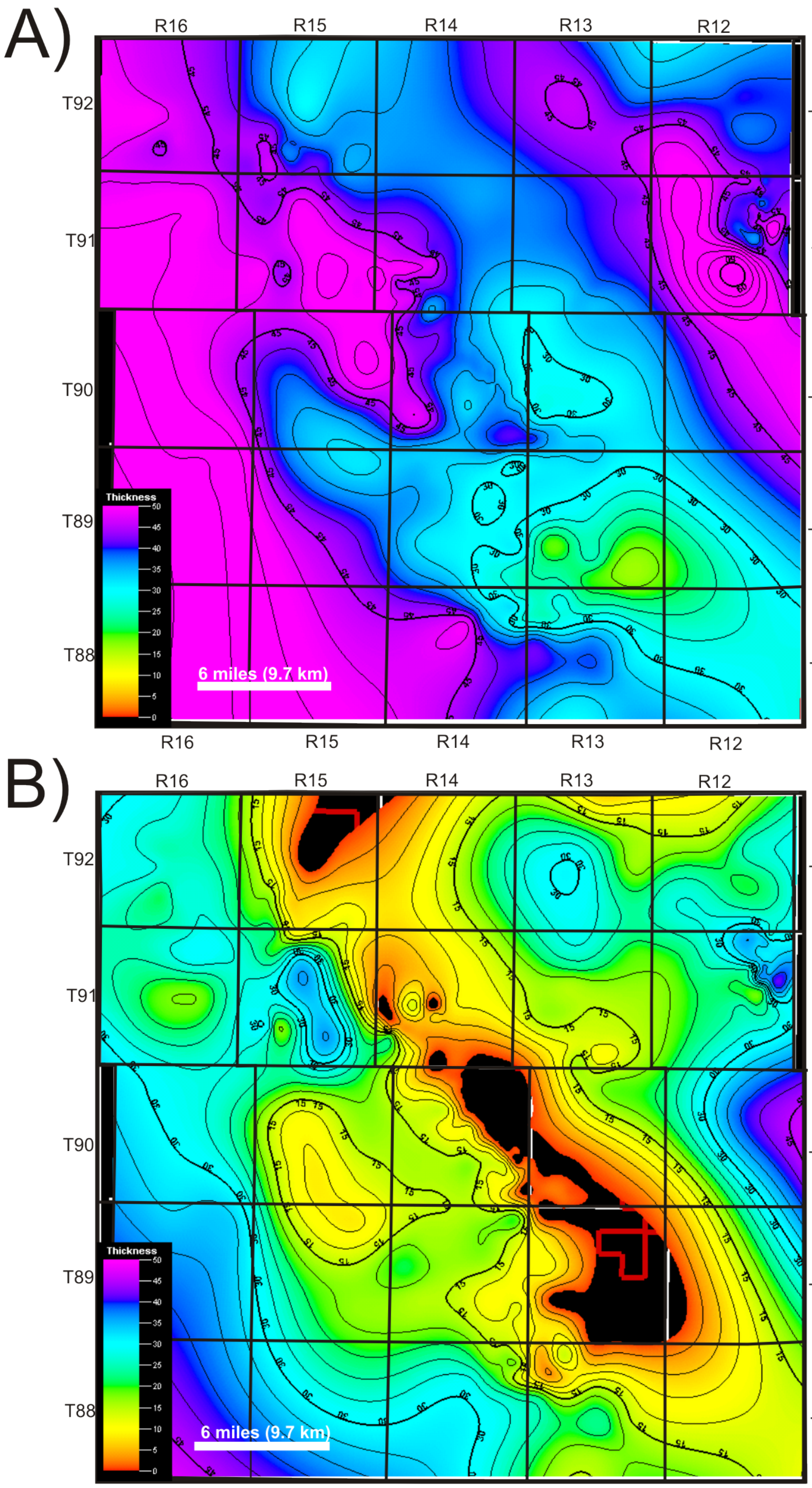
A)
R16
R15
R14
R13
R12
T92
T91
T90
T89
T88
Thickness
50
45
40
35
30
25
20
15
10
5
0
6 miles (9.7 km)
B)
R16
R15
R14
R13
R12
T92
T91
T90
T89
T88
Thickness
50
45
40
35
30
25
20
15
10
5
0
6 miles (9.7 km)

FIGURE III-5

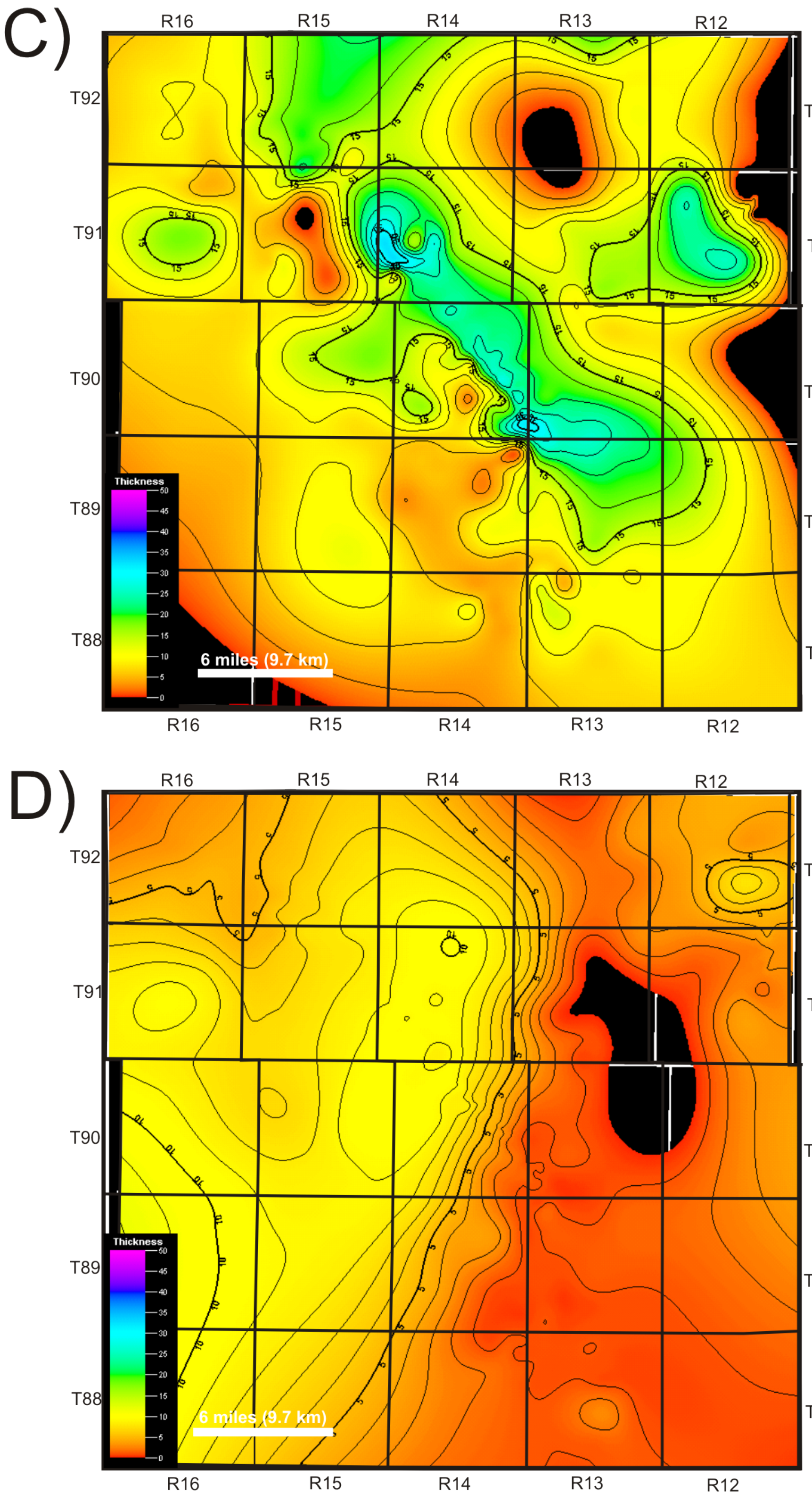

FIGURE III-5 CONTINUED: Regional isopach maps for the main stratigraphic intervals in the MacKay River area. A) McMurray-Wabiskaw succession, contour interval=3m. B) Middle McMurray Formation, contour interval=3m. C) Upper McMurray Formation, contour interval=3m. D) Wabiskaw Member sand, contour interval=1m.

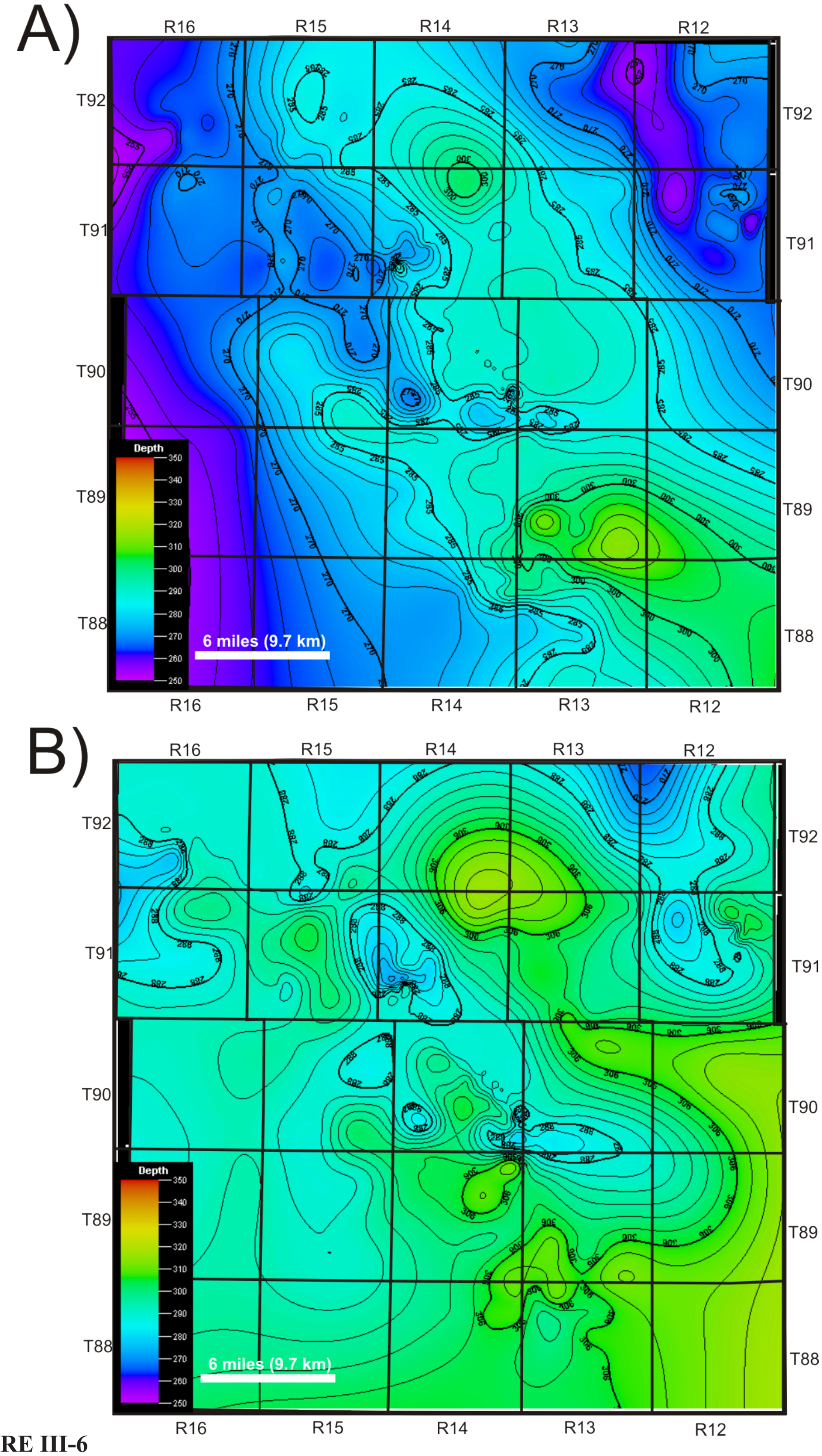
A)
B)
R16
R15
R14
R13
R12
T92
T91
T90
T89
T88
Depth
350
340
330
320
310
300
290
280
270
260
250
6 miles (9.7 km)

FIGURE III-6

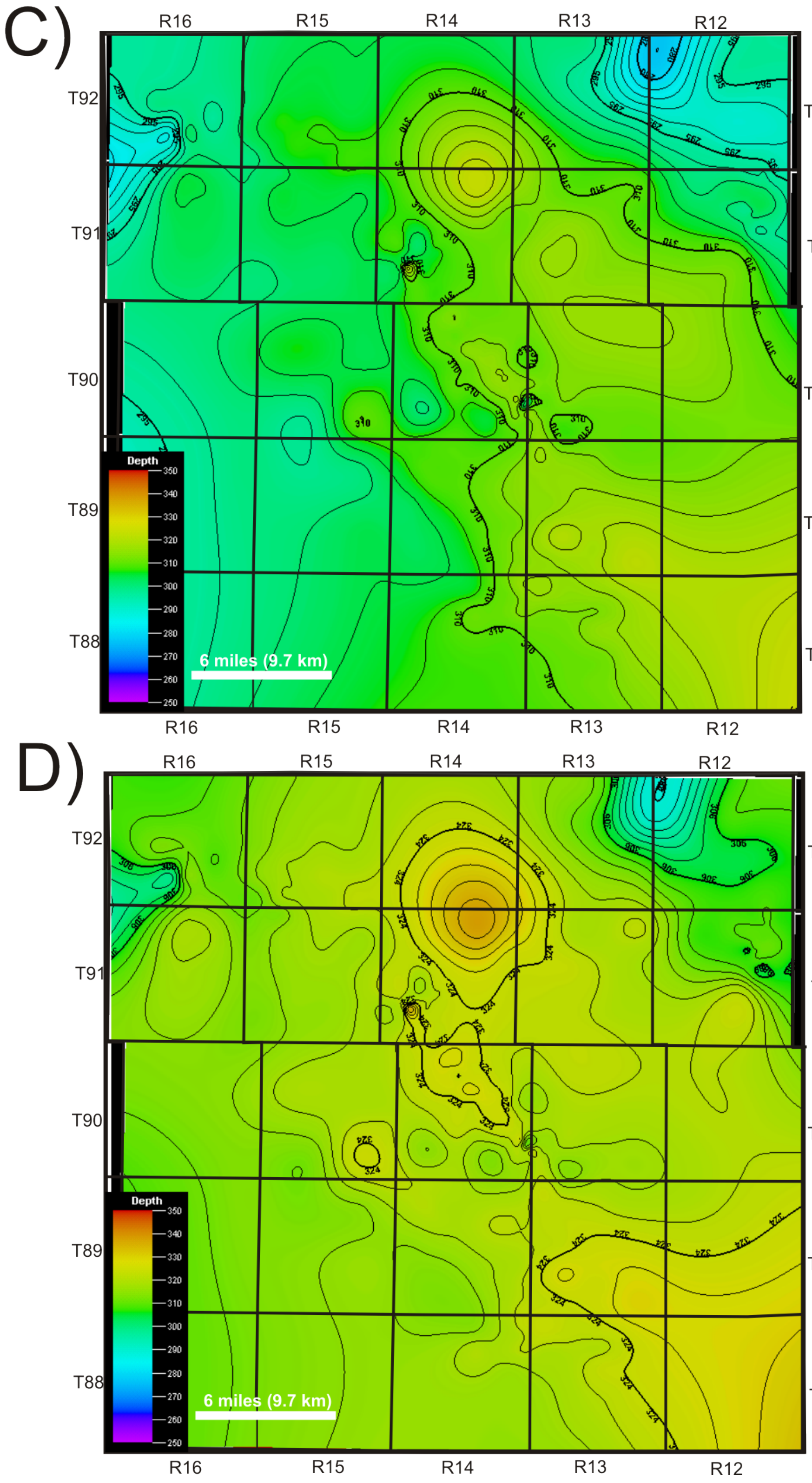

FIGURE III-6 CONTINUED: Regional structure maps of the main stratigraphic intervals in the MacKay River area. (A) Devonian Beaverhill Lake Group, (B) middle McMurray Formation, (C) upper McMurray Formation, and (D) Wabiskaw Member. Contour interval=3m.

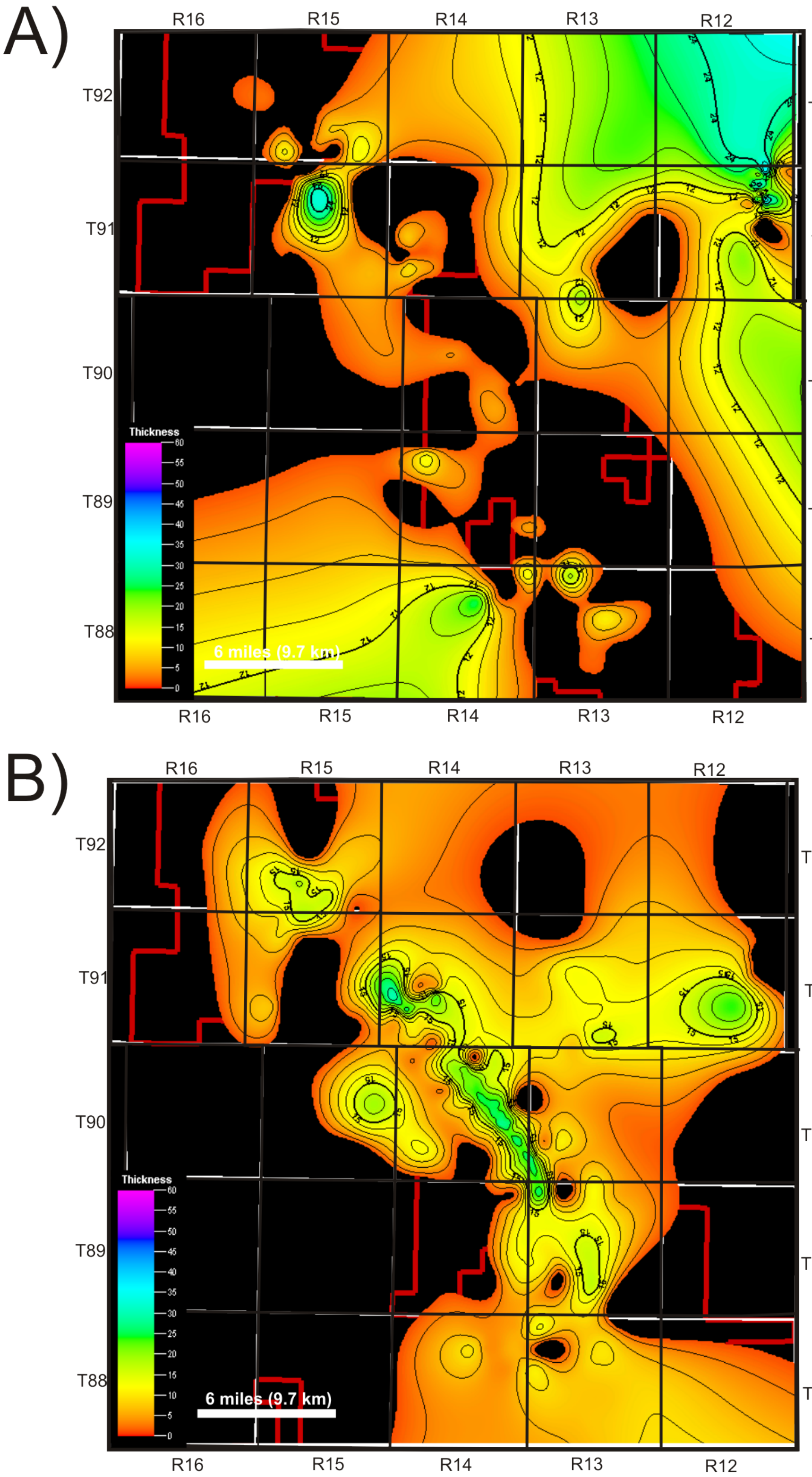

FIGURE III-7: Net sand thickness maps of the (a) middle McMurray and (b) upper McMurray in the MacKay River area. Reservoir quality sands are relatively thin and compartmentalized throughout the middle McMurray, compared to thick laterally continuous sand deposits of the upper McMurray. Contour interval=3m.

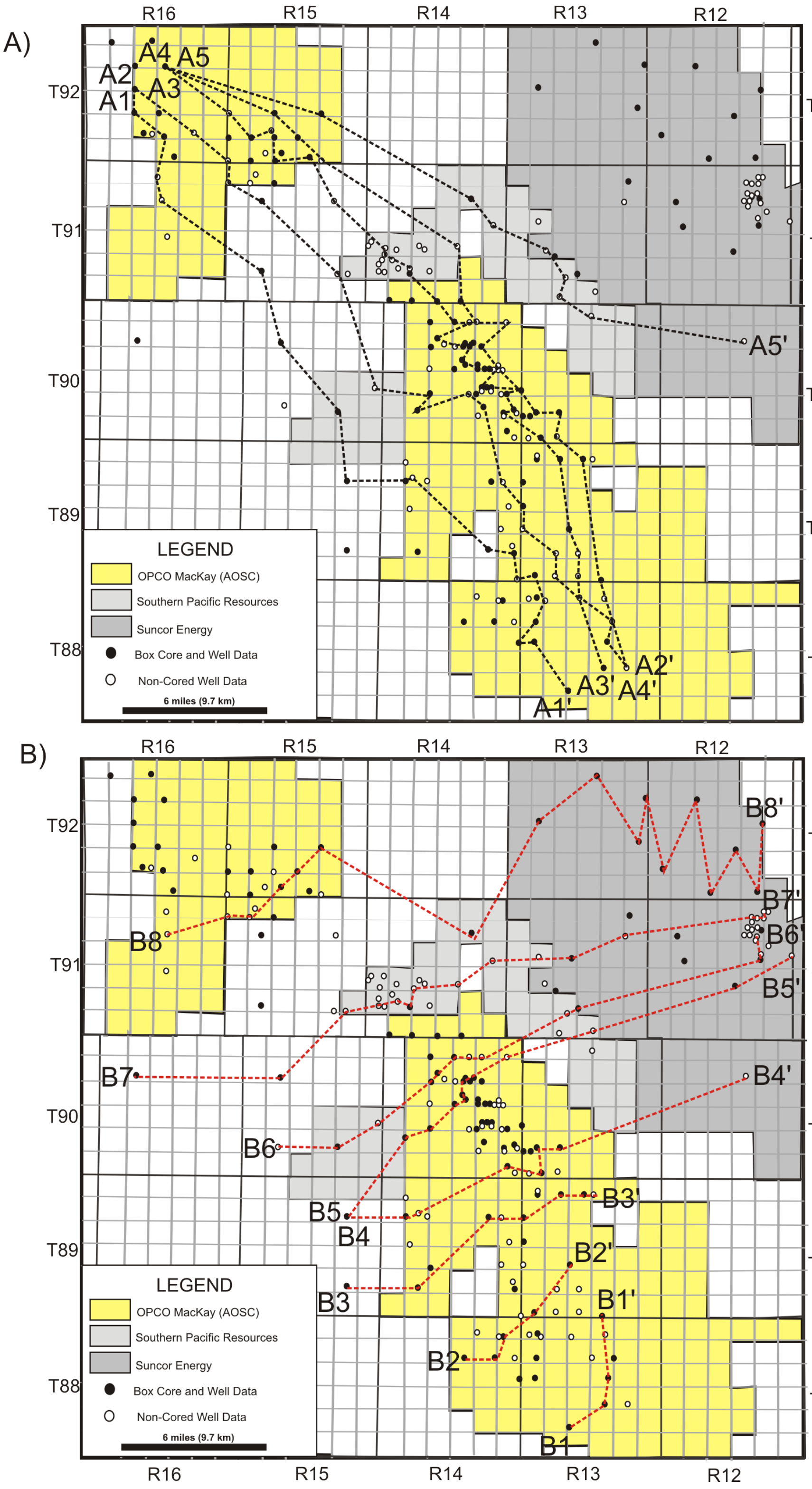

FIGURE: III-8: Cross-Section network through the Mackay River area. A) The northwest to southeast-trending network is outlined in black dashed lines and comprises five sections (A1-A5), utilizing a total of 96 different well locations. B) The southwest to north-east trending network (perpendicular) is outlined in red and comprises eight sections (B1-B8), utilizing an additional 40 wells.

area were integrated into Petrel 2010.v2, and well localities without cored data were assigned electrofacies, determined based on comparisons of wireline-log signatures. A variety of geological maps were then constructed, including net sand thickness maps, regional structure and isopach maps, and also isopach maps of the identified facies associations. Through extensive facies correlations and mapping, several cross-sections were constructed. In total, 5 NW-SE trending sections and 8 perpendicular SW-NE trending sections were constructed, utilizing a total of 136 well localities across the area, all of which tie to core-logged data (Fig.III-8; Fig.III-9 to Fig.III-12; Fig.III-14). The development of these sections then led to the identification of individual lithostratigraphic trends and the delineation of sequence stratigraphic surfaces and stratal packages. Isopach and structure maps for these stratal packages and surfaces were then constructed. More detailed, and additional cross-sections are illustrated in appendix C.

Lithostratigraphic correlations are based on facies associations and the vertical and lateral relationships between them, as designated by their conformable or unconformable contacts. This results in the identification of correlative rock units, or lithostratigraphic units, that represent the stratigraphy based on FA distribution. Sequence stratigraphic analysis represents temporal sedimentological correlation based on relative sea level and variations in sediment supply. This method employs the integration of lithological data and facies successions with the recognition of regional stratigraphic surfaces that are assumed to represent timelines, and therefore place stratigraphy into a chronostratigraphic framework. Both methodologies were implemented in order to emphasize the spatial and temporal significance of the sedimentological and ichnological observations.

Stratigraphic Datum

All stratigraphic sections in this study use the Wabiskaw silty muds (F20) as a datum, which most approximately represents the structural configuration during time of deposition. These muds are typically dark grey in color, are parallel-laminated, have a fining-upward profile, and are gradational to sharp with underlying burrowed glauconitic muddy-sand. These muds may also appear massive to cross-laminated, and are non- to weakly bioturbated by a distal *Cruziana* ichnofacies consisting of *Chondrites, Phycosiphon/Helminthopsis* and subordinate *Teichichnus, Planolites, Thalassinoides, Asterosoma* and *Skolithos.* This datum corresponds to a maximum flooding surface, which is easily

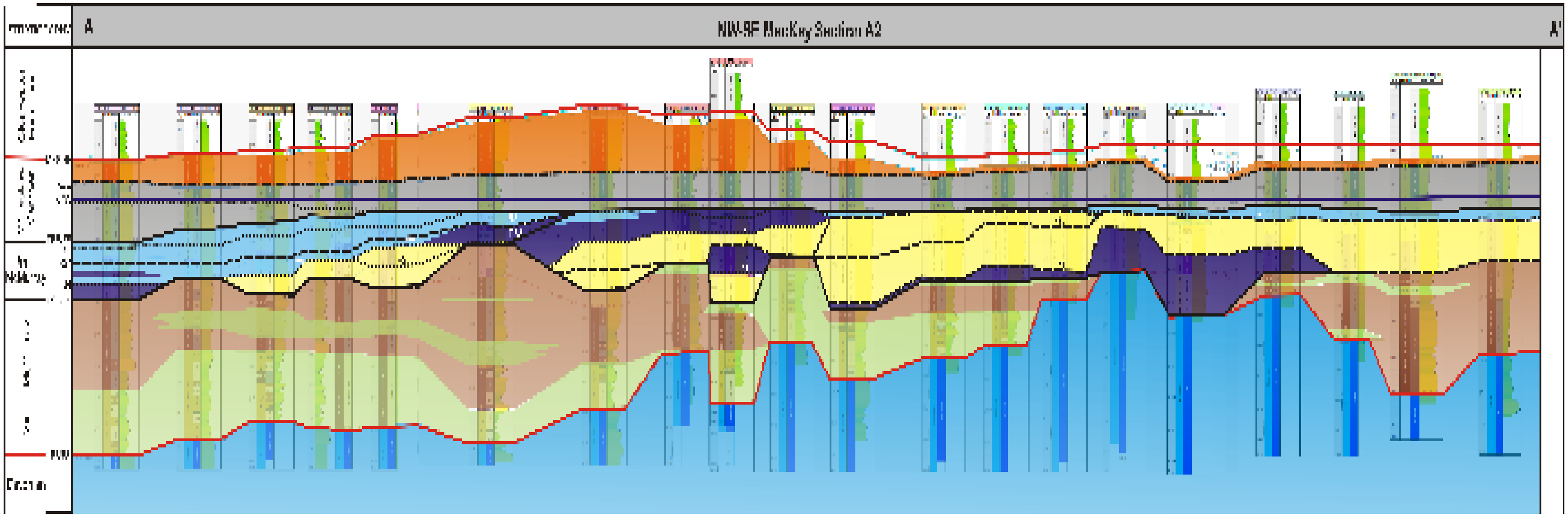

Figure III-9: Stratigraphic cross-section A2. This section is the second of five regional NW-SE oriented sections in the network of cross-sections and contains 20 wells across a distance of ~39 km. Refer to Figure III-14 for legend.

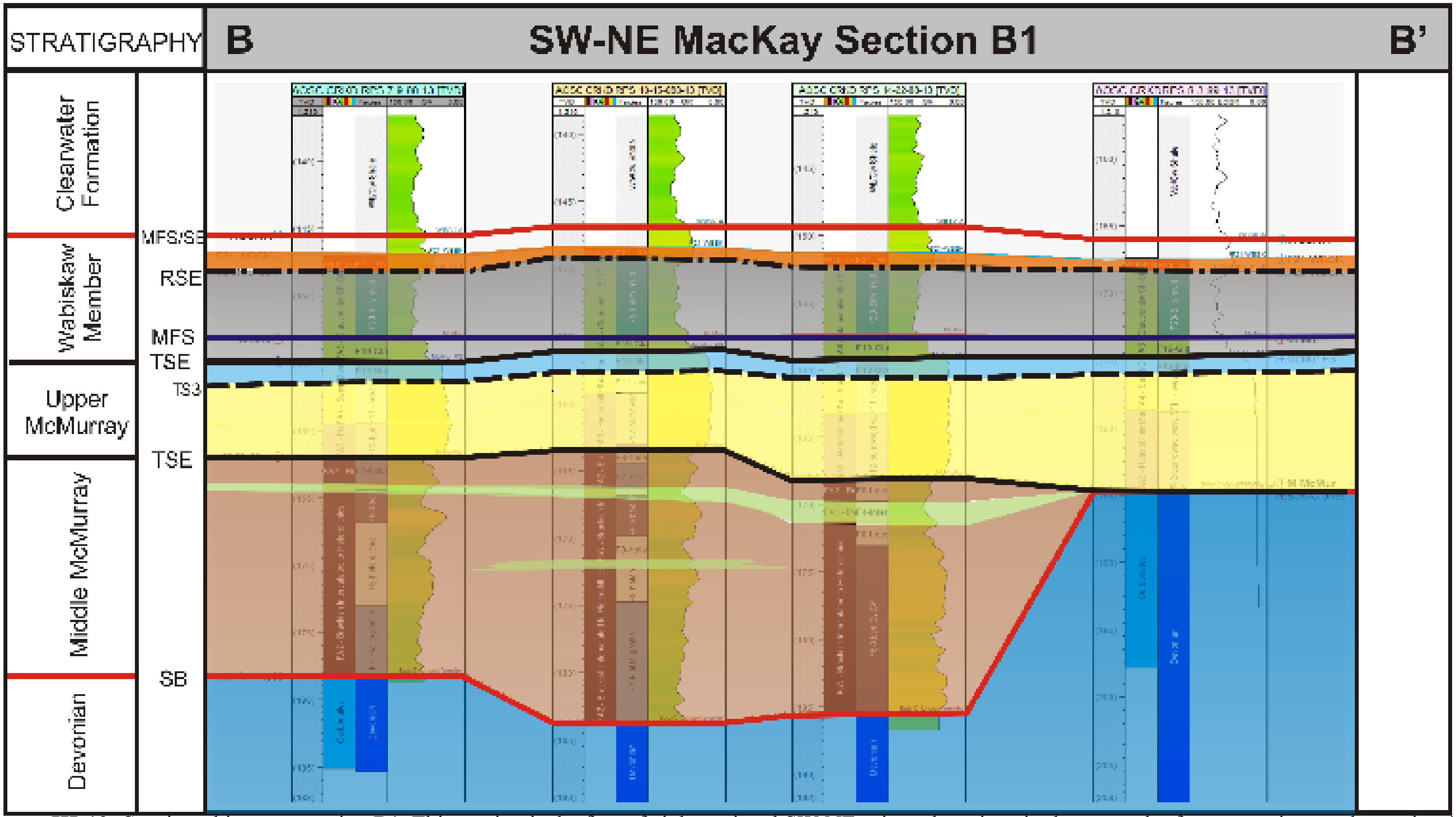

Figure III-10: Stratigraphic cross-section B1. This section is the first of eight regional SW-NE oriented sections in the network of cross-sections and contains 4 wells across a distance of ~9 km. Refer to Figure III-14 for legend.

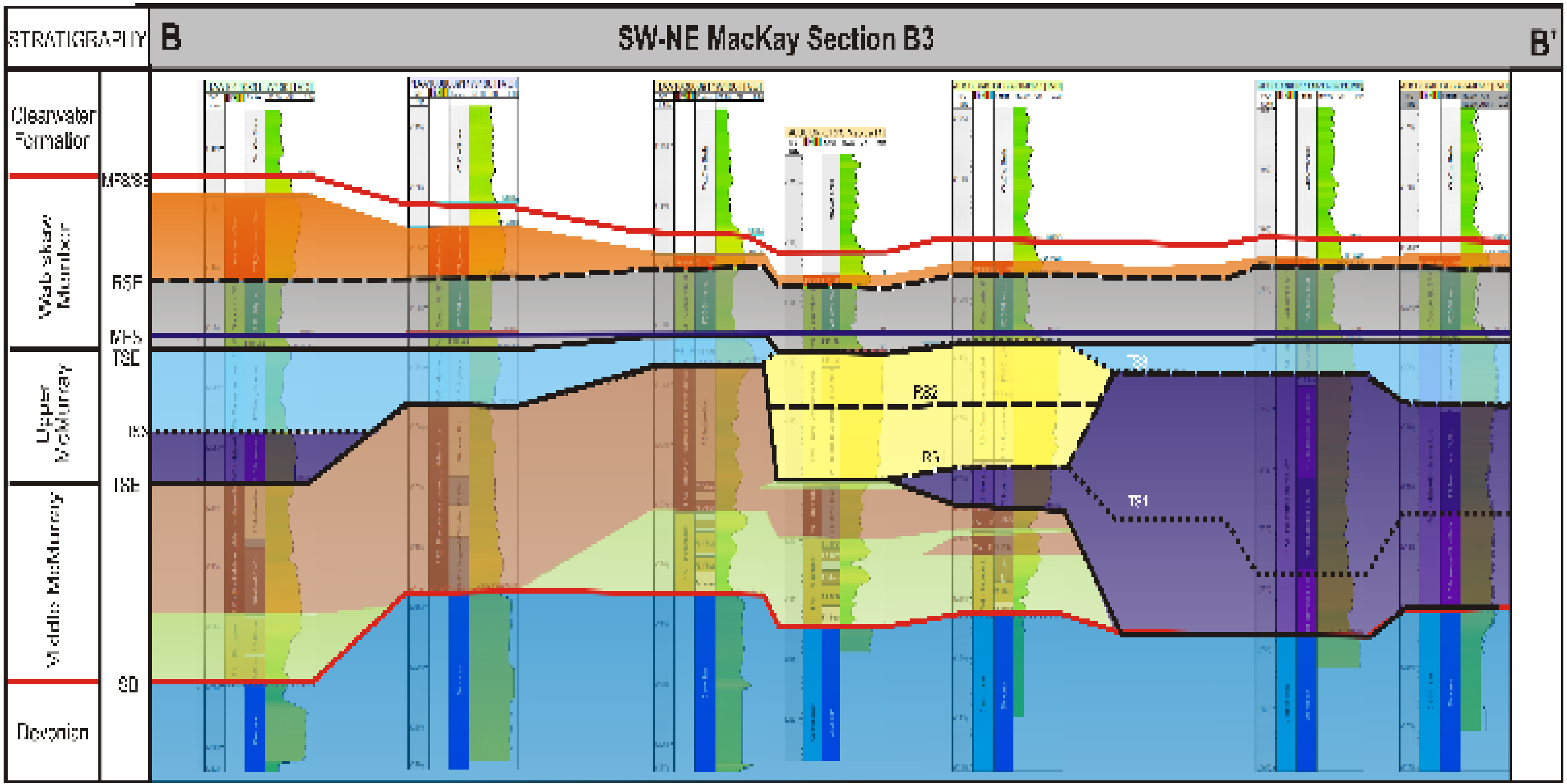

Figure III-11: Stratigraphic cross-section B3. This section is the third of eight regional SW-NE oriented sections in the network of cross-sections and contains 7 wells across a distance of ~20 km. Refer to Figure III-14 for legend.

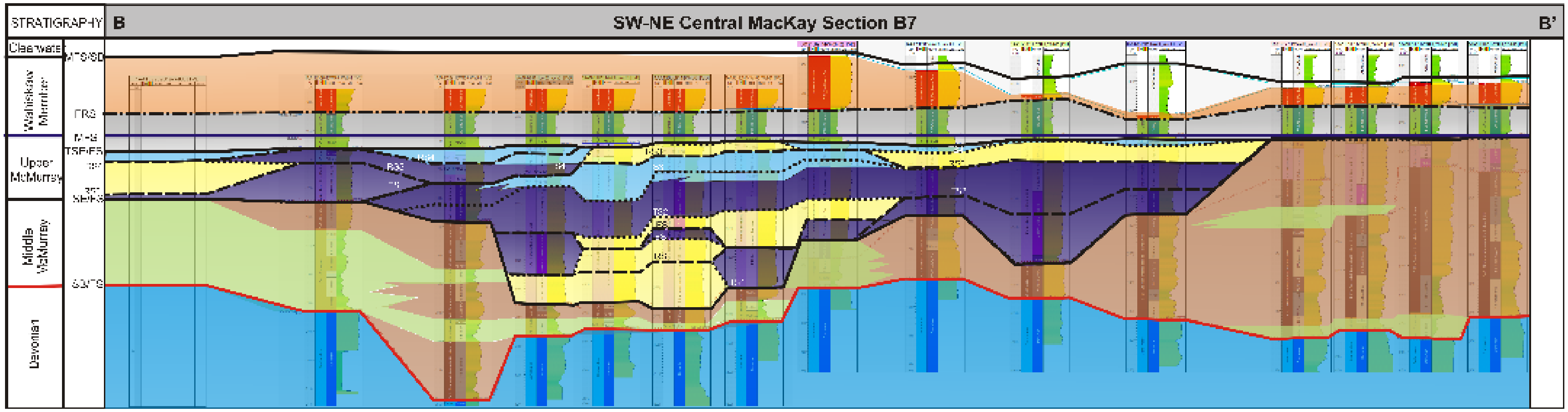

Figure III-12: Stratigraphic cross-section B7. This section is the seventh of eight regional SW-NE oriented sections in the network of cross-sections and contains 15 wells across a distance of ~41 km. Refer to FIgure III-14 for legend.

recognized on wire-line log signatures (refer to cross-sections in Appendix C). It is also consistent to Badgley's (1952) initial lithologic distinction between the McMurray Formation and Wabiskaw Member, and later as the "blue steel-gray" Wabiskaw mud distinction as described by Carrigy (1959) and Wightman *et al.,* (1995). The base of these muds is also consistent with the T11 surface (first regional marine mud) as used by Hein *et al.,* (2000). The top of the Wabiskaw Member is coeval with the T21 surface used by Hein *et al.,* (2000). This is the best available datum as it represents a relatively flat paleo-surface and lacks any evidence of erosion. Although further from the McMurray, it provides the best representation of stratal dips.

LITHOSTRATIGRAPHIC ANALYSIS

Facies Associations

FA were subsequently subdivided into a 'lower,' 'upper,' and Wabiskaw division, corresponding to the 'middle' and 'upper' informal members of the McMurray Formation, and the overlying Wabiskaw Member. Table III-1 contains a summary of the sedimentological and ichnological characteristics of each FA.

ECP: Estuary Coastal Plain Association

The first facies association represents middle McMurray deposits that are characterized by non-reservoir fine-grained pedogenically altered media. Facies association 1 is interpreted as vertical accretion of an estuary coastal plain. Deposits consist of rooted muds (F1), organic muds and low-grade coals (F2), burrowed to rhizoturbated silts and sands (F3), parallel inter-laminated to inter-bedded silts and sands (F4) and thin laminated to burrowed sands (F5). More specifically, these facies correspond to eluviated deposition representing paleosols, backswamp deposits, levee-crevasse splays, and sandy intertidal flats with local distributary tidal channels.

IME: Inner to Middle Estuary Association

The second facies association reflects middle McMurray deposition characterized by flat-lying to inclined heterolithic media. These deposits are interpreted as subtidal to intertidal deposition within the inner to middle estuary. Deposits of FA2 are characterized by cross-bedded to ripple-laminated fine-grained sands with helical- and *Cylindrichnus*-dominated silt and mud inter-beds (F6), flat-lying to inclined inter-bedded to inter-laminated heterolithics (F7), and well burrowed heterolithic media (F8). More specifically these non-reservoir deposits reflect brackish-water deposition of lateral accreting subtidal channel bars that grade into intertidal mixed flats.

SMBF: Shallow Marine Bay-Fill Association

Facies association 3 is the first association of the upper McMurray stratigraphic interval and illustrates extremely different character than middle McMurray deposits in terms of sediment calibre and ichnological signature. This association reflects well burrowed media interpreted as background bay-fill and/or interbar sedimentation of a fully marine shallow embayment. Deposits include a mix of non-reservoir and reservoir facies comprising well burrowed inter-bedded sand, silt, and mudstone (F9), well burrowed sand with silt and mudstone-filled burrows (F10), and weak to moderately burrowed wavy bedded fine-grained sands (F11).

TSB: Proximal to Medial Tidal Sand Bar Association

Facies association 4 of the upper McMurray reflects the main reservoir interval and comprises clean coarsening-upward successions interpreted as proximal to medial tidal sand bars that are laterally accreting to the bay-margin and islands within a shallow marine embayment. Successions of FA4 consist of moderately burrowed wavy bedded fine-grained sands (F11), weakly burrowed fine-grained sands (F12), weakly burrowed rippled to small-scale cross-bedded sands (F13), upper-fine to medium-grained large-scale cross-bedded sands (F14), and cryptobioturbated medium-grained sands (F15). Sands of FA4 reflect variable positions of proximal to distal positions of tidal sand bar deposits, with F15 reflecting a proximal subtidal channel position, and F11 reflecting most distal subtidal channel deposition, respectively.

POLS: Proximal Offshore to Lower Shoreface Association

Facies association 5 of the upper McMurray is characterized by well bioturbated coarsening- and sandier-upward successions interpreted as fully marine proximal offshore to proximal lower shoreface deposition. Deposits include a mix of reservoir and non-reservoir facies. Reservoir facies correspond to moderately bioturbated fine-grained sands with silt- and mudstone-filled burrows (F16). Non-reservoir facies consist of burrowed argillaceous mudstone with silt and sand inter-beds (F18) and well bioturbated to planar laminated sands (F17). More specifically, these deposits reflect dominantly fair-weather sedimentation with remnant tempestites. Unique to FA5 is the finer-grained nature of well-sorted sands compared to those observed in FA3 and FA4.

DOS: Distal Offshore to Shelf Association

Facies association 6 represent non-reservoir facies of the Wabiskaw Member and are interpreted as distal offshore to shelf sedimentation. Deposits are characterized by fining-upward successions of burrowed planar-parallel glauconitic sand to sandy-mud (F19) and bluish silty mud to moderate grey mudstone with sand inter-beds (F20). More specifically, these deposits are interpreted as the progressive deepening of remnant distal tempestite to fair-weather deposition above storm wave base and shelfal mud deposits below storm wave base (i.e. offshore to shelf transition).

LSF: Lower Shoreface Association

Facies association 7 comprises bitumen-saturated sands of the Wabiskaw Member that are interpreted as lower shoreface deposition. These deposits consist of gradational to sharp-based, cleaning-and coarsening-upward, moderately burrowed fine-grained to medium-grained sands (F21). Deposits are dominated by wave-generated structures and exhibit trough cross-beds, oscillatory ripples, and HCS that represent the dominance of fair-weather and storm wave activity.

Lithostratigraphic Unit and Contact Descriptions

The McMurray Formation is bounded below by the sub-Cretaceous unconformity surface, reflecting a long period of erosion and non-deposition. Overlying deposits are characterized by complex stratal organization and lateral heterogeneity.

Stratigraphic correlation in the middle McMurray has resulted in an interpretation of up to four laterally extensive and preserved stacked depositional cycles. Each cycle consists of estuarine tidal channel point bars and/or tidal flat successions (IME), capped by fine-grained pedogenically altered salt marsh deposits (ECP). These deposits correspond to the brown and green units in the cross-sections, respectively. The middle McMurray represents filling of paleo-valleys in the Devonian surface, and underlies and flanks, thick upper McMurray deposits along a NW-trend in the central portion of the study area. This corresponds to a thickening of middle McMurray deposits outward from central OPCO south MacKay (where non-preserved) to the east-southeast and west-northwest in the deepest depressions of the Devonian paleo-surface (Fig.III-5B; III-6A). Correlation of individual channel successions in the middle McMurray is difficult across the study area due to the complexity of channel amalgamation, overall heterogeneity, lateral variability, and erosive nature of overlying upper McMurray deposits.

The base of the upper McMurray Formation is marked by a regionally extensive transgressive surface of erosion as defined by Allen and Posamentier (1993). Above this contact, any upper McMurray facies association can directly overlie the middle McMurray (Fig.III-13). This is an extremely distinct stratigraphic contact that is demarcated by a *Glossifungites* firmground in places, where *Thalassinoides, Teichichnus*, and *Arenicolites* burrows at the top of middle McMurray deposits are passively-filled with upper McMurray sediments. This firmground is most discernable in the south and southwestern portion of the study area. To the north-northeast, this surface becomes more difficult to trace, and wave-induced structures are more commonly observed directly above this contact (Fig.III-13). This contact is most distinct when overlying deposits consist of burrowed muddier bay-fill or offshore deposits. Where the middle McMurray Formation is not preserved, upper McMurray deposits directly overlie the sub-Cretaceous unconformity. This indicates that the ravinement surface eroded to, and reworked, the underlying Devonian carbonates. Contacts of the middle McMurray are indicated by solid lines in cross-sections.

The upper McMurray comprises ten cycles of deposition across the study area comprised of Low Energy Bay-fill (LEBF), Tidal Bars (TSB), Lower Shoreface and offshore (LSFO) lithostratigraphic units (Fig.III-14). These units correspond to the purple, yellow, and blue units in the cross-sections, respectively (Fig.III-9 to Fig.III-12).

Tidal Bar (TSB) stratal packages are characterized by the amalgamation of laterally accreting tidal sands, which produce broad and continuous bar complexes (Fig.III-14). Three main cycles of TSB deposition have been identified from the southwest-northeast that can be traced laterally across the study area (Fig.III-15). Each cycle has an erosive base, and ranges in thickness from approximately 2-15 m. A number of sharp contacts also exist within each cycle: these are due to intrabar amalgamation. Tidal bar complexes are thickest to the southeast of the study area, within the deepest depressions of the middle McMurray structural surface, and become thinner and less extensive to the northwest (Fig.III-6; Fig. III-15).

There are three low energy bay-fill cycles (LEBF) across the study area ranging from (5-15 m thick) (Fig.III-9 to Fig.III-12; Fig.III-14). These cycles are

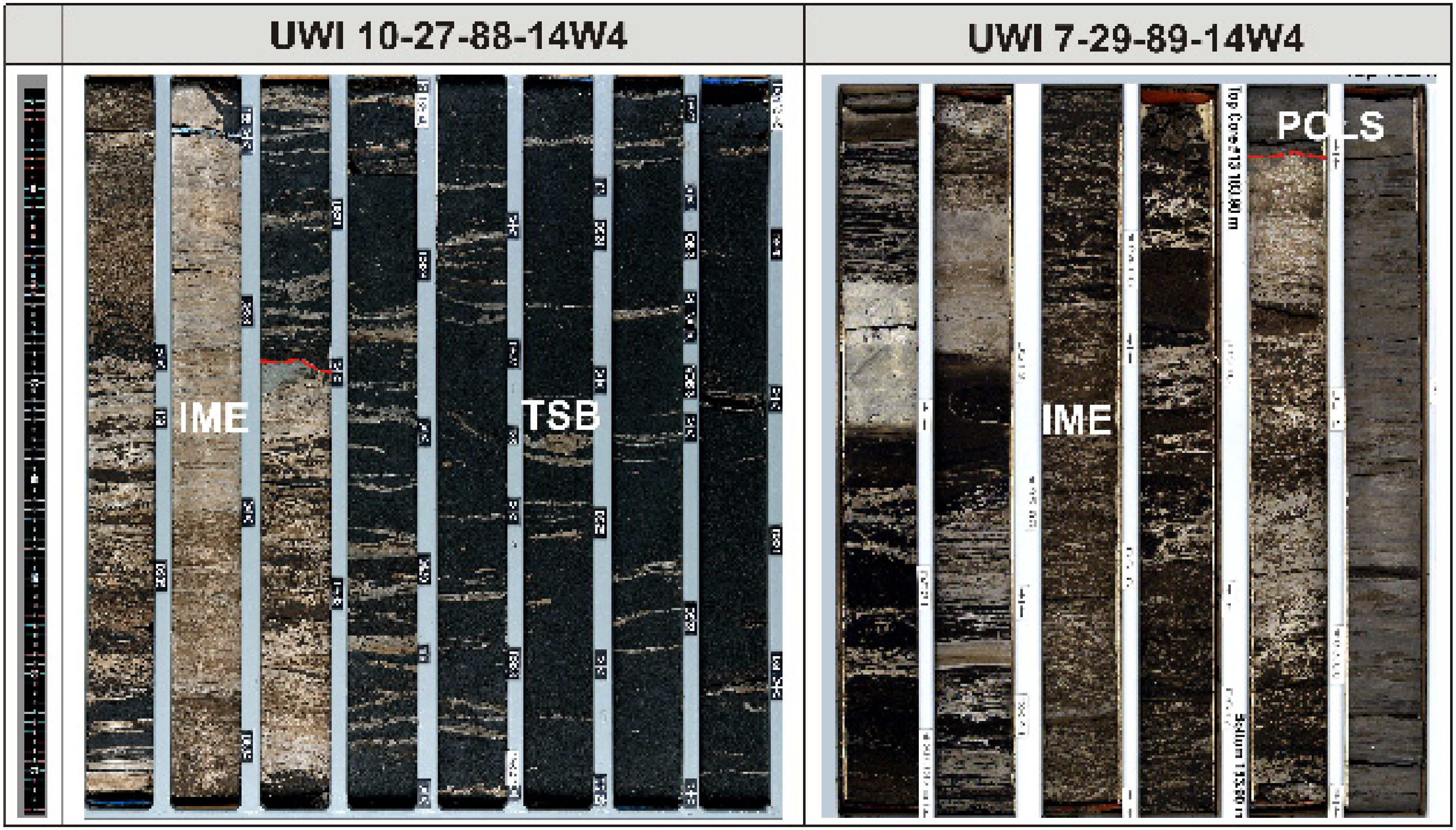

FIGURE III-13A: Core examples of the contact and relationship of facies associations in successions between the middle and upper McMurray.

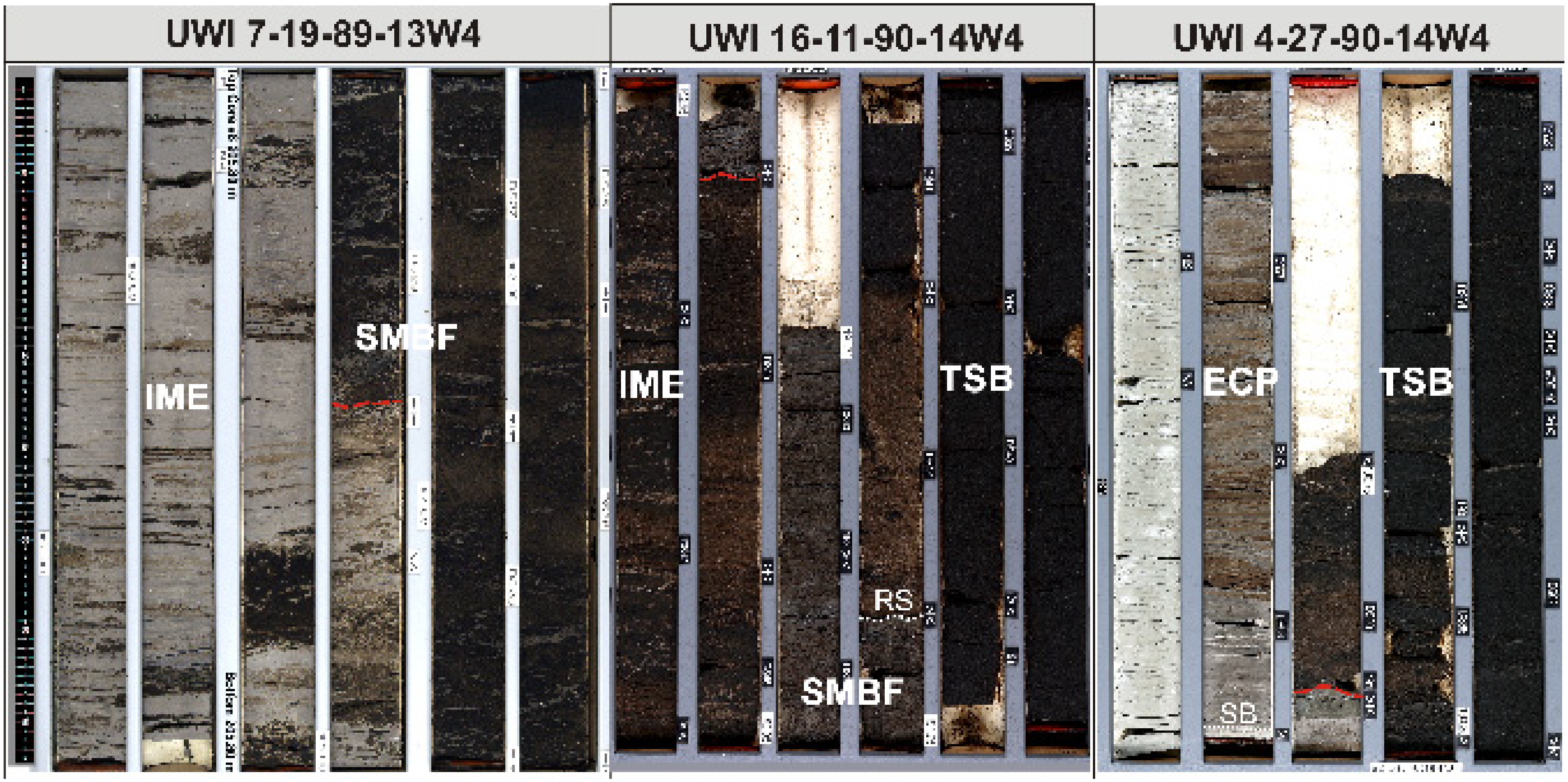

FIGURE III-13B: Core examples of the contact and relationship of facies associations in successions between the middle and upper McMurray.

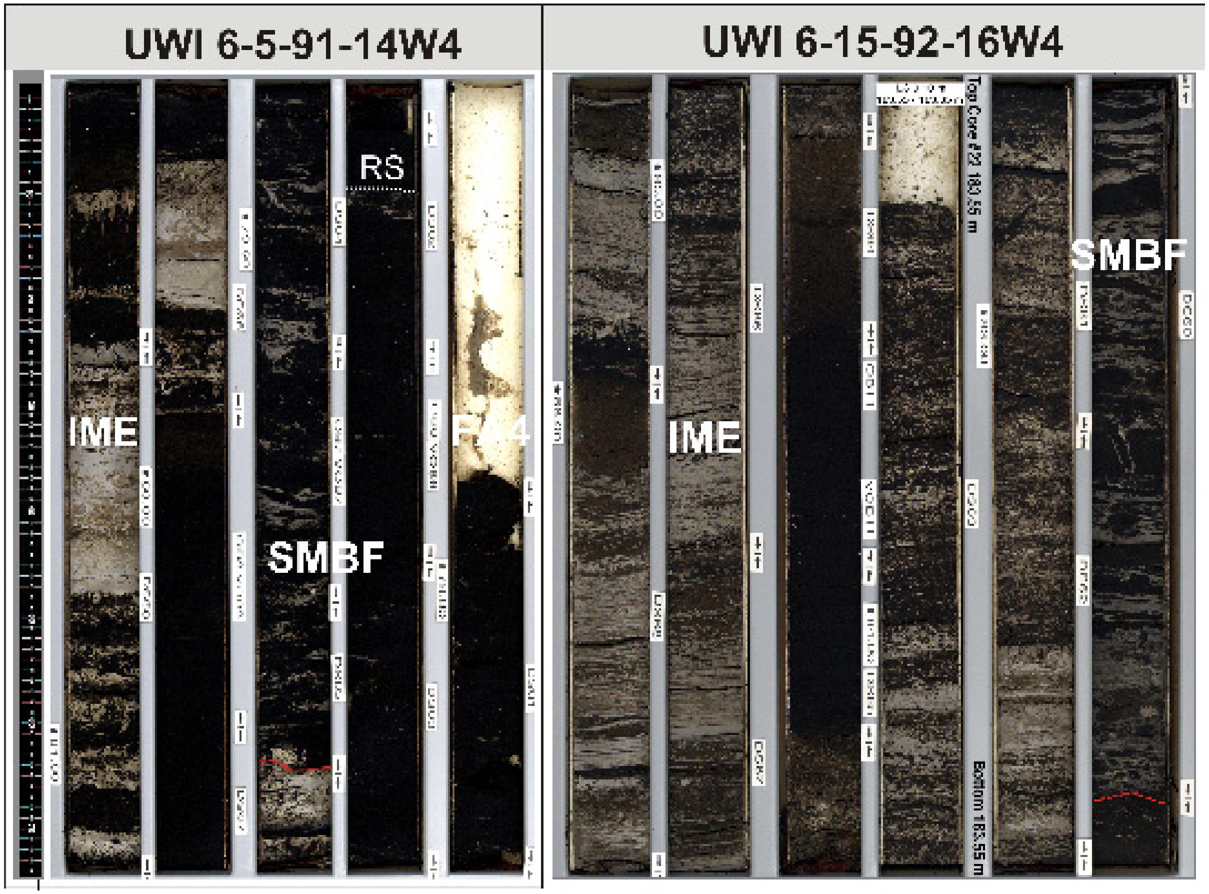

FIGURE III-13C: Core examples of the contact and relationship of facies associations in successions between the middle and upper McMurray. A distinct ichnological change occurs across the contact from middle to upper McMurray deposits from a brackish water ichnofacies to a tidally-influenced or proximal *Cruziana* ichnofacies. Examples are organized from south to north of the study area from 13A to 13C. This contact is highlighted in red. Additional allostratigraphic contacts are highlighted in white; RS-Regressive Surface; SB-Sequence Boundary. For detailed sedimentological and ichnological descriptions of FA refer to table III-1.

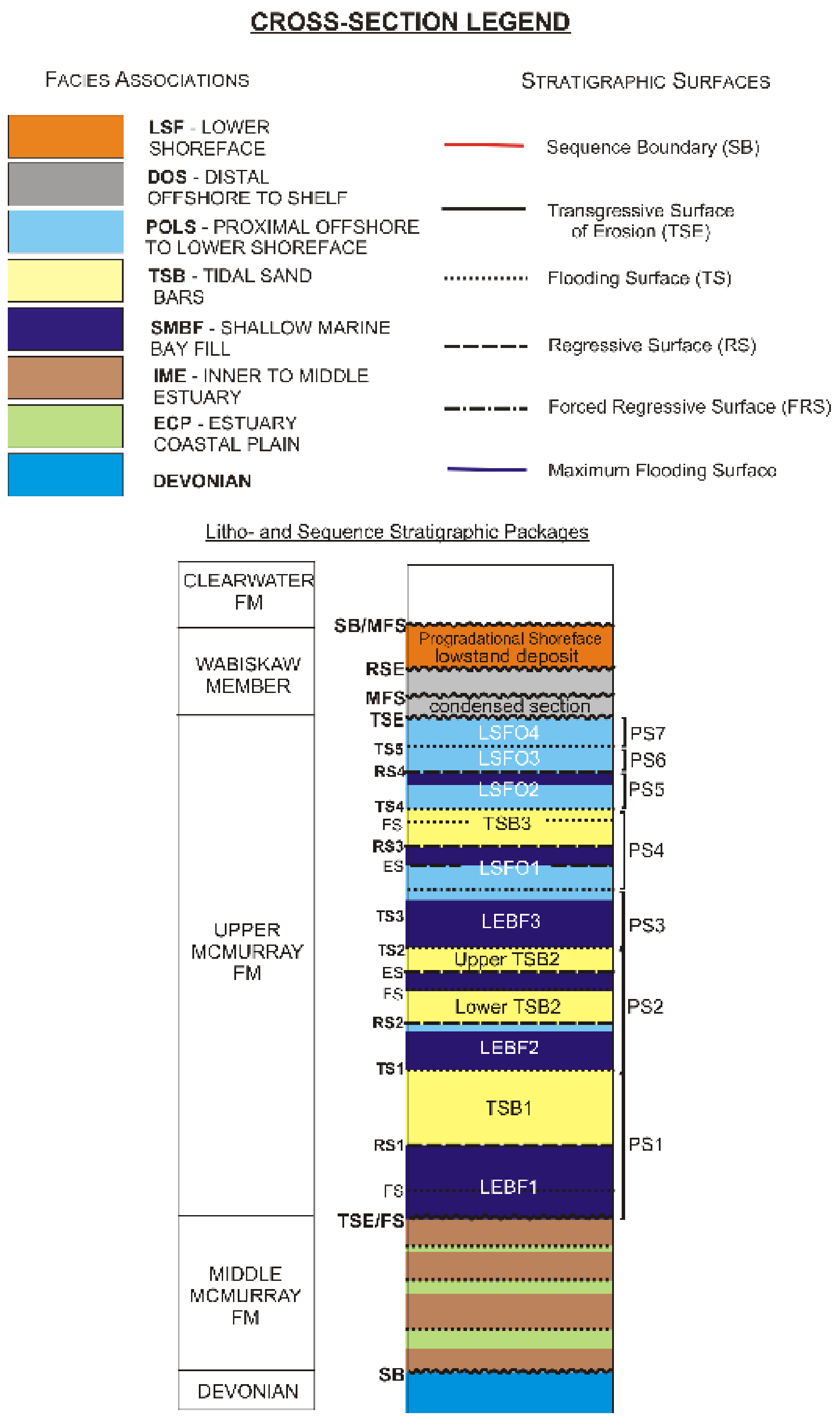

Figure III-14: Idealized schematic illustrating both lithostratigraphic and sequence stratigraphic packages and surfaces interpreted in the McMurray-Wabiskaw stratigraphic

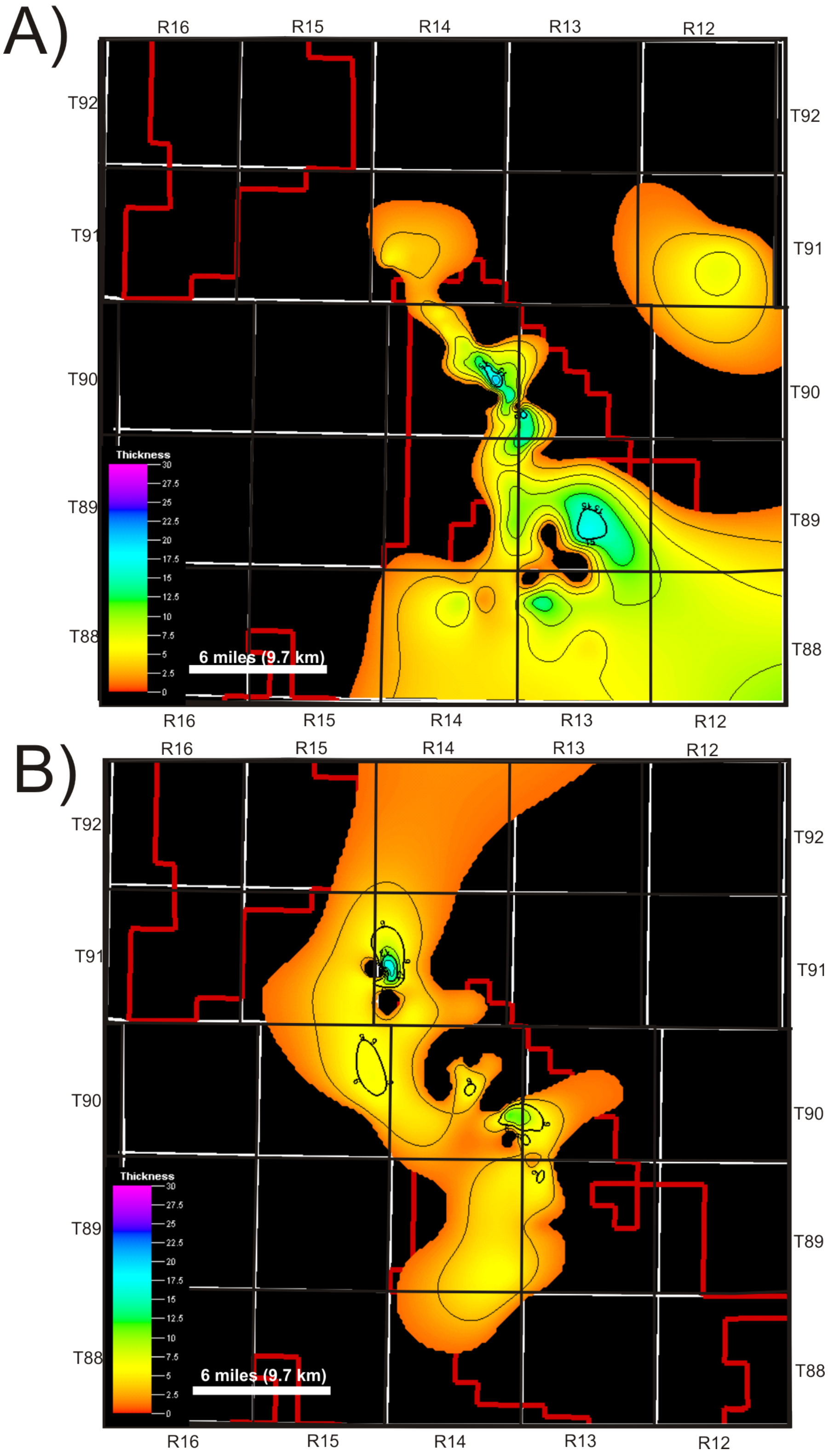

FIGURE III-15

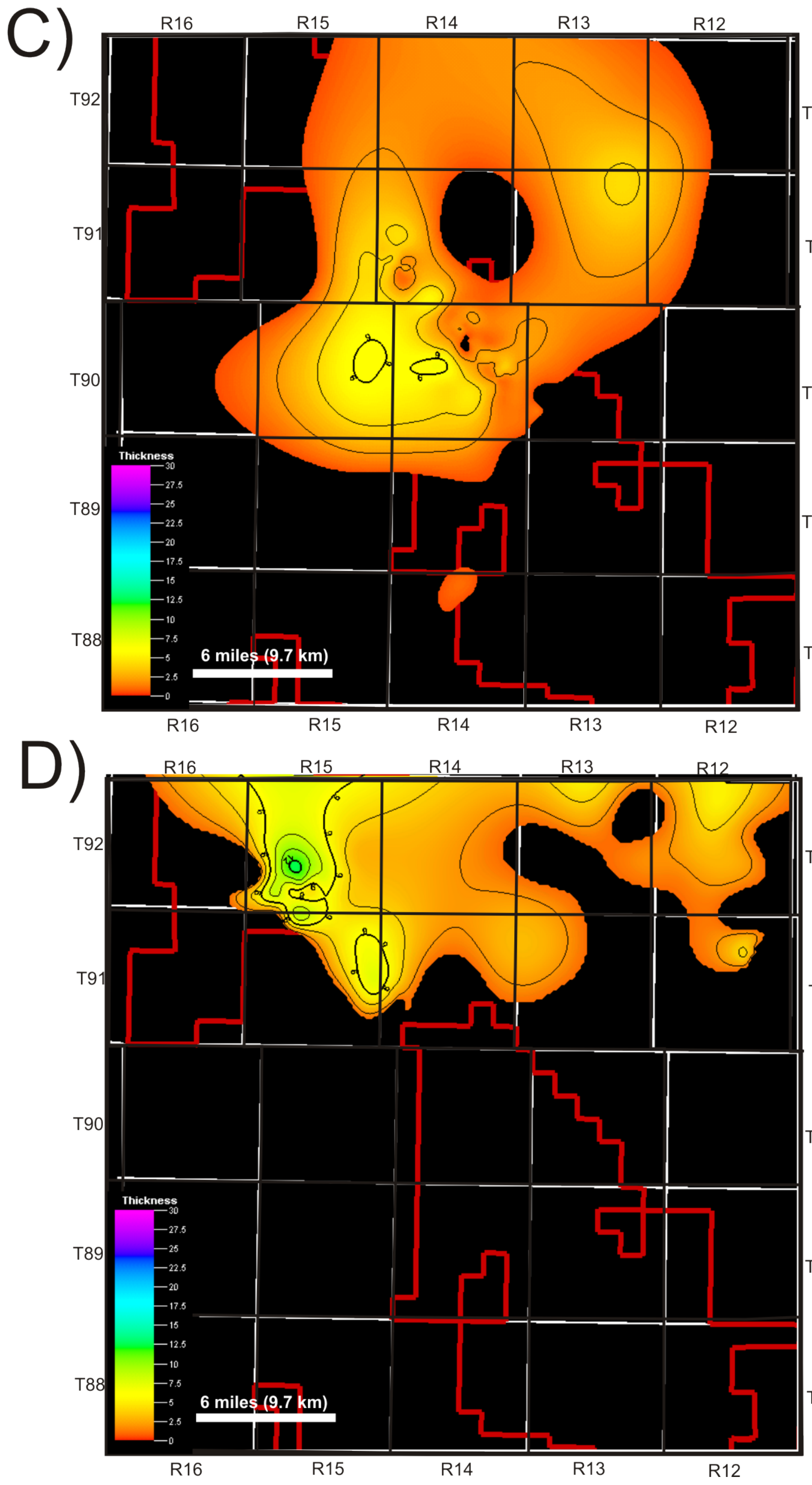

FIGURE III-15 CONTINUED: Isopach maps of the upper McMurray tidal sand bar depositional cycles. Three main cycles were identified and are ordered from oldest (A) TSB1 (B-C) TSB2 to youngest (D) TSB3. The first depositional cycle reflects the thickest laterally continuous sands in the study area (TSB1). AOSC lease areas are outlined in red. (A-B) Contour interval=3m. (C-D) Contour interval=2m.

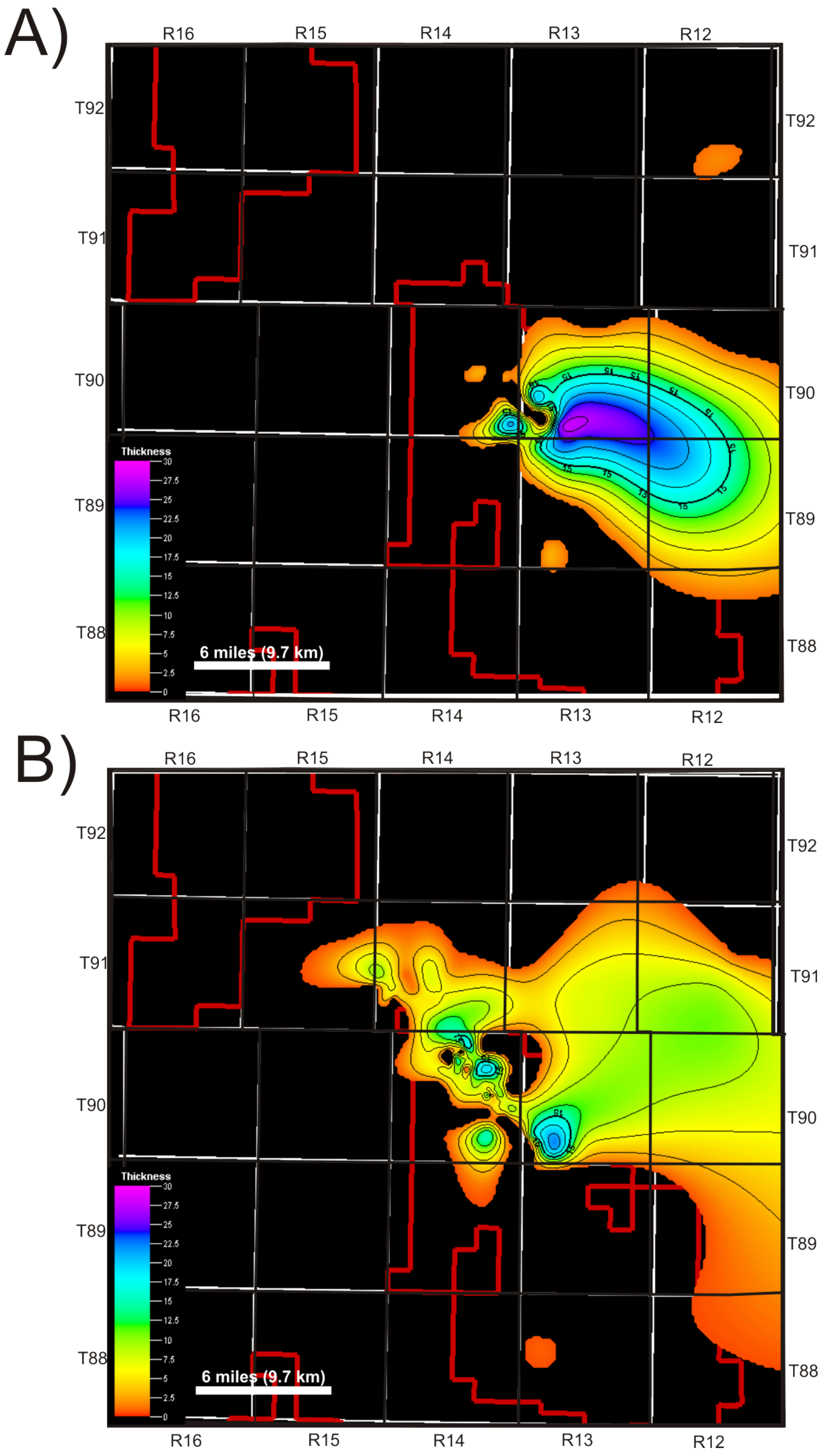

FIGURE III-16

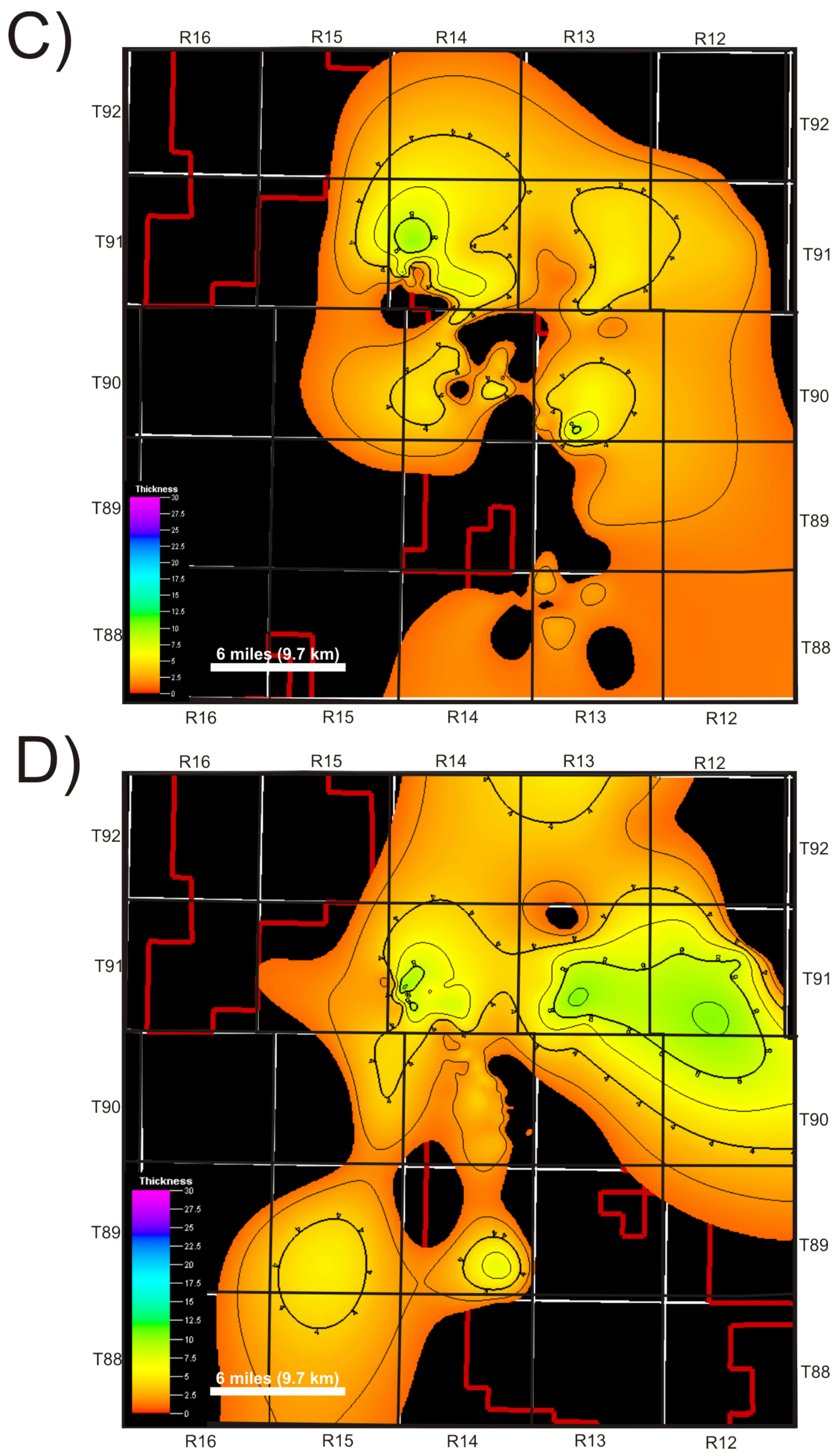

FIGURE III-16 CONTINUED

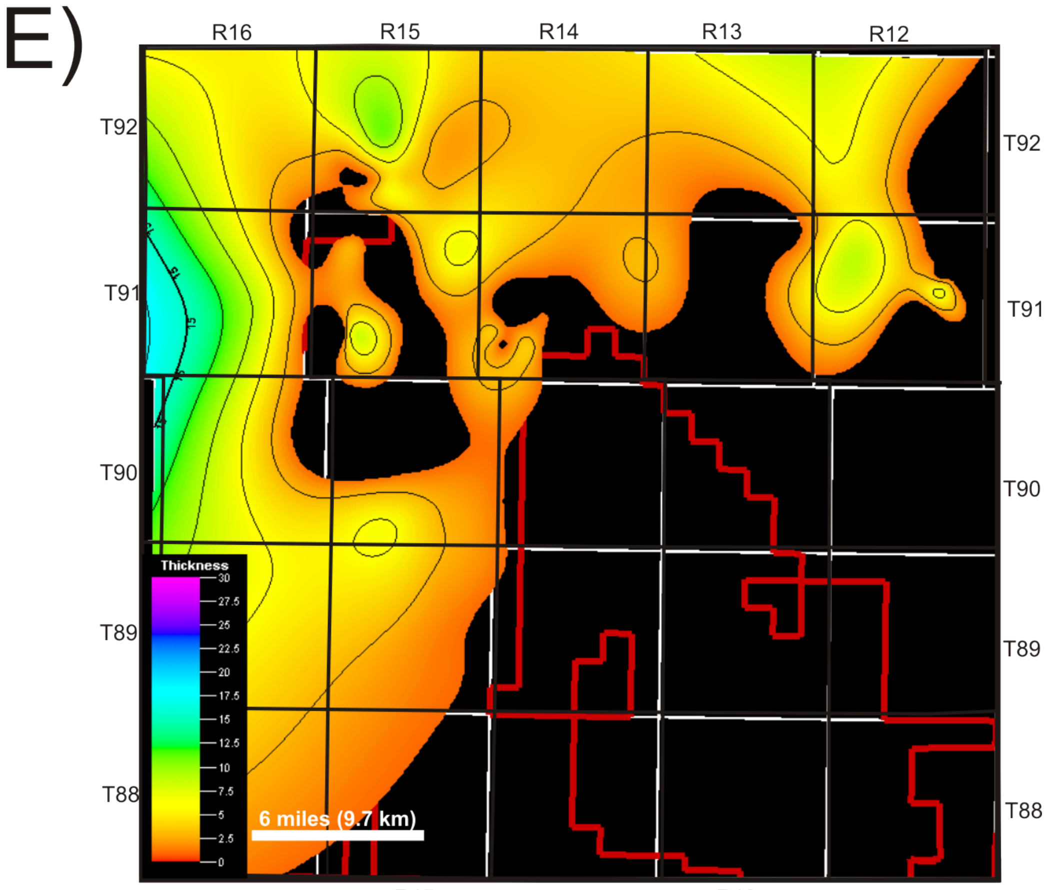

FIGURE III-16 CONTINUED: Isopach maps of upper McMurray SMBF packages. Five cycles were identified and are ordered from oldest (A) to youngest (E). Bay-fill cycles occur between tidal bar successions and comprise the three main LEBF lithostratigraphic packages as illustrated by (A) (B) and (D). (C) reflects SMBF deposition between TSB2. LEBF are initially thick and localized within paleotopographic lows. Through time they become thin deposits that are more regionally widespread. AOSC lease areas are outlined in red. (A-D) Contour interval=3m. (E) Contour interval=2m.

thickest in the southern MacKay OPCO lease area and typically form coarsening-upward retrogradational successions of well-burrowed SMBF deposits, and are gradational with overlying POLS deposits. Bay-fill cycles (LEBF) occur between TSB successions and are initially thickest in the east of the study area along a northwest-trend within lows of the middle McMurray structure (Fig.III-16; Fig. III-6B). Throughout McMurray time, deposits thin, become more regionally widespread, and exhibit a decrease in the sand to mud ratio. Cycles can also inter-finger with TSB, and show both fining- and coarsening-upward cycles, reflecting the multifaceted migration of the tidal bar complex.

Four lower shoreface to offshore (LSFO) cycles also exist in coarsen-upward successions dominated by POLS that are based by SMBF to the northwest (Fig.III-9 to Fig.III-12; Fig.III-14). These cycles are typically less than 6 m thick and are regionally extensive across the northwest half of the study area, with thickest and most distal deposits to the west-southwest (Fig.III-17). Successions are laterally extensive and continuous, averaging approximately 5-8 m thick (Fig. III-17). Depending on the stacking and lithologic relationship between these units, cycles can be both progradational or retrogradational across the area.

A regionally extensive erosional bounding discontinuity occurs at the top of the McMurray Formation, as indicated by a dashed surface line in cross-section, and separates strata of the Wabiskaw Member (Fig.III-9 to Fig.III-12; Fig. III-18). This surface is relatively flat and scours into underlying McMurray stratal packages. In places, particularly in the southwest portion of the study area, it is also characterized by a *Glossifungites* firmground, where robust *Diplocraterion* burrows are passively-filled by overlying glauconitic Wabiskaw DOS marine sands. To the north, this surface is more commonly abruptly overlain by storm event deposition. To the eastern-most portion of the study area, upper McMurray deposits are not preserved, and Wabiskaw DOS deposits directly overlie the middle McMurray Formation (Fig.III-19). The Wabiskaw Member reflects a regionally extensive succession of consistent thickness, reflecting the offshore to shelf transition that is marked by a maximum flooding surface (datum). Shelfal muds (DOS) overlie this surface and are then abruptly overlain by the northeast-trending sharp-based Wabiskaw LSF. These associations correspond to grey and orange units in the cross-sections, respectively. The top of the Wabiskaw sand is bound by a maximum flooding surface separating marine muds of the Clearwater Formation.

Lithostratigraphic Interpretation

Two distinct paleo-lows are evident, to the west and to the east, which influenced the initial stages of estuarine development (Fig.III-7A). The estuarine complex is interpreted to have migrated within these lows, developing multiple terraces as the valleys in-filled with sediment. Transgressive middle McMurray sedimentation ceased when paleo-lows in the Devonian surface were filled, resulting in a relatively flat sub-basin configuration.

Upper McMurray Formation deposition is interpreted to have commenced following a transgression of the Boreal Sea. This change resulted in a relatively flat, broad marine embayment that filled from the south-southeast to the north-northwest. This marine embayment likely had shallow depths and little relief across the study area. The basal surface is interpreted as an erosional surface

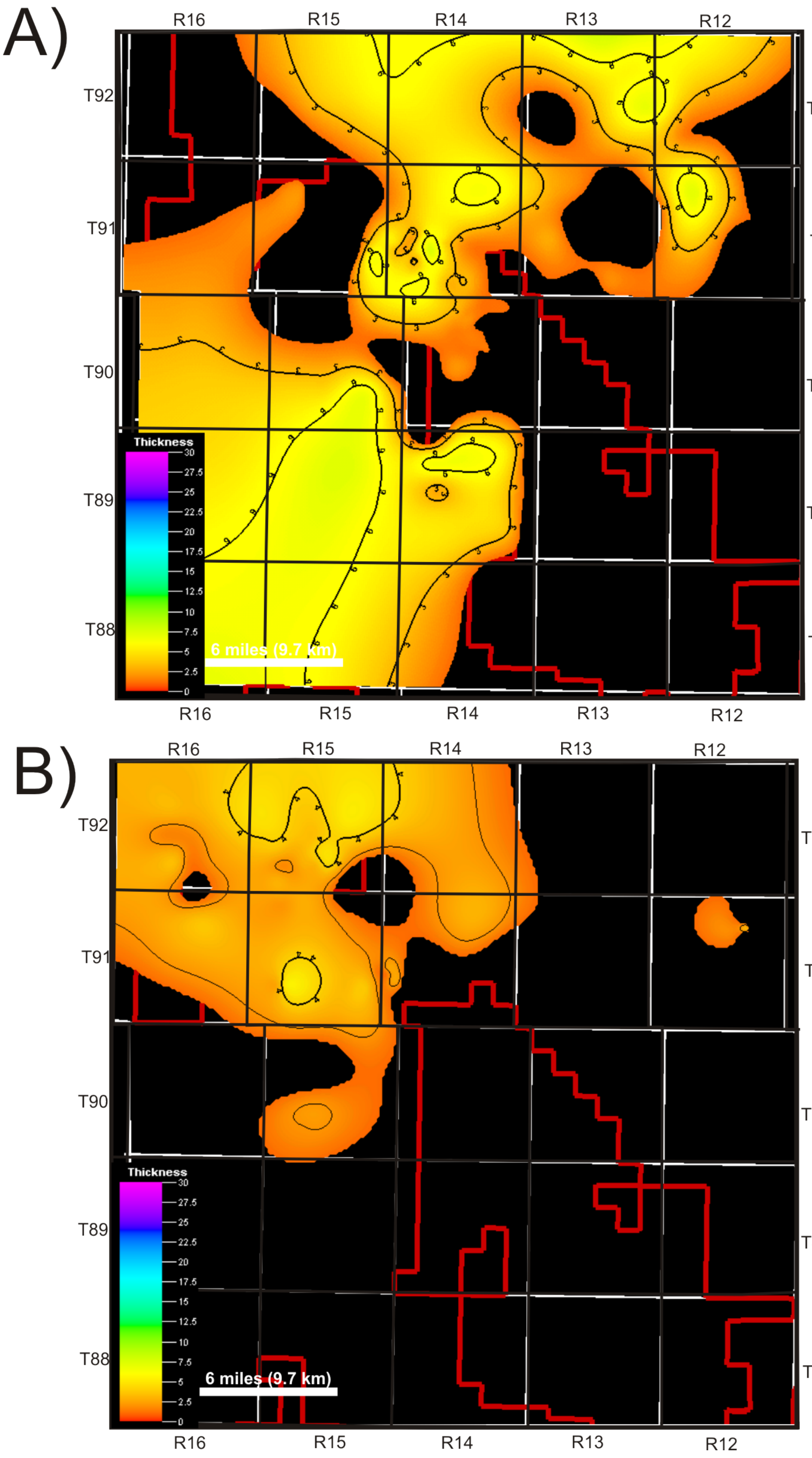

FIGURE III-17

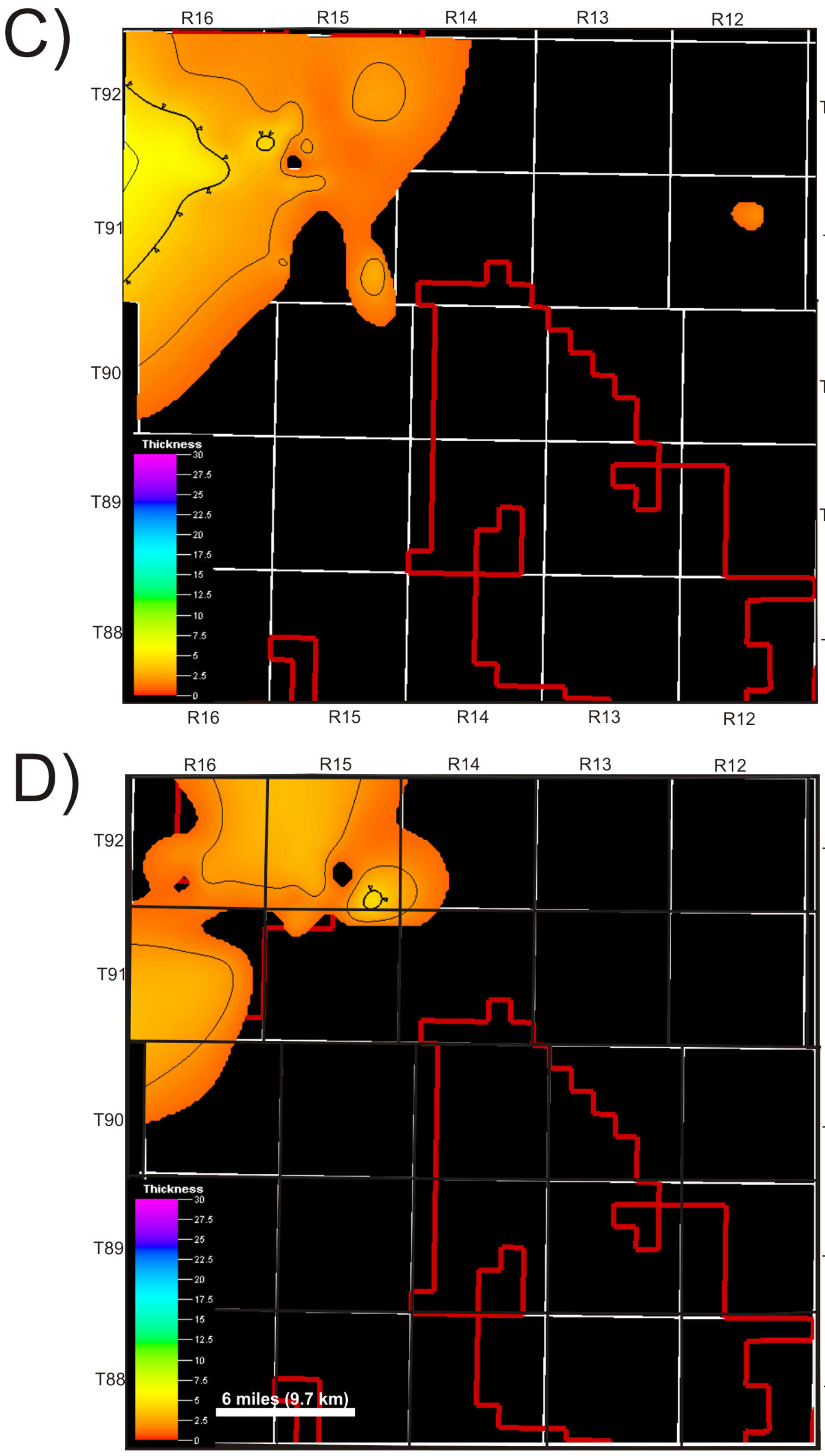

FIGURE III-17 CONTINUED: Isopach maps of upper McMurray offshore to lower shoreface depositional cycles. Four main cycles ordered from oldest (A) to youngest (D) were identified and are restricted to the northwest portion of the study area where thickest deposits occur along a northeast-trend. AOSC lease areas are outlined in red. (A) Contour interval=3m. (B-D) Contour interval=2m.

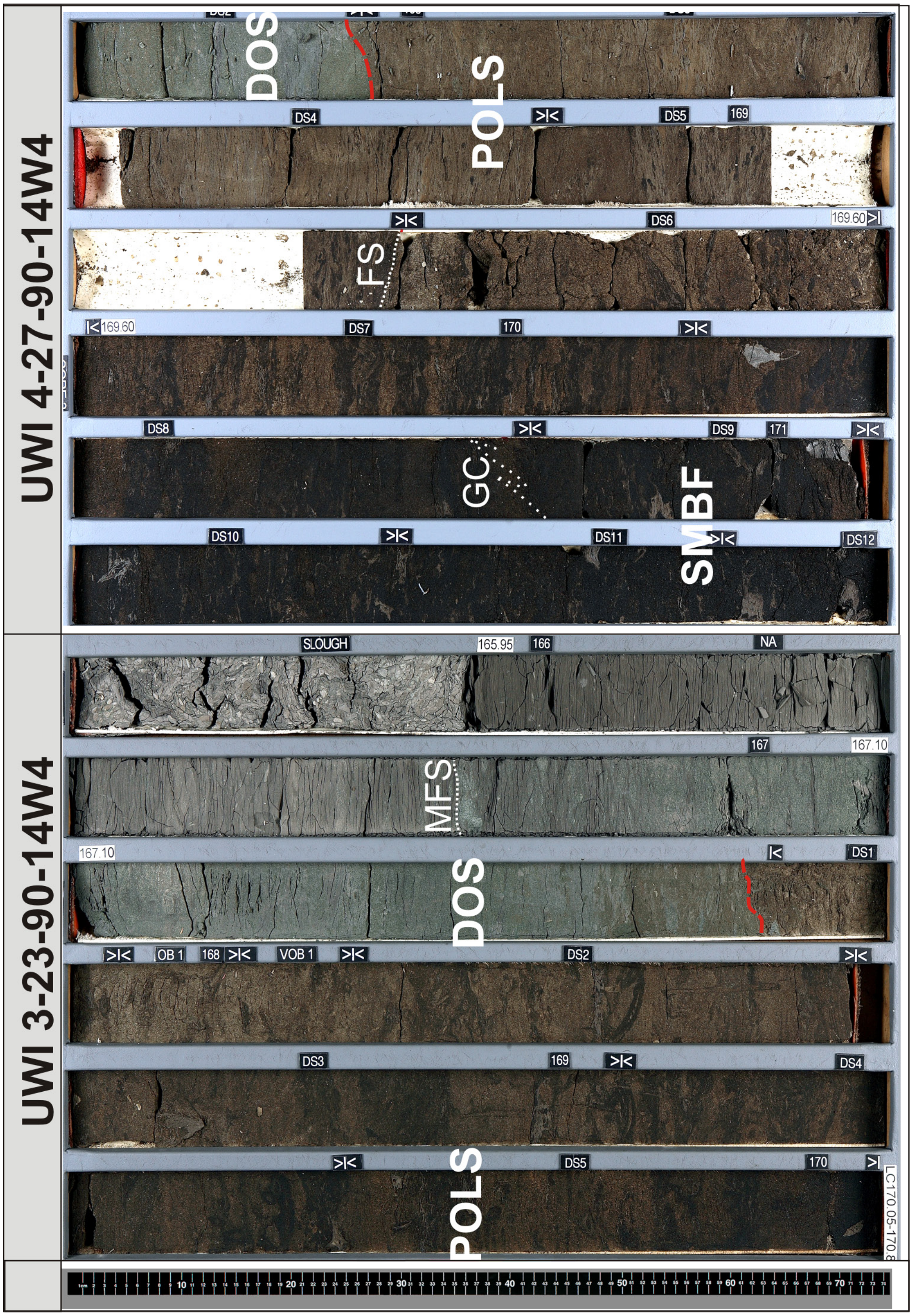

FIGURE III-18

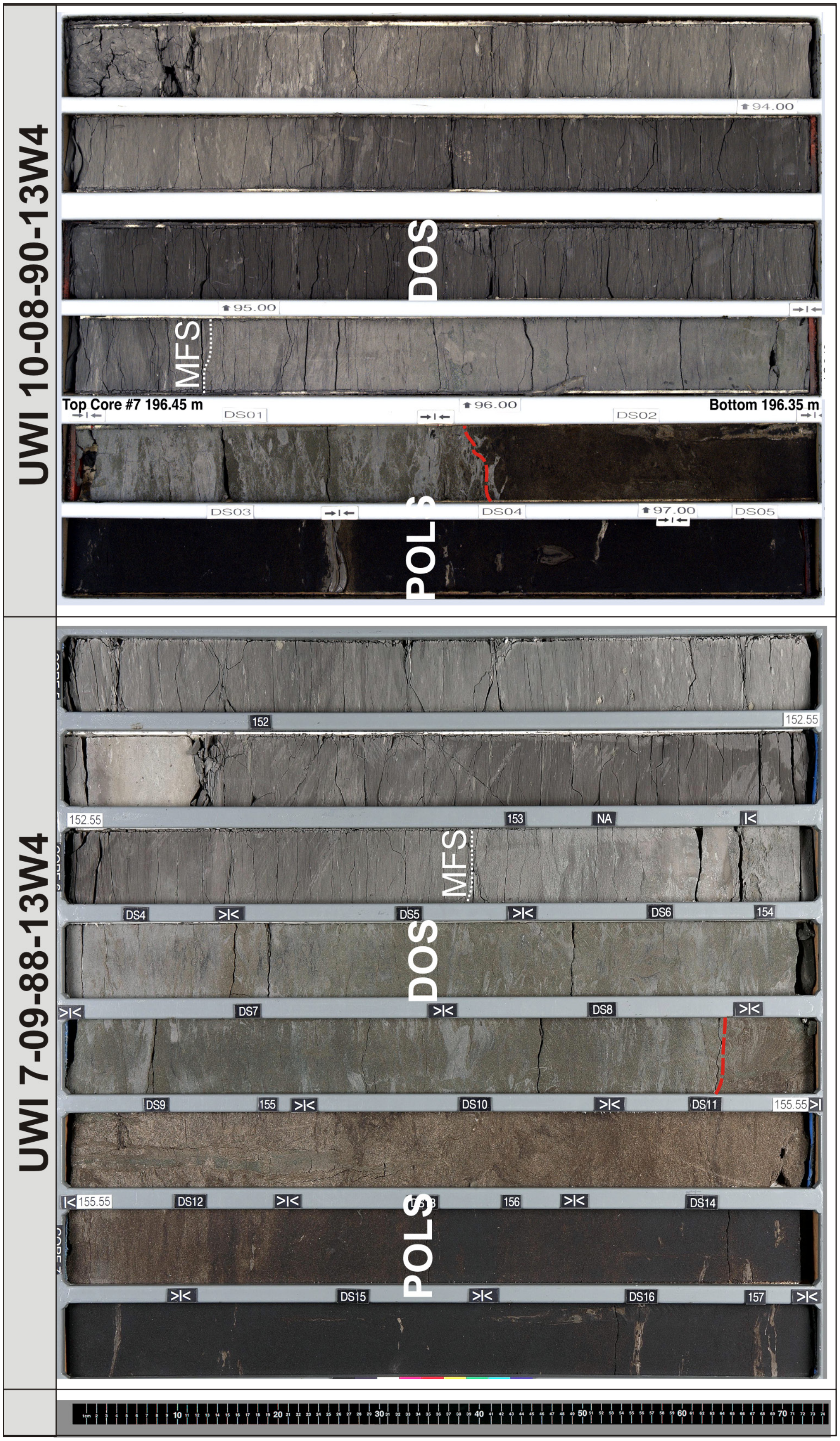

FIGURE III-18 CONTINUED

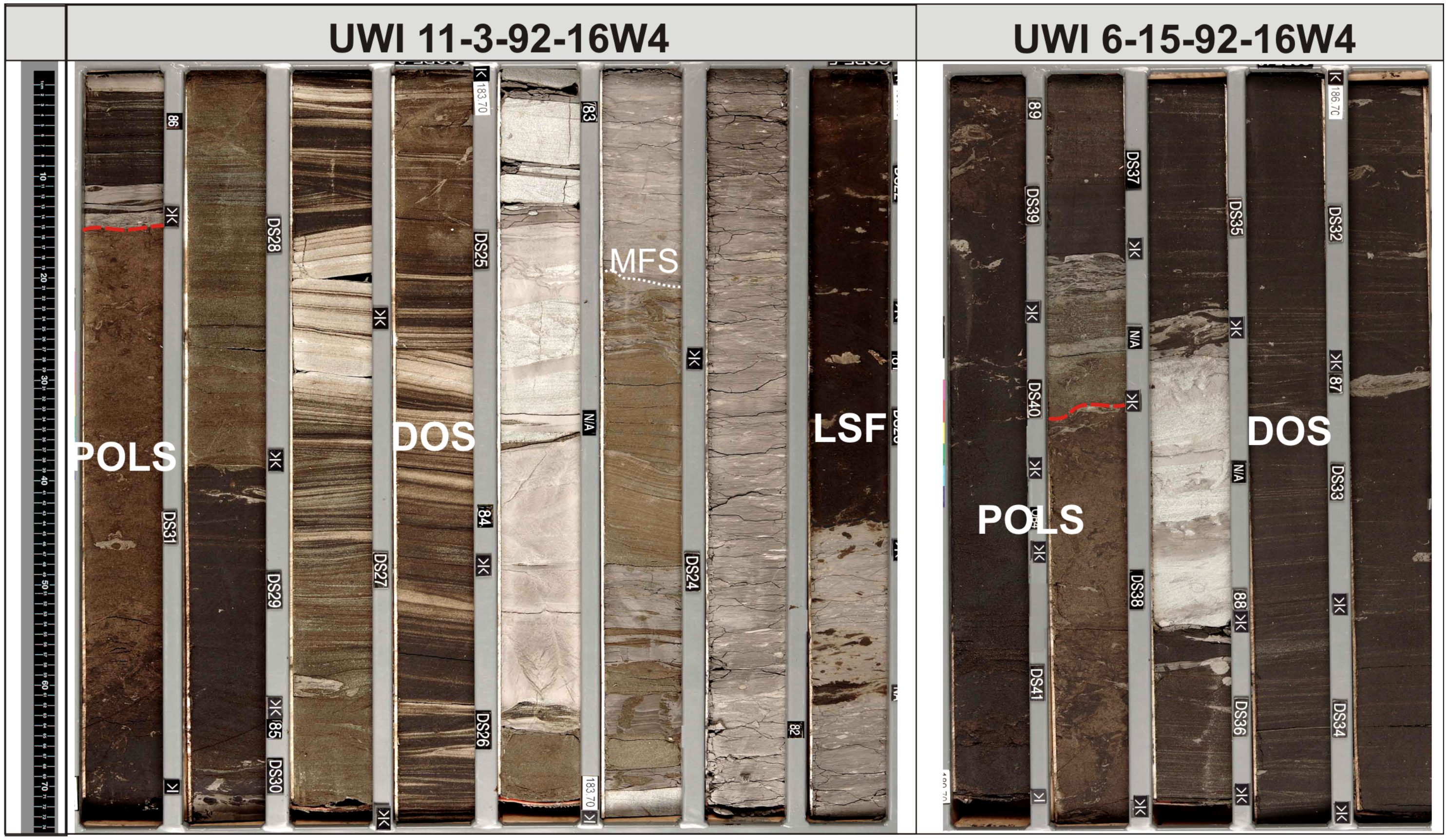

FIGURE III-18 CONTINUED: Core examples of the contact between upper McMurray and Wabiskaw Member deposits. A distinct sedimentological change occurs across the contact from upper McMurray to deposits of the Wabiskaw Member with the presence of glauconite. This contact reflects a TSE and omission surface, and is typically marked by a *Glossifungites* hardground, but may be overlain by storm deposits. Where this occurs, it is interpreted as modification through wave ravinement. Examples are organized from south to north of the study area from top left to bottom right. This contact is highlighted in red. Additional allostratigraphic contacts are highlighted in white; FS-Flooding Surface; MFS-Maximum Flooding Surface; GC-Gradational Facies Contact. For detailed sedimentological and ichnological descriptions of FA refer to table II, Appendix A.

between middle and upper McMurray deposits, caused by both wave and tidal ravinement processes (Fig.III-13). Locally, tidal ravinement has deepened this surface several meters forming lows in the middle McMurray structure (Fig.III-6B). In much of the South MacKay OPCO lease area, middle McMurray deposits are not preserved, indicating that tidal ravinement eroded to, and reworked the sub-Cretaceous unconformity. This is best observed along the northwest-trending central MacKay section and perpendicular northeast-trending section. Cross-sections have also identified that localized tidal ravinement reaches depths of at least 20 m. This erosional surface is regionally widespread and is also known to be mappable further to the north of the study area.

<u>Stratal Package 1:</u> Overlying this surface is the first depositional package of the upper McMurray Formation reflecting a LEBF cycle deposited in the lowermost southeast-most portions of the study area. Lithostratigraphic units consist of two stacked SMBF cycles that are separated by a flooding surface (Fig.III-16A). Successions are typically coarsening- and cleaning-upwards, less commonly, fining- and muddier-upward, and are dominated by well burrowed non-reservoir sand and mud facies. These cycles also appear to be structurally confined to the deepest depressions in the middle McMurray structure (Fig.III-7B) to the southeast along a north-northeast trend, and reflect background interbar sedimentation. To east-northeast there is a lack of well control and to the west-northwest these deposits down-lap onto a thicker package of middle McMurray strata.

<u>Stratal Package 2:</u> Overlying these bay-fill deposits is the second depositional package, consisting of coarsening-upward amalgamated TSB. These deposits deeply incised and eroded the southeast and northwest margins of the underlying LEBF cycle, where incision is estimated to at least 25 m (Fig.III-20; Fig.III-21A). In these areas, deposits reflect the base of upper McMurray reservoir sands and directly overlie and down-lap onto the middle McMurray or the sub-cretaceous unconformity. These erosional surfaces become correlative in a basin-ward direction (northwest) (Fig.III-22).

Stratal package 2 was deposited as northwest-trending elongate sand bars, commencing along a southwest to northeast trend in the southeast portion of the study (Fig.III-15A). In the southeast, these reservoir sands are dominated by wavy-bedding that clean-upwards to weakly bioturbated horizontal to cross-bedded sands, forming a laterally extensive amalgamated succession averaging 10-15 m in thickness. Down-dip (to the northwest), this succession becomes

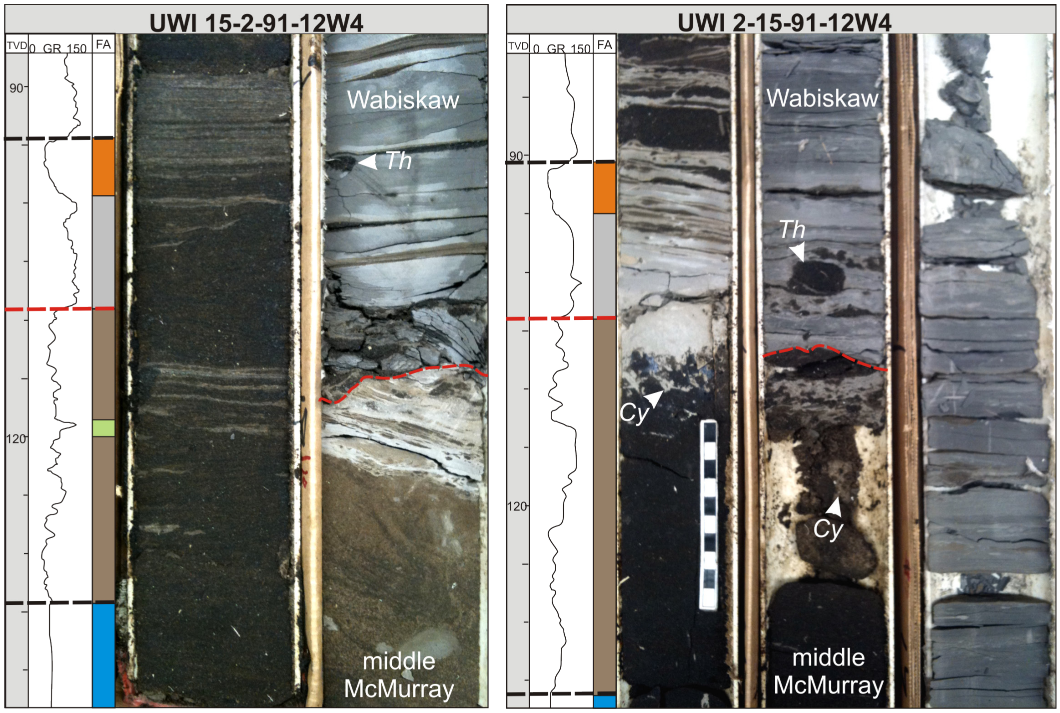

FIGURE III-19: Core examples of the contact between middle McMurray and Wabiskaw Member deposits. When the upper McMurray Formation is not preserved, distal offshore and shelf deposits of the Wabiskaw Member directly overlie estuary deposits of the middle McMurray. This contact is marked by an erosional discontinuity, outlined in red, and illustrates a *Glossifungites* firmground. Well 15-2-91-12 and 2-15-91-12w4 illustrate good examples of this surface and are compared to their corresponding gamma-ray wire-line log signatures.

slightly muddier and has more marine ichnogenera, and a decrease in thickness, bioturbation intensity and diversity upwards. These deposits are interpreted as the amalgamation of medial to distal tidal sand bars.

Following deposition in the southeast, TSB migrated to the northwest depositing as an elongate sand bar complex, up to 18 m in thickness, in the S-central portion of the study area (Fig.III-15A). In this area, tidal bars are dominated by ripple-laminated and cross-bedded reservoir sands, interpreted as medial to proximal sand bars. These sands illustrate weak bioturbation overall, with a decreases upwards, corresponding to increased energy levels upwards. Deposits also thin to less than 5 m, and down-lap, to the northwest, making this bar complex appear to be progradational. A northwest-trending depression in this area however, illustrates that this is instead attributed to strong structural control and bar restricted migration rather than progradation (Fig.III-7B). This package is interpreted to reflect the lateral accretion and migration process along the bay-margin and between bedrock islands, where elongate geometries are a result of confinement to structural lows. A discrete flooding surface marks the top of these

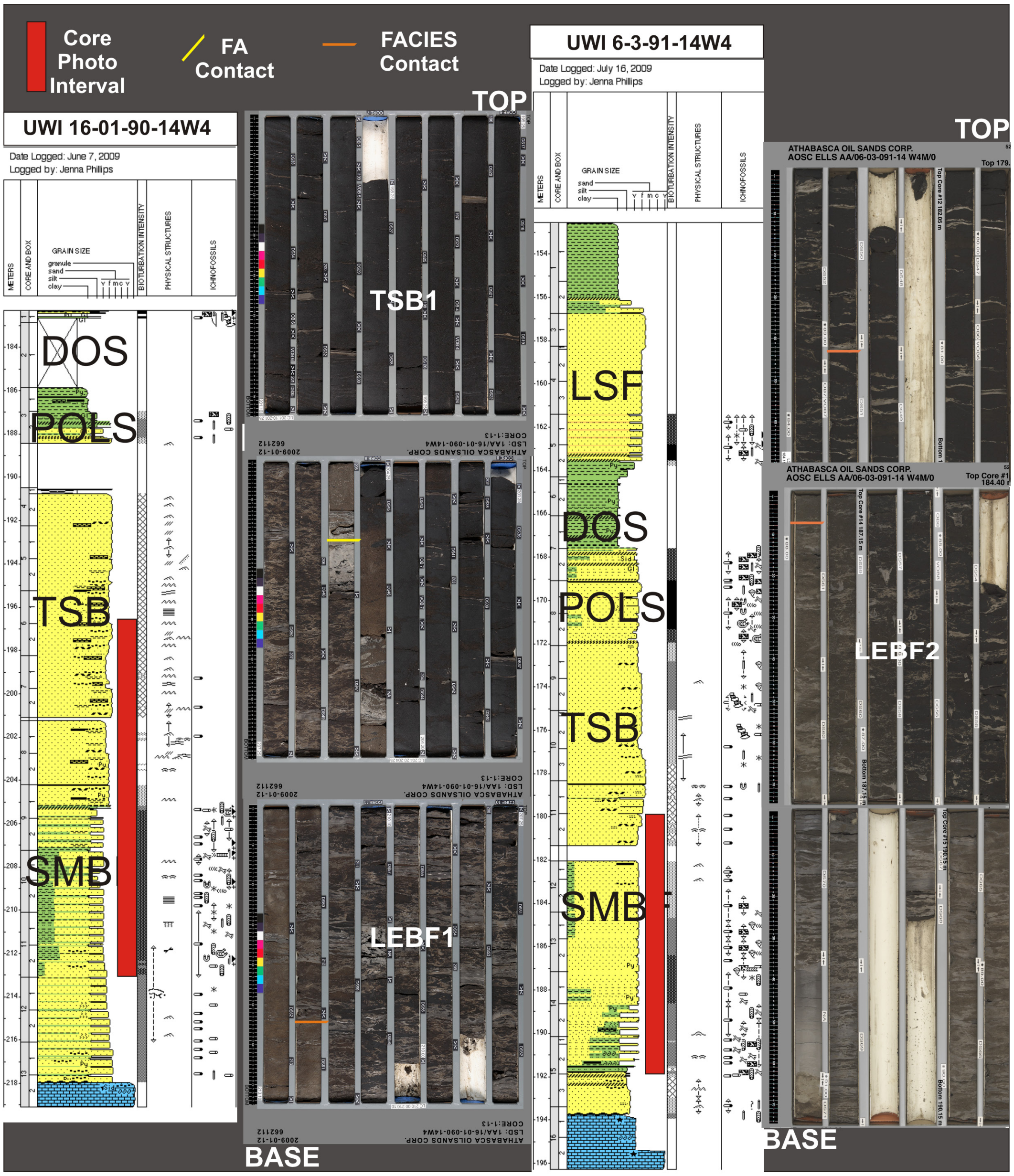

Figure III-20: Examples of the first three lithostratigraphic packages in core. Well 16-01-90-14W4 illustrates longate amalgamated sand bars of TSB1 and the erosional contact with underlying SMBF deposits of LEBF1. This is interpreted as a tidal ravinement surface. A discrete flooding surface marks the top of TSB1 and is overlain by SMBF deposits of LEBF2. This is illustrated in well 06-03-91-14W4 and is interpreted as retrogradation and on-lap of the underlying flooding surface and TSB cycle.

TSB complexes and terminates down-dip onto middle McMurray deposits.

Stratal Package 3: The third depositional package overlies this flooding surface, which is typically characterized by a decrease in grain-size and change in ichnological content. This surface is extremely subtle in most places, indicating very slow transgression and sedimentation. Overlying deposits consist of a

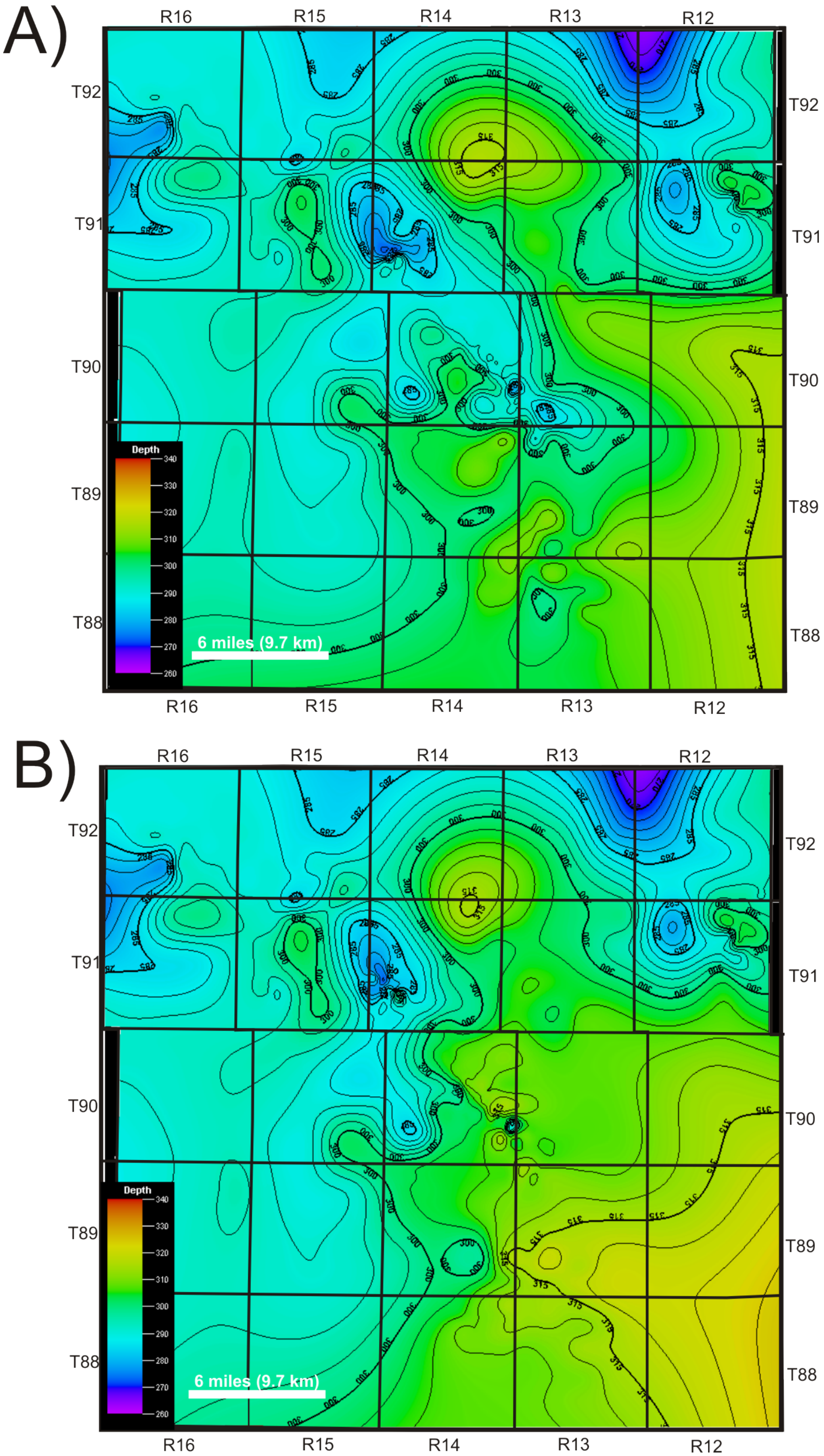

FIGURE III-21

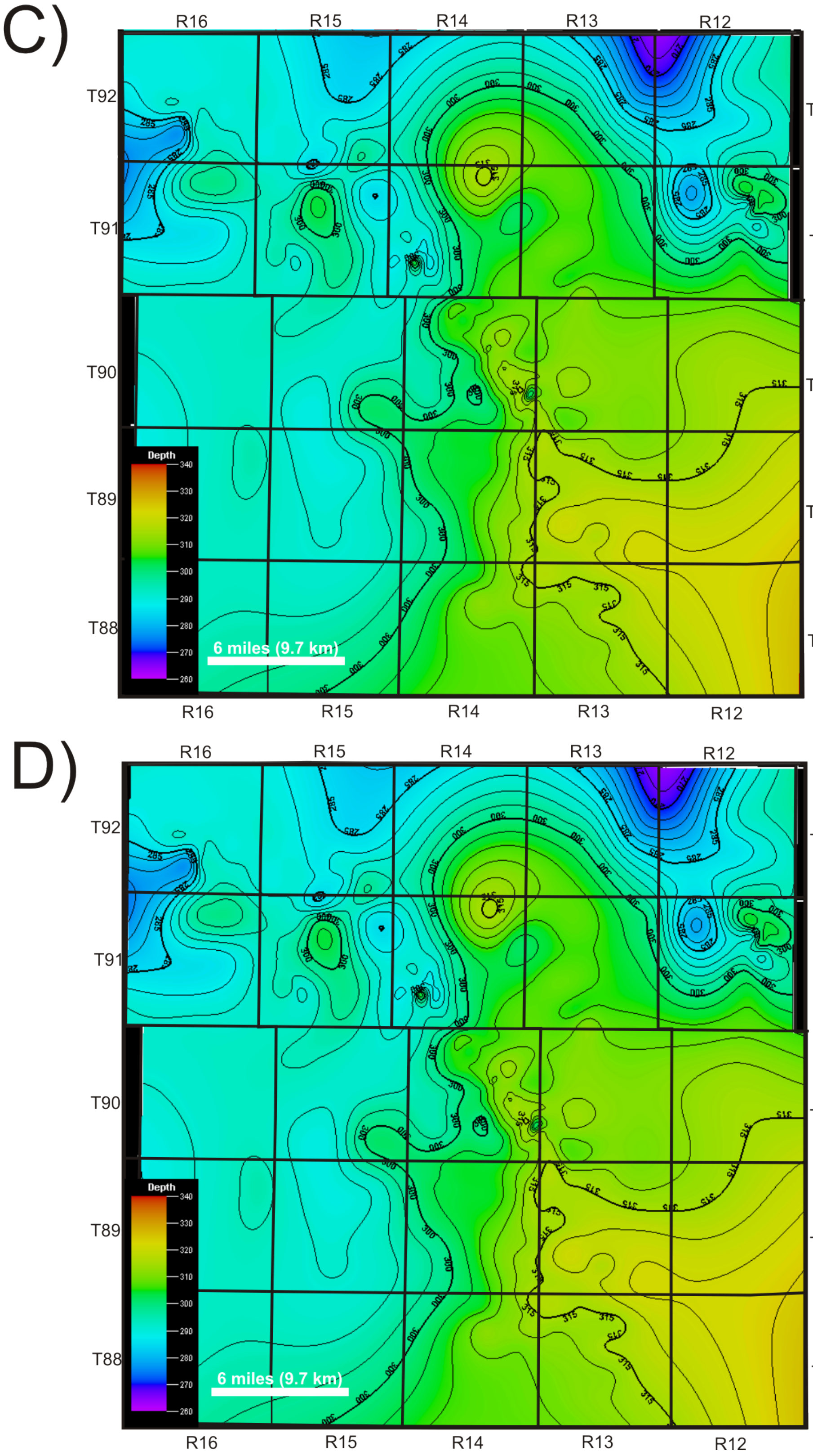

FIGURE III-21 CONTINUED: Structure maps of allostratigraphic surfaces in the upper McMurray Formation. (A) Top of bay-fill cycle 1 (RSE1), (B) top of bay-fill cycle 2 (RSE2), (C) top of bay-fill 2 (RSE3), and (D) top of bay-fill 5 (RS5). Contour Interval=3m.

FIGURE III-22: Core examples of ravinement and flooding surfaces. Ravinement of underlying bay-fill cycles through tidal current action is interpreted to have developed the major allostratigraphic surfaces illustrated in wells 16-01-90-14w4. Both examples illustrate tidal bar successions (TBS) erosionally overlying fair-weather bay-fill deposition (SMBF). Well 6-16-90-14w4 illustrates the first major flooding surface, with a bay-fill cycle overlying tidal bar successions. Refer to Figures 9 to 12 for more detail on the stratigraphic position and nature of these surfaces. RS-Regressive Surface; FS-Flooding Surface.

LEBF cycle characterized by wavy-bedded sands, high bioturbation intensities and a high diversity and density assemblage of mud-filled burrows and linings of complex marine ichnogenera. Overall, deposits are sand-dominated in the N-central MacKay River area, comprising dominantly reservoir quality sands, but become inter-bedded and muddier to the east (Fig.III-16B). An up-dip lateral facies change from distal and medial SMBF to POLS reflects a progressive deepening upward, and to the southeast. This is interpreted as retrogradation and on-lap of the underlying flooding surface and TSB cycle (Fig.III-20).

Thickest deposits of strata package 3 occur in the north-central MacKay OPCO lease areas, where they average 15 m thick, and are laterally continuous to the northeast. From north-central MacKay River (T90-R14), these deposits are dominated by POLS that eventually thin and on-lap onto thicker middle McMurray deposits to the northeast (Fig.III-16B). Deposits of this bay-fill cycle are interpreted to reflect filling of the remaining lows during slow transgressive conditions (Fig.III-21B,C).

Stratal Package 4: Stratal package 4 exhibits two stacked proximal to medial TSB cycles averaging ~3-12 m thick (Fig.III-15B,C). TSB's are dominated by small- to large-scale cross-bedded and cryptobioturbated medium-grained reservoir sands. The lower TSB succession typically has a fining- and muddier-upward trend. The second TSB is typically a coarsening- and cleaning-upward cycle. Tidal bars in both successions also exhibit linear, elongate geometries and locally scour the underlying bay-fill cycle of at least 7 m depth. Thin (~3-5 m thick) wavy-bedded SMBF deposits locally separate TSB successions reflecting the complexity in tidal bar accretion and migration (Fig.III-16C). This is evident in the South MacKay OPCO lease area where basal contacts of both TSB are sharp and erosive in nature, with extensive rip-up clasts and pebbles that indicate tidal ravinement. These proximal tidal bars are preferentially deposited in the north-central MacKay OPCO and Southern Pacific lease areas, interpreted to reflect a shift in location of sediment supply to lows in the north (Fig.III-21B/C). A flooding surface occurs at the top of strata package 4 and may locally occur between TSB cycles.

Stratal Package 5: This LEBF is the next major depositional cycle that comprises a laterally extensive coarsening- and cleaning-upward succession, ranging from less than 3 m to 10 m thick (Fig.III-16D). Deposits illustrate a lateral facies change up-dip and to the east, which reflects progressive deepening from SMBF in north-central MacKay River POLS in southeast MacKay River.

This indicates retrogradational stacking and on-lap onto the older TSB package and is interpreted as slow sedimentation during slow transgressive conditions.

Deposits average 4-8m thick where the thickest deposits are situated along an northeast-southwest trend within lows in the north-central MacKay OPCO and Southern Pacific lease areas (Fig.III-16D). To the southwest (i.e. T89-R15), these deposits also thicken but decrease in reservoir quality become increasingly muddier, with a higher bioturbation intensity of a fully marine *Cruziana* trace fossil assemblage. Otherwise, this package reflects moderate to good reservoir quality, with poorer quality reservoir sands at the base of the succession. A flooding surface caps the top of this stratal package.

Stratal Package 6: Above this flooding reflects a coarsening-upward LSFO stratal package reflecting more distal, mixed wave- and tide-influenced succession (Fig.III-17A). Successions illustrate progressive shallowing of facies from argillaceous muds with sand inter-beds that grade upwards into fine-grained lower shoreface tempestite and fair-weather beds of POLS. Deposits in the southwest of the study area (i.e. 90-15W4) are dominated by distal POLS facies. In the notheast (i.e. 91-15W4) deposits are dominated by proximal POLS facies and storm- and wave-influence more pronounced.

Stratal package 6 is laterally extensive across the basin and deposits are thickest in a southwest to northeast trend in the central MacKay River area. This package also illustrates a progressive thickening from the southeast (Central Mackay OPCO Lease Area) (i.e.T90-R14), to the northwest (i.e. Southern Pacific Lease Areas) (Fig.III-17A).

Stratal package 6 also illustrates more proximal facies basinward (northwest), as successions grade into burrowed wavy-bedded SMBF sands. This reflects down-lap of the underlying flooding surface onto middle McMurray deposits to the northwest and is interpreted as a progradational pulse of sedimentation during transgression.

Stratal Package 7: Overlying the LSFO is the third TSB complex, deposited (Fig.III-15D). This cycle occurs in the northwest along an east-west trend in the North MacKay OPCO area (T92-R15). This is interpreted to represent a regressive cycle within the embayment, where sedimentation of elongate TSB and elongate tidal sand bars of FA4 shifted to the north. SMBF deposits may directly overlie this surface and are thickest where lows have been deeply scoured down into the middle McMurray Formation (Fig.III-16E). These lows are apparent in the western- and eastern-most regions of the study area (Fig.III-

21D). In these areas, SMBF deposits are dominated by parallel-laminated muds that illustrate lower degrees of bioturbation and are interpreted to reflect a lack of oxygen.

Overlying these SMBF deposits are sharp-based, coarsening-upward, TSB (Fig.III-15D). Sands illustrate small- to large-scale cross-bedded to parallel-laminated sands and are non-bioturbated. In the east-most region of North MacKay River OPCO area, TSB directly overly middle McMurray deposits. The sharp-based nature of these sands coupled with the basal lag reflects a tidal ravinement surface where erosive forces through tidal current action scoured the underlying surface, developing an irregular topography. Sands average 3-5 m and reach 8m thick in the north-central area (T92-R15), and down-lap onto thick middle McMurray to the west. Deposits also pinch-out onto thick middle McMurray deposits in the east (T92-R12) or top-lap older strata to the southeast. The preferential deposition in the North MacKay OPCO area and northeast areas reflects the shift in location of sediment supply to the northeast (Fig.III-21D). Locally, overlying this stratal package is a second, thin (<5 m thick) wavy-bedded, coarsening-upward TSB cycle separated by a local flooding surface. This stratal package is bound by a flooding surface reflecting continued transgression of the embayment.

<u>Stratal Package 8:</u> This depositional cycle is the second LSFO reflecting a coarsening-upward progradational pulse of sedimentation. The base of this succession comprises POLS argillaceous mud-dominated offshore sedimentation. These muds grade into POLS wavy bedding and ripple-lamination with moderate bioturbation that clean-upward into *Asterosoma* and *Rosselia* dominated sands. The succession is 2-4 m thick and on-laps older strata. It is restricted to the northwest along a southwest-northeast trend that does not extend southeast of southern Pacific leases (T91-R14) (Fig.III-17B).

<u>Stratal Package 9</u>: The next depositional cycle consists of a coarsening-upward LSFO cycle (Fig.III-17B). Deposits are dominated by clean, fine-grained POLS sands that consist of remnant tempestites illustrating storm- and fair-weather deposition. Storm beds are erosional with underlying fair-weather sands or argillaceous muds and are characterized by low-angle to parallel-lamination representing HCS, wave ripple-lamination, and a lack of bioturbation. Deposition is interpreted as wave-influenced due to the increasing evidence of storm and wave-generated structures. Thick lower shoreface reservoir sands are <2 to 4 m thick and reflect the youngest progradational pulse of shoreface sedimentation

(Fig.III-17C). These deposits illustrate a southwest-northeast trend and down-lap onto older strata to the northwest. Deposits also on-lap to the east, and are restricted to the north of Southern Pacific areas. Both successions of this depositional cycle reflect filling of the embayment to the northwest. A flooding surface illustrated by an abrupt basinward shift of facies caps the top of this depositional cycle.

Stratal Package 10: This stratal package represents the final LFSO cycle during transgression within the upper McMurray, where POLS well burrowed to low-angle to parallel-laminated sands and thin argillaceous sands and muds top-lap the previous coarsening-upward shoreface sands to the southeast (Fig. III-17D). This is a retrogradational fining-upward succession that thins from northern-most MacKay River along a northeast-southwest trend (T92-R16), and does not extend S of Southern Pacific lease areas (T91-R14). These deposits are mixed-influence and represent remnant tempestites where laminated bedding alternates with well burrowed units (“lam-scram”). This non-reservoir facies represents deposition of distal lower shoreface to proximal offshore deposition.

The upper McMurray Formation is bound by a regionally extensive bounding discontinuity that separates overlying strata of the Wabiskaw Member of the Clearwater Formation. This surface is characterized by a *Glossifungites* firmground surface that can be traced across the study area (Fig.III-18). Above this surface lie extensive, burrowed, glauconitic wavy bedded muddy-sand to sandy-mud deposits that fine upwards into the offshore/shelf transition that is separated by a maximum flooding surface (MFS). To the nothwest, this surface may exhibit an erosional lag and incision into underlying McMurray strata. Where erosional, these DOS deposits are characterized by alternating fair-weather and storm events, interpreted as remnant tempestites that have alternating, non-burrowed HCS sands (the storm event), and well burrowed sands (fair-weather deposition). In the northwest where these deposits are most common (up to ~6 m thick), this surface is interpreted to have developed through wave action during transgressive conditions, resulting in the development of a wave ravinement surface (Fig.III-18).

Overlying the MFS of the Wabiskaw Member are regionally widespread DOS shelfal muds that are consistent in thickness and gradational with, or sharply overlain by a northeast-trending LSF of the Wabiskaw Member (Fig.III-5D). This shoreface succession is thickest with the cleanest sands in the north-central portion of the study area (i.e. T91-R14). To the north, this coarsening-upward succession is more gradationally based with an abundance of mud inter-beds. To the east-southeast, this succession thins to less than 1 m, becomes increasingly mud-dominated, and is often fining-upward in nature. This Wabiskaw sand is interpreted as a forced regression where low sediment supply in a shallow water setting was sufficient for progradation during relative sea level (RSL) fall.

SEQUENCE STRATIGRAPHIC ANALYSIS

Sequence Stratigraphic Models

By utilizing the principles of sequence stratigraphy, the stratal stacking patterns of the McMurray-Wabiskaw succession observed in the MacKay River area can be arranged into a chronostratigraphic framework based on relative sea level history. Five main sequence stratigraphic models exist in literature, with the primary difference being the placement of the sequence boundary surface (Catuneanu, 2002; Catuneanu, 2006; Catuneanu *et al.,* 2009). These include the depositional sequence, which are further subdivided into three categories (i.e. Depositional sequence II; Haq *et al.,* 1987, Posamentier *et al.,* 1988; Depositional Sequence III; Van Wagoner *et al.,* 1988; Van Wagoner *et al.,* 1990; Christie-Blick, 1991; Depositional Sequence IV; Hunt and Tucker, 1992; Hunt and Tucker, 1995; Plint and Nummendal, 2000), genetic sequences (Galloway, 1989), and transgressive-regressive (T-R) sequences (Embry and Johannessen, 1992). The most plausible and practical model to describe deposits of the McMurray-Wabiskaw succession is the depositional sequence IV, where placement of the sequence boundary follows a lowstand systems tract (LST), marking the end of base level fall (Hunt and Tucker, 1992; Hunt and Tucker, 1995; Plint and Nummendal, 2000). This is largely because it is the best model for successions dominated by transgressive periods corresponding to relative sea level (eustacy and subsidence) outpacing sedimentation. This model will be utilized for interpreting McMurray-Wabiskaw strata.

Sequence Stratigraphic Surfaces and Systems Tracts

A number of significant stratal disconformities and unconformities formed in this succession in response to changes in relative sea level. The sub-Cretaceous unconformity reflects a diachronous erosional surface interpreted as the result of a fall in sea level, where underlying marine carbonate sequences were subaerially exposed and eroded. In a sequence stratigraphic framework, the incision period is consistent with the falling stage systems tract (FSST) (Plint and Nummendal, 2000; Coe *et al.,* 2002). Following a significant period of non-deposition, this surface, which reflects the top of the underlying Devonian was overlain by estuarine deposits of the middle McMurray Formation. In a sequence stratigraphic framework, this surface reflects a coplanar sequence boundary/flooding surface (SB) (VanWagoner *et al.,* 1988).

Estuarine deposits of the middle McMurray Formation reflect a retrogradational parasequence set that developed during the onset of transgressive conditions, where the sediment flux was less than the rate of relative sea level increase. This resulted in depositional back-stepping (landward) which is common towards the later stages of a lowstand systems tract (LST). It also comprises the fill, or partial-fill of incised-valleys that were cut into earlier deposits during the FSST (Posamentier and Allen, 1999).

The top of the estuarine depositional cycles are capped by the first significant marine flooding surface, marking the onset of accommodation space being created faster than the rate of sedimentation. This surface displays a *Glossifungites*-demarcated surface of erosion, reflecting erosive ravinement and exposure of a cohesive sediment surface at the sediment-water interface (Droser *et al.,* 2002). This is characteristic of a transgressive surface of erosion (TSE) and is diachronous in nature, caused by continual nearshore erosion during relative sea level rise. This surface is further interpreted to reflect a combination of tidal and wave ravinement processes. Tidal ravinement is supported through the localized deep incisions to significant depths into the middle McMurray developing high relief of the surface. Wave ravinement is supported where the surface exhibits a flat, gentle relief overlain by wave- and storm-generated structures, reflecting widespread wave winnowing. Ravinement processes are also responsible in places for the lack of preserved LST deposits above the SB. In these areas, the TSE is correlative with the SB. As the middle McMurray depositional sequence reflects accumulation succeeding the onset of relative sea level rise, and is bound by a SB and TSE, it is interpreted as the late phase of a LST.

The overall upper McMurray stratal stacking pattern is interpreted as a retrogradational parasequence set and is based by the TSE that bounds middle McMurray deposits. Parasequences on-lap the SB in a landward direction, and illustrate progressively more distal facies basinward, where they down-lap onto the TSE. Stacking patterns also exhibit back-stepping on-lapping retrogradational aggrading clinoforms that thicken landward. The overall decline of sedimentation rates and sediment supply through time is also suggestive as parasequences become thinner and less widespread. In a sequence stratigraphic framework, these characteristics are consistent with the TST that develops from the onset of transgression, until maximum transgression of the coast, prior to renewed regression.

Within the upper McMurray, a total of seven parasequences were deposited, and are separated by marine flooding surfaces or their correlative conformities (Fig.III-14). A total of five marine flooding surfaces/transgressive surfaces (TS1-TS5) separate younger from older upper McMurray parasequences that demonstrate an abrupt increase in water depth. Three local flooding surfaces (FS) were also identified. Flooding surfaces are autogenic and result from cyclic retrogradation and variations in sedimentation rates and/or accommodation space that have resulted in a progressive basinward deepening.

A total of four regressive ravinement surfaces (RS1-RS4) (Galloway, 2001) are identified. These surfaces are characterized by subaqueous marine erosion, where tidal- and/or wave currents removed and reworked deposits of the underlying parasequence as a result of relative sea level fall. Wave ravinement becomes more pronounced over tidal ravinement further basinward, as surfaces show progressively less relief. The lack of *Glossifungites* firmgrounds common to these surfaces may also be attributed to higher energy deposition and scouring following transgression, and thus environmentally inhospitable conditions for benthic colonization. Due to such a complex interplay of relative sea level, deposition, and erosion, multiple surfaces often merge, and may become correlative in both up-dip and down-dip directions. Two local erosional surfaces were also identified (ES).

Upper McMurray parasequences exhibit both retrogradational and progradational clinoforms corresponding to landward thickening and basinward thinning, respectively. This is likely the result of punctuated episodes of sediment supply outpacing relative sea level rise, developing periods of progradation in an overall retrogradational stacking pattern of the TST. Overall retrogradation is likely, since tidal sand bar parasequences display an overall thinning, and offshore parasequences increase in frequency, basinward.

Upper McMurray parasequences are bound by a second significant TSE that is demarcated by a *Glossifungites* firmground and overlying glauconitic sedimentation. This is interpreted as a condensed section, as glauconitic sedimentation indicates very slow sediment accumulation on the basin-floor and is often associated with widespread condensed sections related to maximum flooding surfaces (MFS) (Vail *et al.,* 1984). Condensed sections also commonly merge landward with transgressive surfaces, further supporting this interpretation (Catuneanu, 2002).

The condensed section of the upper McMurray-Wabiskaw transition is bound by a diachronous surface characterized by a fining-upward succession of shelfal muds, interpreted as the MFS. This reflects the time of maximum transgression within the basin and occurs at the top of retrogradational strata (Posamentier and Allen, 1999). As the upper McMurray Formation and Wabiskaw transition zone reflects accumulation during relative sea level rise, and is bound by a TSE and a MFS, it is interpreted to reflect the cessation of the TST.

This MFS marks the lower bounding surface of the coarsening-upward Wabiskaw Member parasequence, which illustrates shallowing of the geological section. The overlying parasequences are interpreted to have been deposited when sediment accumulation rates exceeded the rate of relative sea-level rise, resulting in progradation and down-lap onto the MFS. Wabiskaw shelfal deposits overlie this surface and exhibit a very subtle coarsening-upward. These shales are bound by a RSE. In a sequence stratigraphic framework this reflects deposition of the HST.

The superimposition of coarser-grained shoreface deposits sharply overlying finer-grained shelf deposits is characteristic of a forced regression, which is induced by the seaward movement of the shoreline in response to relative sea level fall (Catuneanu, 2006). More specifically, it indicates base level fall and regression, regardless of sediment supply, causing erosion of underlying units by wave action at the coast. This also results in a diagnostic progradational and down-stepping stacking pattern (Posamentier and Allen, 1999). A *Glossifungites* firmground surface is also locally observed, typically where deposits are more gradational. This surface is interpreted as material deposited or reworked during sea level fall or during the following transgression. This sharp contact between shelf and shoreface deposits is interpreted as a regressive surface of marine erosion (RSE).

The top of the Wabiskaw sand is interpreted as the upper surface of a forced regression which is a diachronous and highly erosional marine correlative conformity that relates to the end of base level fall (Hunt and Tucker, 1992). This reflects a SB as well as a maximum flooding surface (MFS) as it bounds the McMurray-Wabiskaw succession from marine shales of the Clearwater

Formation. In a sequence stratigraphic framework, this reflects a forced regressive shoreface sand that is bound by a RSE and a SB/MFS and is interpreted as a FSST and lowstand sand deposit.

Based on the nature of these bounding sequence stratigraphic surfaces, the McMurray-Wabiskaw succession is interpreted to reflect a third-order depositional sequence comprising a LST, TST, HST, and FSST (Fig.III-23) (Hunt and Tucker, 1995; Plint and Nummendal, 2000; Catuneanu, 2006; Catuneanu *et al.,* 2009). Overall, this succession is dominated by a TST fill, with associated poorly developed lowstand and highstand systems tracts. The upper McMurray member reflects smaller (4th/5th order) depositional sequences attributed to relative sea level changes and transgressive-regressive pulses within the overall Clearwater transgression (Fig.III-23).

DISCUSSION

Lithostratigraphic vs. Chronostratigraphic Correlations

As core data and wire-line logs do not continuously document the nature of stratal surfaces, correlations were based primarily on lithology (FA) and their relationships, and therefore, represent diachronous facies contacts to some degree. Additionally, local seismic and chronometric data were not available for higher resolution correlations. Although interpretations may be simplified, they illustrate observations that best demonstrate the dataset and are therefore preferred.

Isopach maps should also be interpreted with caution as they were generated by Petrel using a convergent extrapolation formula. Where data points are sparse, this formula results in the development of a bulls-eyed pattern that reflects some degree of error and uncertainty that should be taken into consideration.

The McMurray-Wabiskaw Transition

Placement of the base of the Wabiskaw Member is commonly arguable, forming a McMurray-Wabiskaw transition zone. This zone is characterized by the abrupt appearance of glauconitic-rich sediments above a transgressive surface of erosion. This presence of glauconite is typically the identifier of Wabiskaw deposition and the top of the McMurray is generally placed below these deposits. In the MacKay River area, this zone has been identified as a condensed section below a MFS in the MacKay River area, reflecting a thin accumulation of

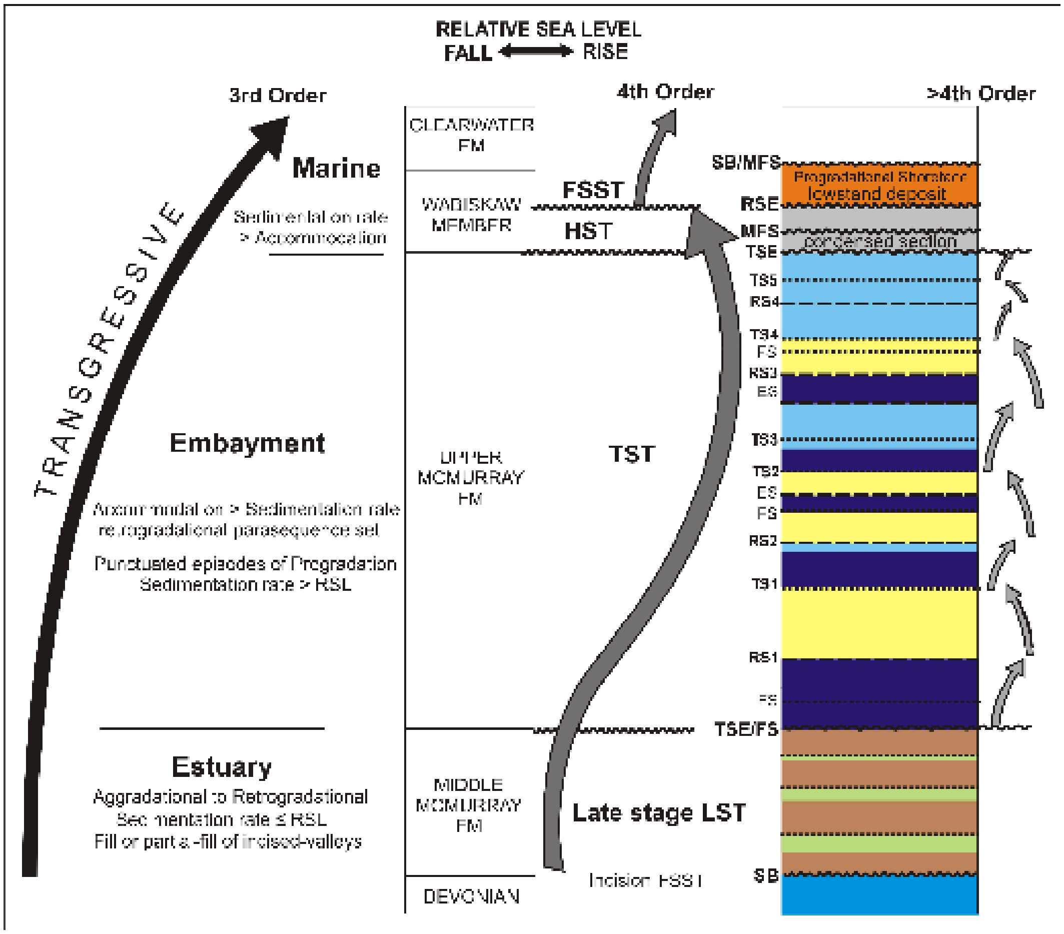

FIGURE III-23: Relative sea-level history and sequence stratigraphic interpretation for the McMurray-Wabiskaw Succession in the MacKay River area. Refer to stratigraphic section legend, and lithostratigraphic unit color designations in figure II-14.

continuous sedimentation without any depositional break (Van Wagoner *et al.,* 1990). As these deposits reflect long spans of time, underlying facies are thus unrelated to overlying successions. This supports placement of the boundary between McMurray and Wabiskaw Member sedimentation at the end of the transgression, below the MFS.

Informal Stratigraphic Debate

The McMurray Formation has long been recognized as comprising three informal members (lower, middle and upper) across northeastern Alberta, but in recent years, changes have been proposed by some researchers (i.e. Hein *et al.,* 2000, Langenberg *et al.,* 2002). Hein *et al.,* (2000), discarding the middle McMurray altogether, divided the McMurray into a lower and upper division. In doing this they combined the middle and upper members, although the lithostratigraphic differences are significant and mappable both from core and wireline logs (Ranger and Gingras, 2003). With this interpretation, they developed a sequence stratigraphic framework for the McMurray-Wabiskaw succession in the Athabasca area that became a commonly used model (Hein *et al.*, 2000; Hein and Dolby, 2001; AEUB, 2003). This model expanded around the interpretation that the entire McMurray interval reflects a lowstand to transgressive incised valley-fill system and comprises lower member fluvial braided channel lowstand deposits at the base, with transgressive upper member estuarine mega-channel and coastal plain complexes above (Hein *et al.,* 2000). The uppermost McMurray is also interpreted as highstand tidal flats and brackish bay deposits.

Alternatively, a significant sedimentological difference and definite sharp and erosive contact has been argued to exist between the two aforementioned members, indicating a non-genetic relationship (Ranger and Gingras, 2003; Crerar and Arnott, 2007; Ranger and Gingras, 2007; Ranger *et al.,* 2008; Broughton *et al.,* 2009). This has led to an alternative model and a more complex interpretation than just simple aggradation of fluvial, estuarine, and marine environments. Middle McMurray deposits are interpreted as a regressive succession of a prograding tidal system, or a TST to prograding HST in a tide-dominated basin during sea level rise (Ranger *et al.,* 2008). In this model, upper McMurray deposits reflect stacked prograding wave/fluvial-influenced shoreface parasequences capped by alluvial deposits, each floored by transgressive surfaces of erosion, reflecting a major change in basin configuration and transgressive-regressive cycles in sea level rise (Caplan and Ranger, 2001; Ranger *et al.,* 2008).

In the MacKay River area, the resulting stratigraphic interpretations reflect greater similarity towards the latter model where members are not genetic; interpretations conform to the sequence stratigraphic model but not the sedimentological model. This is due to the relative position in the basin that is both sediment- and fresh water-starved, relative to the main valley system.. The McMurray-Wabiskaw succession in the MacKay River area comprises a stacked succession reflecting a transition from estuarine valley-fill (middle McMurray) to shallow marine embayment-fill (upper McMurray) to open marine (Wabiskaw Member) lithostratigraphic units. History of this deposition is strongly related to a complex interplay between ensuing relative sea level rise (overall 3rd order transgression) and local decreases in base-level reflecting >4th order sea level cycles and episodes of regression. In response, the middle and upper McMurray correspond to distinct genetic wedges reflecting a LST and TST, respectively. The McMurray-Wabiskaw transition zone is characterized by a condensed section reflecting the top of the TST, whereas the Wabiskaw Member reflects highstand or stillstand shelfal muds with an overlying genetic wedge reflecting forced regression during falling-stage and ensuing transgression. The wave- and tide-influenced shallow marine sandstone of the Wabiskaw Member is encased in marine shales and is interpreted as a lowstand shoreface deposit. These lowstand and transgressive shorefaces are common in the stratigraphic record among the western interior basin of North America, where isolated deposition on the shelf is related to forced regression (Plint 1988; Posamentier *et al.,* 1992; Walker and Plint 1992; Walker and Bergman, 1993; Walker and Wiseman, 1995; Berne *et al.,* 1998). In the modern, similar progradational shoreface bodies in response to forced regression (FSST) are observed in the Gulf of Lions, France, deposited during the end of the last seal-level fall (Berne *et al.,* 1998).

To stay true to the standard nomenclature of the McMurray, middle and upper members were designated in the MacKay River area, however they may not at all be contemporaneous to those observed in the main valley system (i.e. where these models are based). This can be illustrated through observing the variations between relief of the Devonian paleo-surface and also the relative paleo-geographic positions of these areas. The main valley system was entrenched much deeper into the underlying Devonian surface, and thus, the McMurray-Wabiskaw fill is extremely thick, and can exceed 150 m thick, reflecting a much longer period of deposition. Compared to the main valley, deposits in the MacKay River area completely lack the lower McMurray member and are relatively thin, reaching a maximum of 50 m thick. In a paleogeographic sense, this area is also located much further towards the north. As sedimentation occurred from the southeast to the northwest and was sourced from the highs to the west, this signifies that deposition in the MacKay River area may not have commenced until later in McMurray history. For these reasons, the McMurray-Wabiskaw succession may be contemporaneous to later stages of upper McMurray deposition in the main valley.

Ravinement

In environments influenced by waves and tides, the sand body geometry and distribution within the TST is a function of ravinement processes. Key stratigraphic surfaces formed through ravinement processes punctuate the bay-fill architecture of the MacKay River area. Ravinement is defined as an erosion surface produced during marine transgression of a formerly subaerial environment. A tidal ravinement surface is a scoured surface (erosive) cut by tidal channel currents in a coastal setting during shoreline transgression, and is most commonly preserved in transgressive river-mouth settings such as an estuary (Catuneanu, 2002). These surfaces are highly diachronous as they represent the migration of tidal channels along both depositional strike and dip, thus developing a composite surface that can extend for hundreds of kilometers (Catuneanu, 2006). The regionally extensive transgressive surface of erosion at the base of the upper McMurray Formation comprises deeply eroding ravinement surfaces that merge with and enhance, the earlier formed, subaerially exposed, erosive sequence boundary. This ravinement surface exhibits both an extremely undulatory to nearly horizontal form and marks the basal boundary of the bay-fill. Thus, it is interpreted to have formed through both tidal and wave ravinement processes (Allen and Posamentier, 1993).

Where the surface is extremely undulatory in nature, it is comparable to the anchored tidal ravinement observed in the Gironde estuary (Fenies *et al.,* 2010). In this example, estuary-mouth facies directly overlie central estuary facies and sands are confined to a fixed location by the resistive underlying carbonate basement that forms the valley margin bedrock, generating elongate sands that extend for 45 km in length, and 30-35 m thick (Fenies *et al.,* 2010). Tidal ravinement also resulted in an undulatory surface, where incision reaches depths of up to 35 m (Fenies *et al.,* 2010). The Woburn Sands of southern England also exhibit analogous embayment deposition with a transgressive ravinement surface. In this example, the embayment is characterized by a similar shallow bathymetry and little relief caused by shoreface ravinement (waves and tides), overlain by large tidal sand bars. Locally, this surface is deepened for up to 40 m, reflecting tidal current erosion.

In the case of the MacKay River area, depth of ravinement must be inferred as it is subsequently truncated by younger discontinuities, but has been interpreted to have exceeded 20 m locally. It is this tidal ravinement process, coupled with the depth of the lowstand incision generated during sea level fall that has controlled the preservation potential of underlying lowstand deposits of the middle McMurray. Where sea level fall was shallower than the depth of the tidal ravinement surface generated during sea level rise, the TSE parallels the SB.

Controls on Stratigraphic Architecture in the MacKay River Area

The stratigraphic architecture of the McMurray-Wabiskaw succession was controlled by dominantly autocyclic processes. Middle McMurray deposition was controlled by basin configuration and structural setting, where base-level changes and subsidence through differential erosion of underlying Ireton Formation shales played an integral role in development of structural lows. Autocyclic processes were then extremely instrumental in the distribution and stacking of complex facies patterns that ultimately filled these lows in multiple terraces illustrated by disordered vertical successions. With rapid transgression of these deposits, a major change in basinal configuration took place, and deposition occurred in greater lateral continuity, reflecting more precise chronostratigraphic cycles. Deposition was largely controlled by the location of sediment supply. These coarsening upward successions are thus interpreted as parasequences produced dominantly by autocyclic processes related to sediment supply and accomodation space. This is evidenced through the interplay of lateral accretion and migration, developing complex stacked tidal bar and bay-fill successions that were controlled by the configuration of the bay-margin and islands, coupled with the location of available sediment supply. This separation of allo- and autocyclic controls on stratigraphic architecture is required to interpret the litho- and sequence stratigraphy.

Significance of Ichnology in the MacKay River Area

Ichnological content played a significant role in refining the depositional interpretations for the McMurray Formation. Through the identification of different trace fossils and their assemblages, coupled with documentation of their lateral and vertical variability, a number of environmental parameters were determined that could not have been identified through physical sedimentary structures and textures alone. This is attributed to the fact that environmental conditions and changes directly affect organism behaviours. As trace fossils are a record of organism behaviours, particular environmental parameters were inferred for McMurray-Wabiskaw strata including salinity, energy, sedimentation rates, oxygenation and depositional depth. This provided the rationale for defining the depositional environments and stratigraphic breaks in the middle McMurray and upper McMurray.

Trace fossils played an integral role in both litho- and sequence stratigraphic interpretations. They were essential in recognizing and interpreting a variety of bounding discontinuities in the succession, including erosional discontinuities (TSE/RSE), nondepositional hiatuses (firmgrounds), and depositional discontinuities (condensed section). Ichnological analysis not only helped identify the discontinuities between upper, middle McMurray, and Wabiskaw deposition, it helped in interpreting them as *Glossifungites* firmgrounds and transgressive surfaces through the identification of three ichnological suites: the pre-omission, omission, and post-omission suites.

Lateral and vertical variations in ichnological signature within individual parasequences were also crucial in stratigraphic interpretations. By identifying the changes in diversity, size, bioturbation intensity and individual ichnogenera within parasequences, better interpretations were made regarding transgressive and regressive cycles and the stacking patterns observed. In the upper McMurray, it was also essential in identifying discrete flooding surfaces, through changes in trace fossil assemblages and diversities, which would otherwise be difficult to discern. Overall, ichnology was a fundamental tool in interpreting the depositional history of the McMurray Formation in the MacKay River area.

Comparisons between OPCO and Competitor Lease Areas

Three main lease areas are defined in the MacKay River project area: OPCO MacKay, Sothern Pacific MacKay, and Suncor MacKay (Fig.III-4). All three lease areas exhibit similar facies and FA and are described on the same facies scheme (refer to Table III-1). Variations between lease areas are a result of varying positions within the overall depositional system and are also influenced by depth variations of the Devonian structure. Changes in bioturbation intensity, observed ichnogenera, parasequence thicknesses, and vertical and lateral facies relationships are thus a function of the unique combination of environmental processes imparted on the system coupled with the paleogeographic position, and initial basin configuration. With these respects, OPCO and Suncor leases are least similar, with Southern Pacific being a transition between the two.

The overall McMurray thickness is variable across lease areas. Two distinct paleo-lows are evident in the Devonian structure, one in the west (Suncor) and one to the east of OPCO MacKay (Fig.III-6A). The McMurray-Wabiskaw succession in OPCO and Southern Pacific lands range from ~20-45 m thick and are dominated by upper McMurray deposits. Suncor lands exhibit sections ~25-55 m thick and are dominated by middle McMurray deposits. The thinnest successions occur in a northwest trend in South OPCO MacKay, over a Devonian structural high (Fig.III-5B; Fig.III-6A).

In the middle McMurray, the occurrence and thickness of laterally accreting channel point bars with inclined heterolithic stratification (IHS) facies, is highest in Suncor's lease and lowest in the MacKay South OPCO lease area. In the Suncor area, sand-dominated IHS bedding and tidal channels are well developed with brecciated zones up to 5 m thick. Channel sands are also up to 12 m thick and extremely clean compared to the *Cylindrichnus-Gyrolithes* dominated sands in OPCO lands. Although the trace fossil assemblage in the middle McMurray is similar in Southern Pacific and OPCO lease areas, bioturbation intensity is absent in sands of the Suncor lease and lower overall. Fine-grained ECP deposits are also typically rare to absent. This suggests that these sands represent amalgamated fluvio-estuarine channel deposits that experienced higher energy, and rapid sedimentation with much higher fluvial influence. Remaining deposits are dominated by tidal flats that exhibit a restricted to strong brackish water trace fossil signature. Suncor deposits are thus interpreted as more proximal with respect to the inner estuary, within the fluvio-estuarine transition. Due to the dominance and thickness of sand, and moderate to high bitumen saturations, these deposits have much higher reservoir potential than OPCO and Southern Pacific. When preserved, OPCO MacKay middle McMurray deposits lack fluvial influence and are interpreted to have been deposited away from a main channel as middle to outer estuarine subtidal point bars, mixed tidal flats, and pedogenic deposition dominated by tidal energy. These deposits are much thinner than in Suncor's lease, but thicken to the northwest. Southern Pacific lands contain a very thin preserved middle McMurray package (<5 m) that thickens abruptly to the west (up to 30 m). This is likely a result of the tidal ravinement surface scouring deeper in Southern Pacific and OPCO lands than in Suncor's, thus creating a negligible to much thinner package of middle McMurray sediments. Southern Pacific is similar to OPCO MacKay deposits and has a dominance of heterolithics and pedogenic zones with rare occurrences of sand-dominated IHS.

Upper McMurray deposits abruptly overlie deposits of the middle McMurray across all lease areas and represent a change in basin configuration and shift in depositional style. In the Suncor lease area, upper McMurray deposits consist of relatively well burrowed heterolithics at the base of the succession that are erosionally overlain by a medial-proximal tidal bar. Upper McMurray deposits in this area also become completely absent towards the east, and consist of Wabiskaw mudstones directly above the middle McMurray. These deposits are very similar to those observed in the main bitumen fairway. When the upper McMurray is preserved, sands are a thin, gradational coarsening-upward succession that can be traced laterally until they pinch out to the east. Across the area, similar sedimentology to the southeast South OPCO MacKay area is observed, with wavy bioturbated sands at the base grading into cross-bedded and horizontal bedded sands. Sands in the Suncor area are of reservoir quality but have a higher proportion of fine-grained material and a high diversity assemblage of larger marine traces, consistent with a resident proximal *Cruziana* to *Skolithos* ichnofacies. Wavy- and flaser- to parallel -bedding is most common. These sands are then abruptly overlain by fully marine, LSFO1. This contact is traceable into the southeast and reflects RS2 of the upper McMurray. Overlying the LSFO1 in this area are DOS of the Wabiskaw Member separated by a TSE.

Central OPCO South MacKay has more variability as it lacks middle McMurray deposits. In this region, proximal to medial cycles of amalgamated TSB, up to 22 m thick, overlie the Devonian. This is interpreted to have resulted from tidal ravinement of the underlying middle McMurray. These bars comprise the main reservoir sands and illustrate very little mud, typically as thin tidal drapes/flasers or individual burrows of a mixed *Skolithos-Cruziana* ichnofacies. To the east, the main reservoir appears to thicken indicating that reservoir potential exists east of South MacKay. To the north-northwest, fine-grained material increases in abundance, and burrowing becomes increasingly more marine as bars become more distal. Both coarsening-upward and fining-upward successions are identified in OPCO MacKay and the amalgamation of three main TSB packages has been interpreted in this area.

Southern Pacific MacKay and OPCO North MacKay are an important transition zone within the upper McMurray in the study area, as progradation and retrogradation within packages becomes readily apparent. The overall upper McMurray northeast and is controlled by middle McMurray structure. Finer-grained units also increase in occurrence and thickness to the northwest. Southern Pacific lands mark the position of this change and unfortunately comprise one of the poorer areas of well control in the project. In these leases, four coarsening-upward packages have been interpreted, each of which are based by SMBF or POLS deposits representing episodes of flooding. Sands in these parasequences are laterally continuous and thicken to northwest. They also exhibit wave influence evident from abundant HCS interpreted as storm events. To the southeast they on-lap and terminate up-dip (in Southern Pacific lands). Sands in these areas have moderate reservoir potential as they are still laterally continuous and of reservoir quality, but are separated by semi-regional flooding surfaces represented by burrowed argillaceous or heterolithic deposits of POLS.

Overall, The Suncor lease area represents a thick fluvio-estuarine middle McMurray sequence that had sufficient accommodation space and sediment supply for channels to amalgamate and fill the Devonian paleotopography. These deposits exhibit a higher proportion of wavy, finer-grained material and reservoir potential is higher in amalgamated tidal channel sands of the middle McMurray. TSB of the upper McMurray are thinly preserved in this area due to overlying wave ravinement of the Wabiskaw member.

Southern Pacific and OPCO North MacKay leases represent the onset of additional parasequences and development representing an overall retrogradational stacking pattern. Sands in this area are of reservoir quality but are thinner reservoirs than OPCO South MacKay, and separated by flooding events that contain semi-regional barriers of non-reservoir facies. Sands appear to thicken to the northwest indicating that reservoir potential and reservoir quality sands may thicken or increase in abundance north of north MacKay. The middle McMurray has relatively low reservoir potential where deposits are variable in thickness with a complex stratal architecture and have cycles of heterolithic IME deposits capped by laterally correlative successions of coastal plain deposition (ECP). In South MacKay, amalgamated TSB occur above thicker middle McMurray deposits in the east. These bars may continue to thicken and generate similar reservoirs further to the east of South OPCO MacKay, but this is speculative as there is a lack of well control.

SUMMARY AND CONCLUSIONS

The McMurray Formation is host to the bitumen resource in the MacKay River area of northeastern Alberta and comprises a thick succession of superimposed northwest-trending elongate tidal sand bar complexes that erosionally truncate a thinly preserved package of estuarine deposits. These laterally continuous embayment-filling marine tidal sand bar complexes depart from the conventional, laterally heterogeneous fluvio-estuarine point bar sands observed in the main bitumen fairway. Deposition of the McMurray-Wabiskaw succession in the project area is characterized by complex stratigraphic relationships and numerous stratigraphic surfaces reflecting a third order depositional sequence. This depositional sequence was characterized by overall transgression and a starved sediment supply, resulting in overall retrogradation, punctuated with episodes of progradation.

Estuarine deposits occur at the base of the succession, above the sub-Cretaceous unconformity, and represent the lowstand and initial transgression and filling of the paleo-valley, where distribution was controlled largely by Devonian structure. Overlying deposits are separated from the underlying estuary by a widespread TSE that developed resulting from an increase in RSL and a major change in basin configuration. This surface exhibits both undulatory to near horizontal relief, reflecting the interplay of both wave and tidal ravinement. Overlying deposition occurred as tide-dominated to mixed wave-tide influenced, bay-margin and island-attached laterally accreting tidal sands that migrated according to the interplay between tidal current and bay-margin orientation, resistant underlying bedrock, and location of sediment supply. Tidal bar parasequences are separated by bay-fill and lower shoreface to offshore parasequences that become thicker and more regionally extensive to the northeast. This reflects the TST and filling of the embayment from southeast to northwest. A second TSE marked by a *Glossifungites* surface caps the top of the upper McMurray Formation. An overlying condensed section marks the slow and continuous sedimentation of the Wabiskaw Member during maximum flooding conditions. Overlying shelfal muds reflect highstand or stillstand conditions that are superimposed by a forced regressive lower shoreface reflecting a falling stage of sea level followed by transgressive deposition. Overall, this succession is dominated by a TST fill, with associated poorly developed lowstand and highstand systems tracts. The middle and upper McMurray members and Wabiskaw Member reflect smaller (4th/5th order) depositional sequences attributed to relative sea level changes and transgressive-regressive pulses within the overall Clearwater transgression.

In summary, sedimentation reflects a transition of genetic sequences reflecting estuarine valley-fill (middle McMurray), shallow marine embayment-fill (upper McMurray), and open marine (Wabiskaw Member) environments. This succession does not conform to traditional stratigraphic interpretations of the McMurray Formation for the main valley system. Instead, deposits reflect separate genetic wedges that form a relatively thin succession, compared to the main valley trend. Although similar nomenclature was used for McMurray deposition, middle and upper members may not be coeval to those in the main valley. Instead, deposition in the MacKay River may be interpreted as contemporaneous to late stages of McMurray deposition in the main valley, reflecting upper McMurray to Wabiskaw time.

The McMurray/Wabisakaw transition zone was also scrutinized and placement of the base of the Wabiskaw Member was resolved to the unit above the TSE/*Gossifungites* firmground omission surface and first appearance of glauconite. This marks the base of a condensed section reflecting a very thin unit deposited without interruption, over a very long span of time.

Sequence stratigraphic interpretations were largely a result of a multifaceted approach utilizing a combination of petrophysical, sedimentologic and ichnological interpretations. Ichnology was specifically an important tool in the identification of allostratigraphic surfaces and their sequence stratigraphic interpretations. As the McMurray Formation comprises a significant reservoir interval in the MacKay River area, the results of this work will have important implications in reservoir prediction, modeling, and well placement, and will allow the most economic exploitation of this deposit. It also significantly contributes to a better understanding of the McMurray-Wabiskaw succession of the Athabasca OSA, and may aid in the identification of similar transgressive systems elsewhere.

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CHAPTER IV – SUMMARY AND CONCLUSIONS

This thesis investigates the sedimentologic, ichnologic, and stratigraphic characteristics of the Lower Cretaceous McMurray-Wabiskaw stratigraphic succession in the Mackay River area of northeastern Alberta. In developing a sound understanding of the depositional environments and their relationship in the subsurface, this research contributes an alternative interpretation for strata in this succession. It also illustrates the powerful applications of ichnology with regards to facies and stratigraphic analysis. Ultimately, this research enhances the geologic knowledge of this succession and the resulting interpretations can be used as valuable tools in the exploration and production of bitumen within this understudied interval.

DEPOSITIONAL SETTING

An in depth examination of sedimentologic and ichnologic characteristics utilizing cored intervals was implemented in Chapter II to develop a facies and facies association classification scheme. This led to the identification of 21 main facies that were described and interpreted in detail, and grouped into 7 recurring facies associations. The identification of regional bounding discontinuities resulted in a further division of these facies associations into the lower McMurray, upper McMurray, and Wabiskaw divisions, corresponding to the middle and upper informal McMurray members and Wabiskaw member, respectively. By integrating ichnological and sedimentological characteristics, a greater understanding of the physical and chemical environmental parameters influencing deposition led to a refined paleoenvironmental interpretation for the middle and upper McMurray members, one that departs from the traditional depositional model.

The McMurray-Wabiskaw succession records the transgressive evolution and shift in depositional system from a tide-dominated estuary (middle McMurray), to a broad, shallow marine, tide-influenced embayment (upper McMurray), to a mixed wave- and storm dominated embayment or inner shelf setting (upper McMurray to Wabiskaw Member).

The middle McMurray is dominated by IHS bedding and a brackish-water trace fossil suite where distribution was largely controlled by the salinity gradient and suspended sediment concentration (SSC); characteristics that are consistent with the lateral accretion of point bars in a channelized estuarine environment. Tidal dominance is also expressed through the prevalence of tidally-generated sedimentation and overwhelming lack of river- and wave-generated sedimentary structures.

The upper McMurray comprises the main reservoir interval and is dominated by large, amalgamated elongate sub-tidal channel sand bars with intervening fair-weather bay-fill sedimentation, reflecting a transitional phase between a confined estuary system and open marine-shelf setting. The identification of an overall open marine trace fossil assemblage was instrumental in the recognition of fully marine deposition in the upper McMurray and in the interpretation of an embayment (Ke *et al.,* 1996) versus deltaic (e.g., Dalrymple *et al.,* 1992; Dalrymple, 1999; Dalrymple *et al.,* 2003) or estuarine (e.g., Dalrymple, 1992; Dalrymple *et al.*, 1992; Dalrymple, 2006) environments.

Bar formation in the upper McMurray reflects the lateral accretion from the bay-margin and headlands/or offshore islands in shallow, non-diluted marine waters, dominated by tidal sedimentation. Wave and episodic storm processes are also observed in the finer-grained sand to argillaceous muds of the upper McMurray and reflect a mix of wave and tidal processes. A proposed generalized model developed for upper McMurray sand bar complexes illustrates, and to some degree simplifies, the facies architecture of these complex deposits. This model was integral in facies mapping and stratigraphic correlation techniques necessary to recognize the variability within these sands and to identify unique depositional packages.

STRATIGRAPHY

Chapter III builds on the depositional foundation identified in Chapter II and utilizes a multidisciplinary approach to stratigraphic interpretation by integrating ichnology with litho- and sequence-stratigraphic methodologies. A network comprising thirteen cross-sections was developed across the area, tied to cored intervals and wire-line log data. Facies associations and allostratigraphic surfaces were correlated across each section to reveal a thick succession of superimposed northwest-trending tidal sand bar complexes separated by lower shoreface to offshore deposits, that erosionally truncate a thinly preserved package of estuarine deposits.

Regional contour maps illustrated that middle McMurray deposition is directly related to the initial basin configuration and depth variations of the Devonian structure. Migration of the estuarine complex occurred within these lows to develop multiple terraces as the valleys in-filled with sediment. The middle McMurray is interpreted to reflect an aggradational to retrogradational parasequence set that developed during the onset of transgressive conditions. Filling of these paleo-lows resulted in a major change in basin configuration and transformation to a relatively flat embayment, which filled from the southeast to the northwest.

The upper McMurray comprises 10 lithostratigraphic cycles of deposition across the study area composed of low energy bay-fill (LEBF), tidal bar (TSB), shoreface and offshore (LSFO) lithostratigraphic units. Contour maps were generated for each individual unit to illustrate the complexity and distribution of facies associations in tidal sand bar complex development. Additionally, 5 regional lithostratigraphic contacts were identified as flooding surfaces (TS) and 4 regional lithostratigraphic contacts as erosional surfaces (RS). Locally, 3 additional flooding surfaces (FS) and 2 additional erosional surfaces (ES) were identified. The overall upper McMurray stratal stacking pattern is interpreted as a retrogradational parasequence set during transgressive conditions. Key stratigraphic surfaces punctuate the bay-fill architecture of the MacKay River area and formed through combined wave and tidal ravinement processes, common to transgressive settings (Catuneanu, 2002).

The onset of Wabiskaw sedimentation is marked by a condensed section related to the cessation of transgression and maximum flooding conditions. The overlying Wabiskaw sand reflects a forced regressive shoreface.

In summary, the succession is dominated by a TST fill comprised of 7 parasequences, with associated poorly developed lowstand and highstand systems tracts. The middle and upper McMurray members and Wabiskaw member reflect smaller ($4^{th}/5^{th}$ order) depositional sequences attributed to relative sea level changes and transgressive-regressive pulses within the overall Clearwater transgression. Deposition of the McMurray-Wabiskaw succession is thus, characterized by complex stratigraphic relationships and numerous stratigraphic surfaces reflecting a third order depositional sequence. This reflects an alternative model to the conventional ideologies (Hein and Dolby, 2001; AEUB, 2003; Hein and Cotterill, 2006) and demonstrates that the middle and upper McMurray members have significant and mappable lithological differences.

CONCLUSIONS

The McMurray Formation in the MacKay River area was found to reflect a unique depositional system within a secondary tributary valley system, where sedimentation was completely unrelated to the main valley trend in the Athabasca Oil Sands Area (AOSA). Instead of a large fluvio-estuarine meandering channel system overlain by wave/river-dominated shoreface parasequences of the main valley, this area records a transition from estuary to shallow marine embayment.

Facies analysis in the MacKay River area demonstrate that embayments have significantly different facies patterns and vertical successions than observed in either estuary or deltaic environments. As there is no formal facies model for an embayment, this study has important contributions to both sedimentologic and stratigraphic ideologies. Ichnological analysis in this study played a key role in this interpretation as it would not have been possible through physical sedimentological investigations alone. Through recognition of trace fossil suites, environmental parameters such as salinity, water depth, energy levels, and sedimentation rates, were inferred. This then became significant criteria in refinement of the depositional setting, the relationship between facies, and in the identification of stratigraphic breaks.

Stratigraphic analysis in this study also illustrated the importance in identifying allocyclic versus autocyclic processes and how they affect the intricacy of stratal architecture. Although the McMurray-Wabiskaw stratigraphic interval in the MacKay River area is consistent with the main valley system and reflects dominantly a TST fill, alloycyclic processes largely controlled the stratal architecture. This resulted in periods of progradation within an overall retrogradational succession, and a complex relationship of lithofacies within individual parasequences. So although McMurray strata in the AOSA are deposited under similar eustatic sea level fluctuations, major differences can occur in relative sea level (i.e. accommodation and sediment supply) over a relatively small area. This ultimately plays a large factor in the resulting depositional systems, sedimentation patterns and stratigraphic architecture across an area.

With respect to regional aspects, both facies- and stratigraphic analysis in the MacKay River area have identified the importance of RSL. Therefore, the middle McMurray, upper McMurray, and Wabiskaw members may not be contemporaneous to those in the main valley. In a broader sense, the overall paleogeographic location and stratigraphic fill in the MacKay River area are completely different resulting from allocyclic controls (i.e. source of sediment supply, accommodation space). These units are completely different depositional environments and should be considered separate from the informal stratigraphic members in the main valley.

With the accelerating depletion of conventional oil resources and a progressive rise in world oil prices, unconventional resources have become a significant facet to the global economy. The Lower Cretaceous McMurray-Wabiskaw stratigraphic succession is a prolific bitumen reservoir interval in the AOSA. In contrast to the main valley system, the main reservoir interval in the MacKay area corresponds to the upper McMurray embayment, comprising laterally continuous, northwest-trending, elongate tidal sand bar complexes that exhibit excellent reservoir quality. As shallow oil sand reservoirs continue to diminish, a shift in paradigm to deeper in-situ exploration and development of these deposits has become the standard.

With a lack of literature on the McMurray-Wabiskaw interval in this area, the resulting depositional and stratigraphic framework may ultimately enhance reservoir predictability, distribution, and the overall geological understanding of the McMurray-Wabiskaw succession in the McKay River area. As tidally-influenced systems are becoming increasingly important with regards to petroleum reservoirs, detailed sedimentological and ichnological observations may improve the understanding of the architecture and ichnological trends of both estuarine and shallow marine sand bar deposits. As embayment environments are underrepresented in current facies models, this case study may prove as an example for similar deposits within the Athabasca Oil Sands, and elsewhere.

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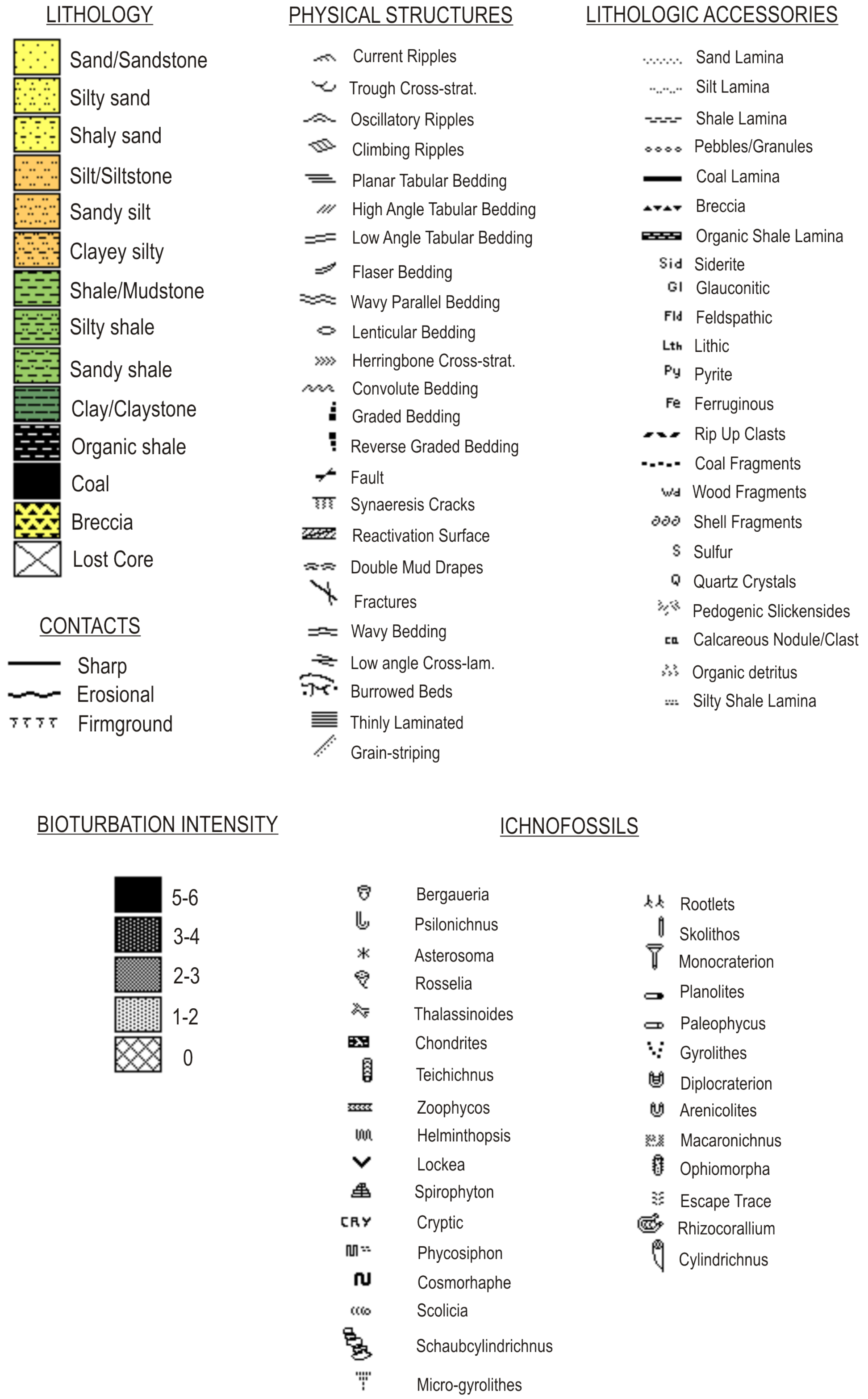
APPENDIX A

LEGEND



LITHOLOGY

- Sand/Sandstone
- Silty sand
- Shaly sand
- Silt/Siltstone
- Sandy silt
- Clayey silty
- Shale/Mudstone
- Silty shale
- Sandy shale
- Clay/Claystone
- Organic shale
- Coal
- Breccia
- Lost Core

CONTACTS

- Sharp
- Erosional
- Firmground

PHYSICAL STRUCTURES

- Current Ripples
- Trough Cross-strat.
- Oscillatory Ripples
- Climbing Ripples
- Planar Tabular Bedding
- High Angle Tabular Bedding
- Low Angle Tabular Bedding
- Flaser Bedding
- Wavy Parallel Bedding
- Lenticular Bedding
- Herringbone Cross-strat.
- Convolute Bedding
- Graded Bedding
- Reverse Graded Bedding
- Fault
- Synaeresis Cracks
- Reactivation Surface
- Double Mud Drapes
- Fractures
- Wavy Bedding
- Low angle Cross-lam.
- Burrowed Beds
- Thinly Laminated
- Grain-striping

LITHOLOGIC ACCESSORIES

- Sand Lamina
- Silt Lamina
- Shale Lamina
- Pebbles/Granules
- Coal Lamina
- Breccia
- Organic Shale Lamina
- Sid Siderite
- Gl Glauconitic
- Fld Feldspathic
- Lth Lithic
- Py Pyrite
- Fe Ferruginous
- Rip Up Clasts
- Coal Fragments
- Wd Wood Fragments
- Shell Fragments
- S Sulfur
- Q Quartz Crystals
- Pedogenic Slickensides
- ca Calcareous Nodule/Clast
- Organic detritus
- Silty Shale Lamina

BIOTURBATION INTENSITY

- 5-6
- 3-4
- 2-3
- 1-2
- 0

ICHNOFOSSILS

- Bergaueria
- Psilonichnus
- Asterosoma
- Rosselia
- Thalassinoides
- Chondrites
- Teichichnus
- Zoophycos
- Helminthopsis
- Lockea
- Spirophyton
- CRY Cryptic
- Phycosiphon
- Cosmorhaphe
- Scolicia
- Schaubcylindrichnus
- Micro-gyrolithes
- Rootlets
- Skolithos
- Monocraterion
- Planolites
- Paleophycus
- Gyrolithes
- Diplocraterion
- Arenicolites
- Macaronichnus
- Ophiomorpha
- Escape Trace
- Rhizocorallium
- Cylindrichnus

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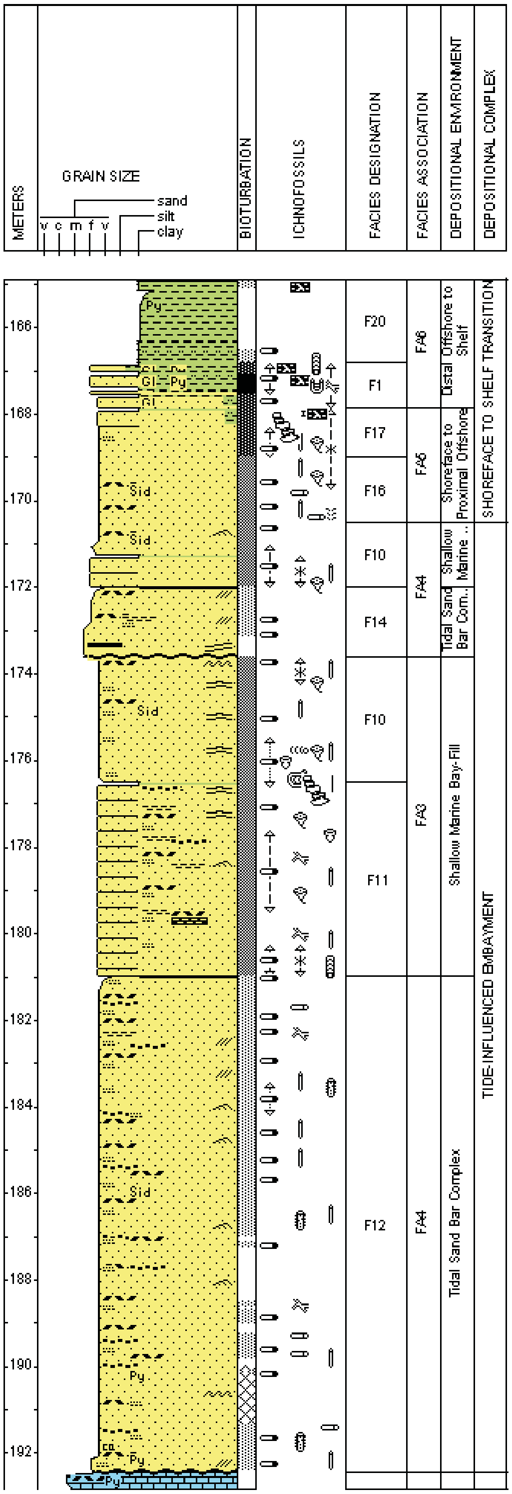

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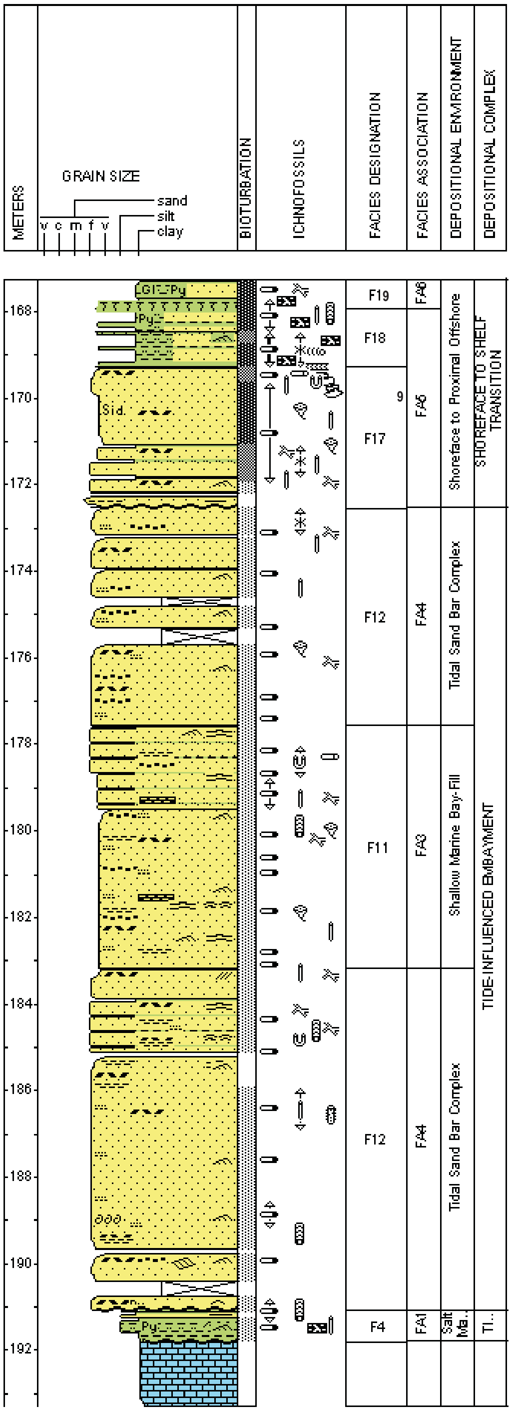

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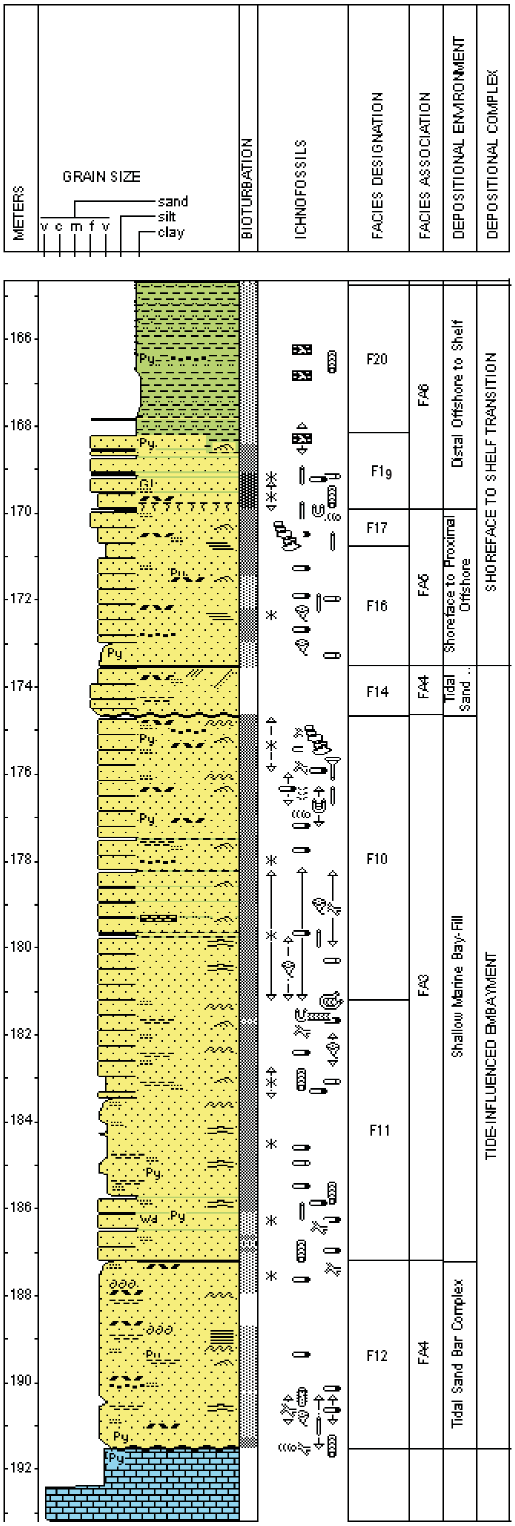

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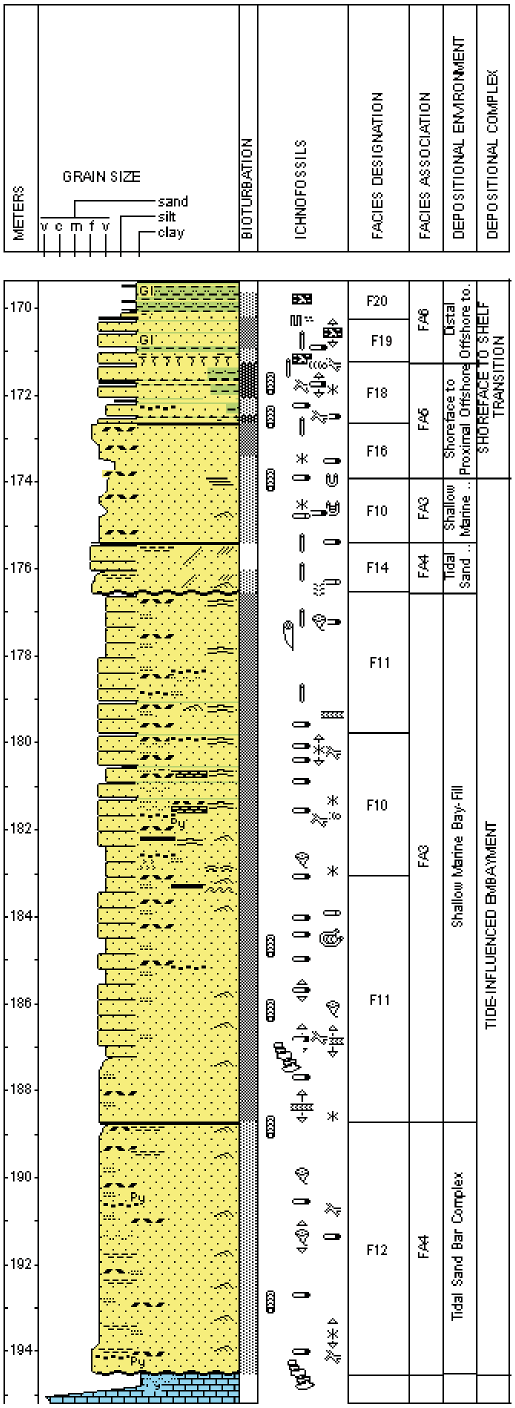

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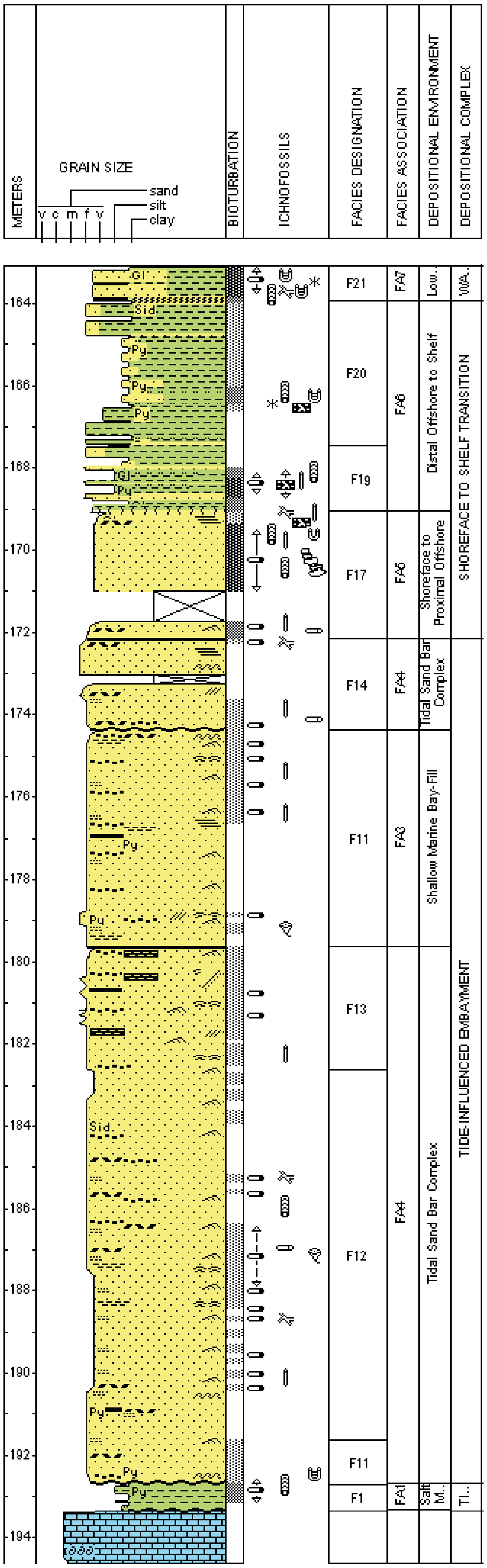

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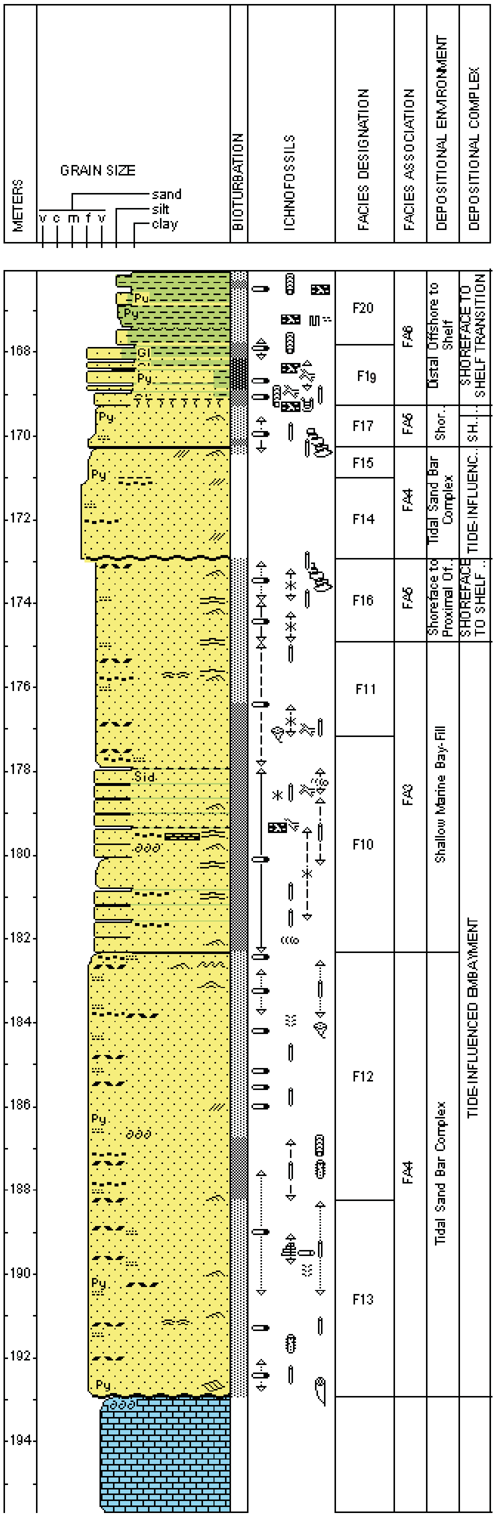

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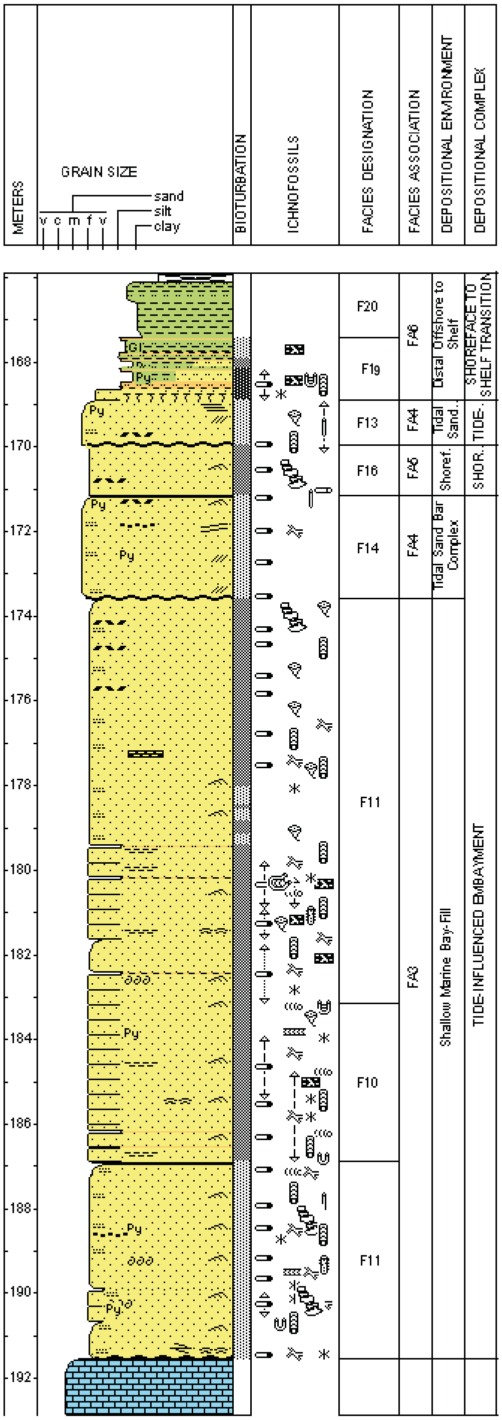

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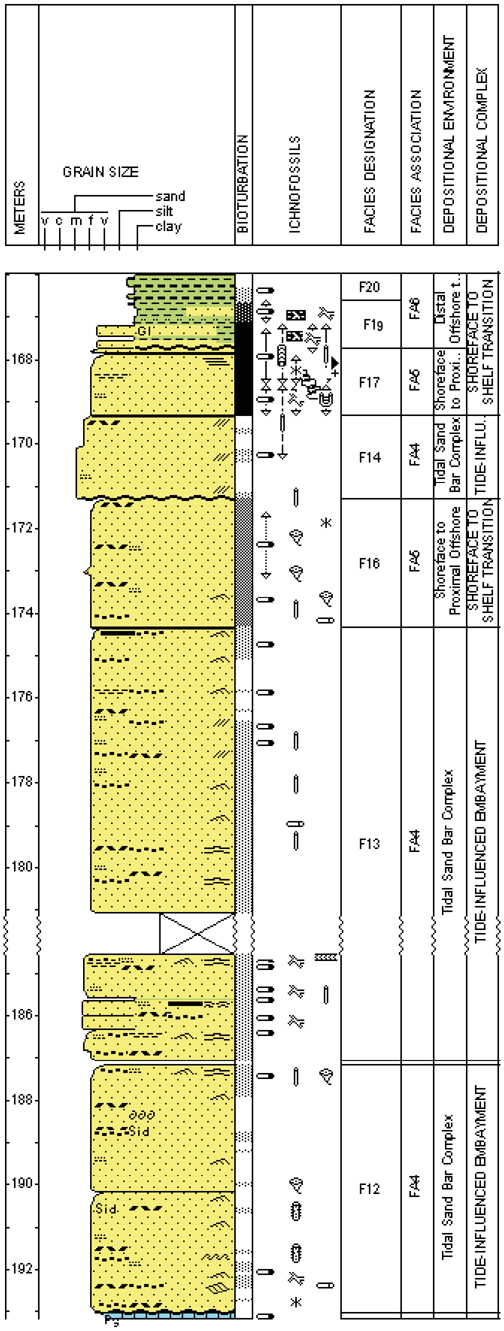

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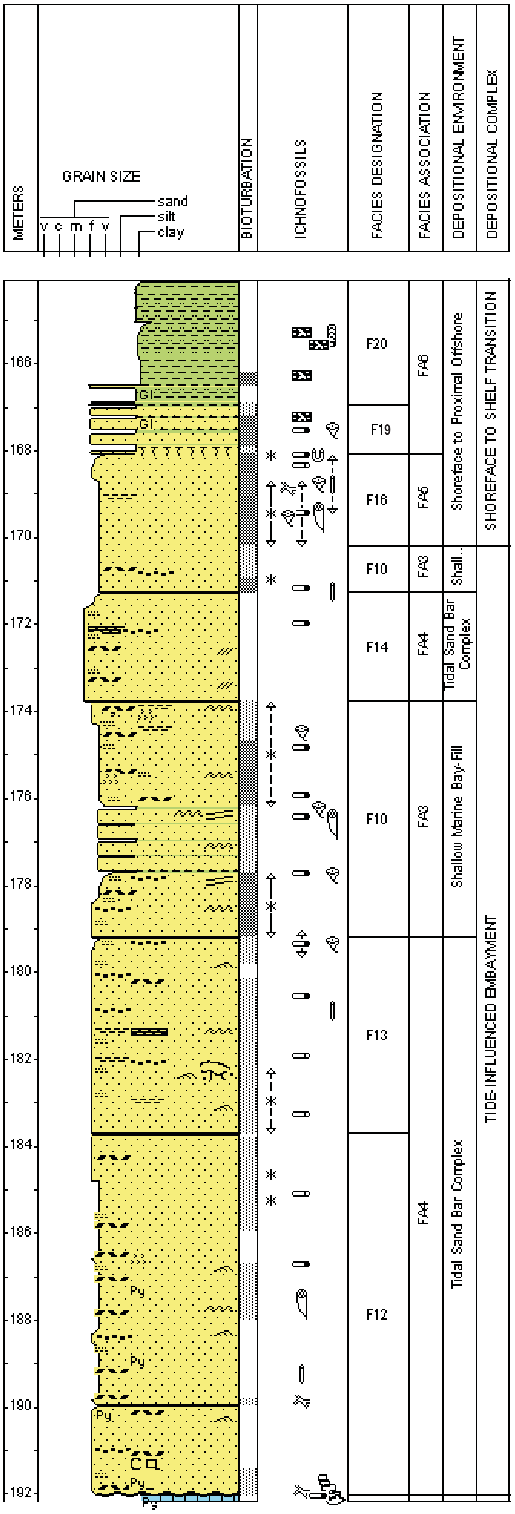

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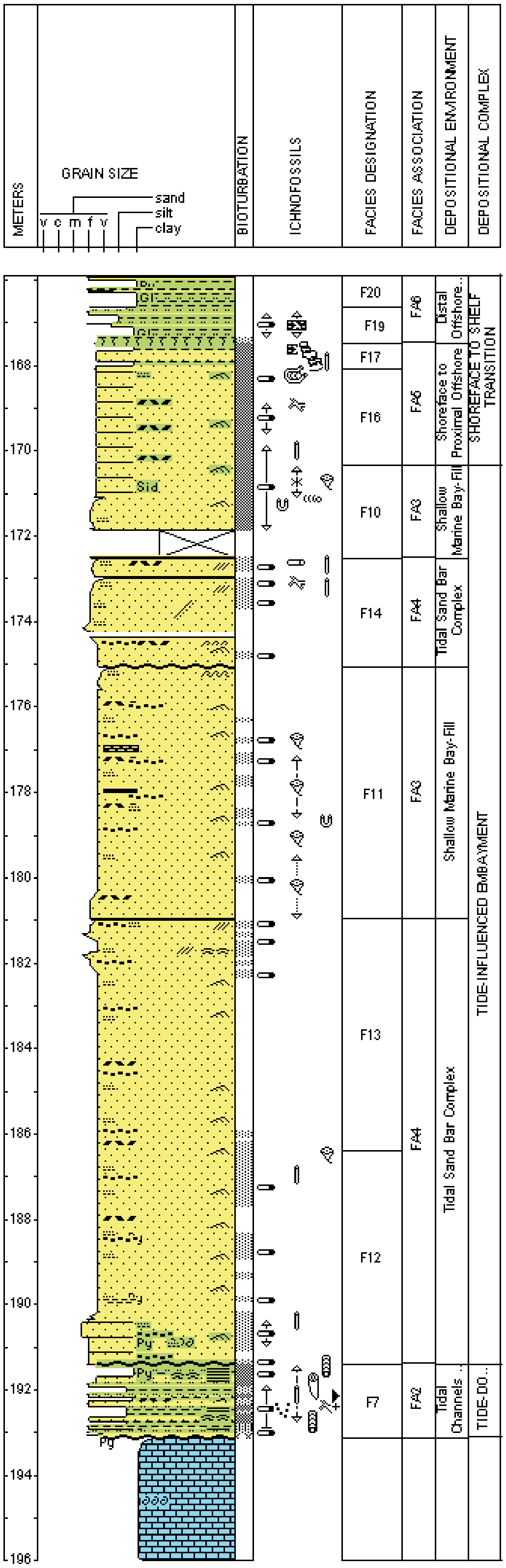

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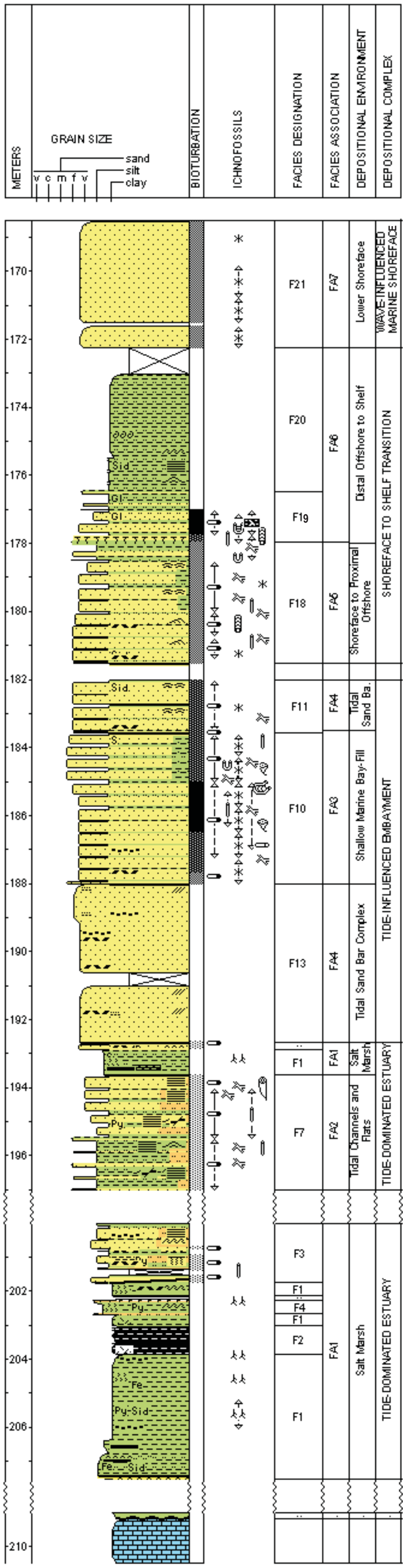

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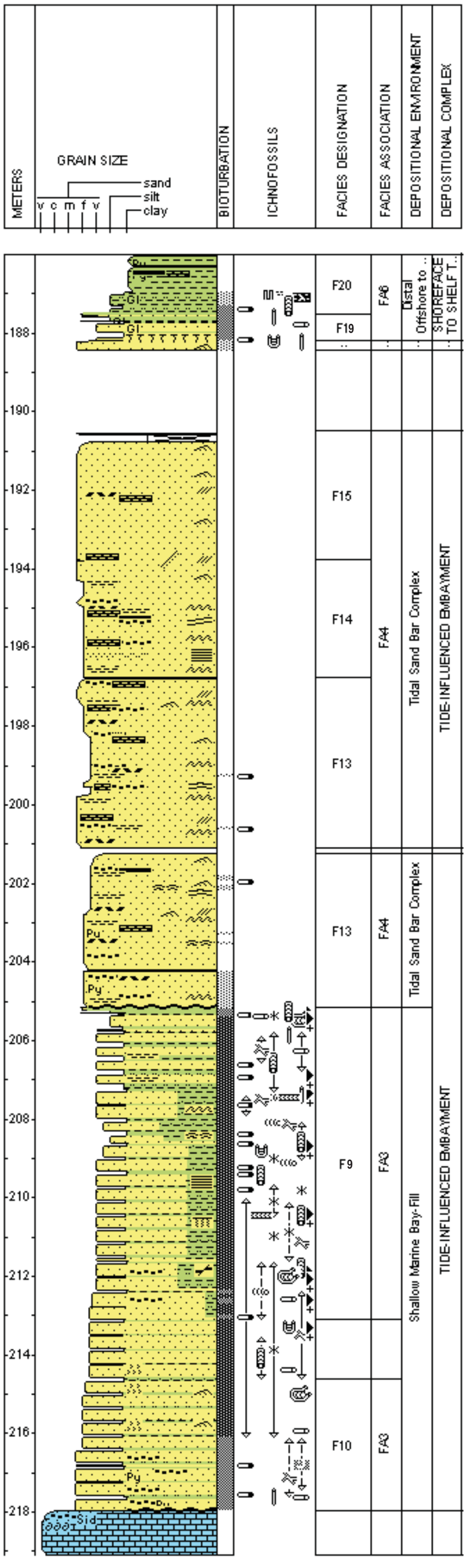

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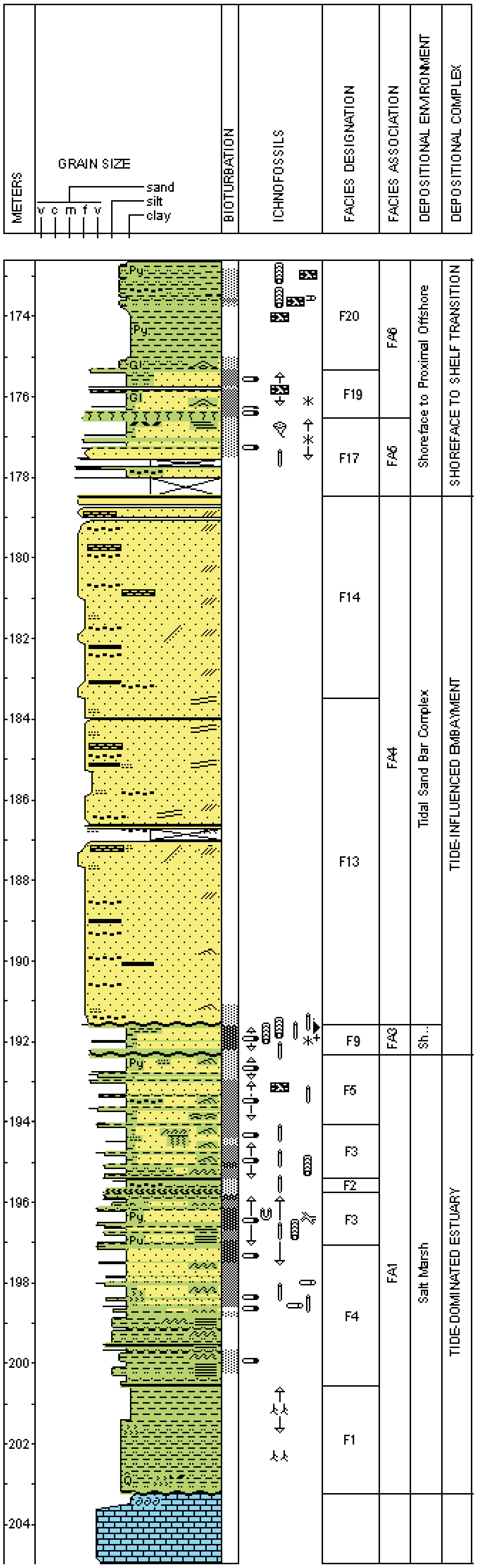

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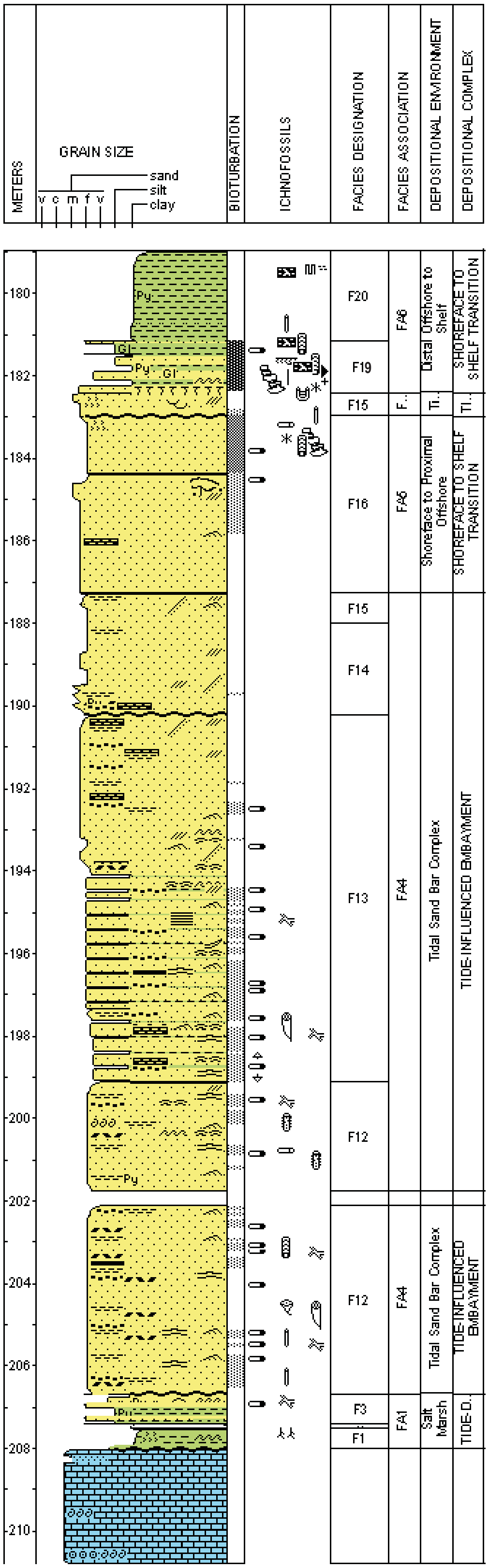

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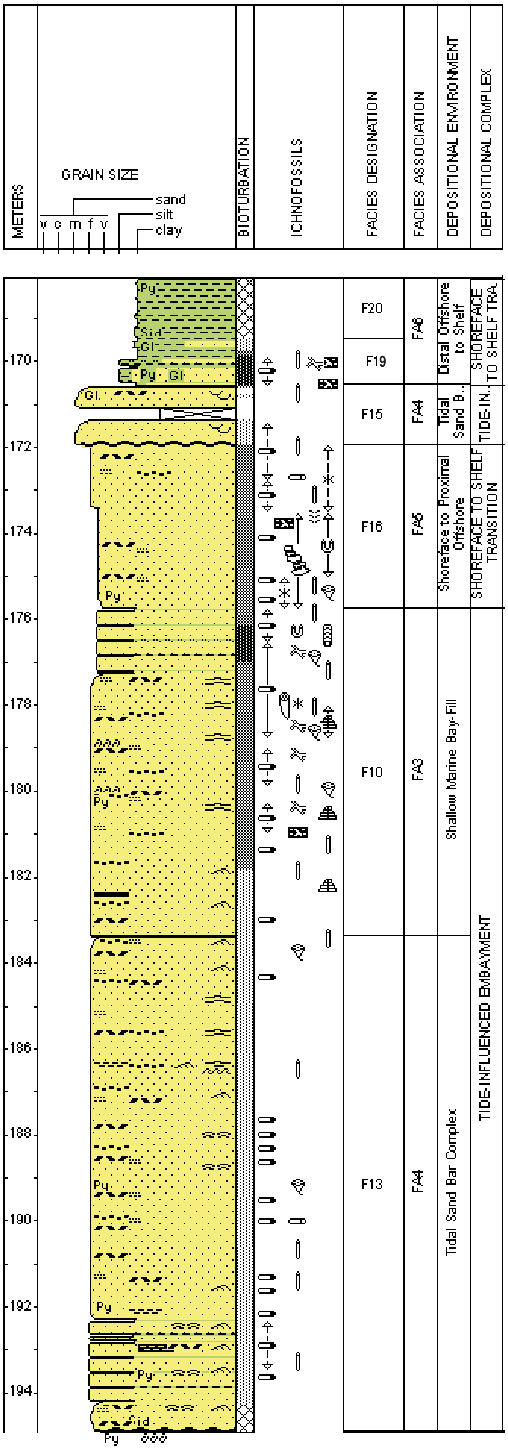

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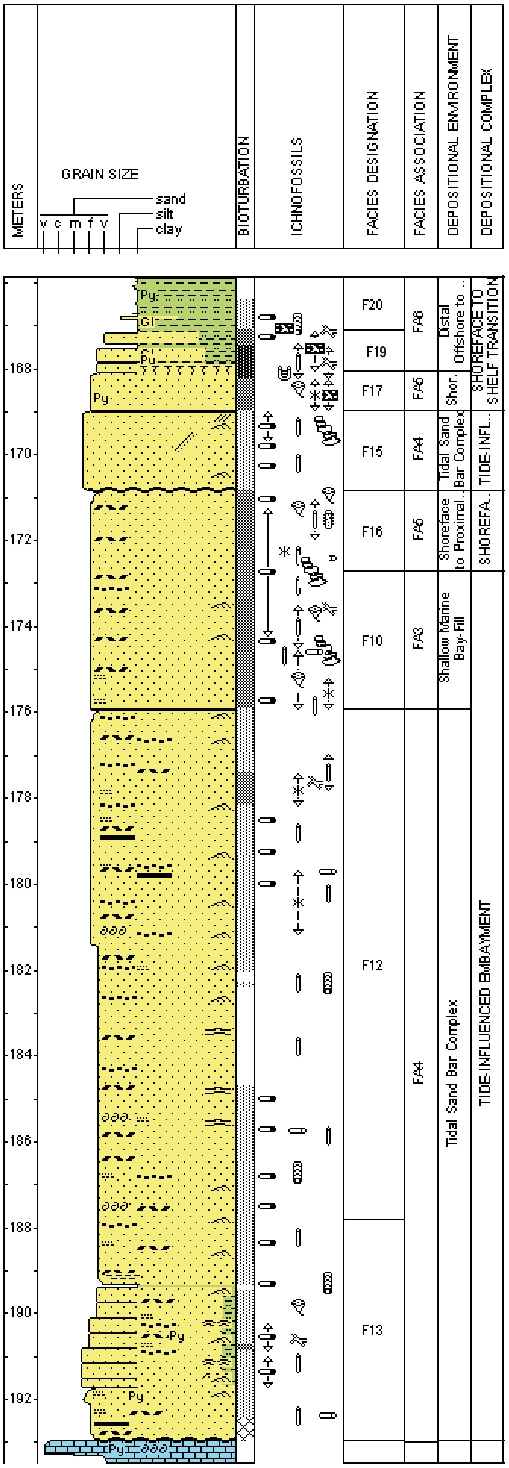

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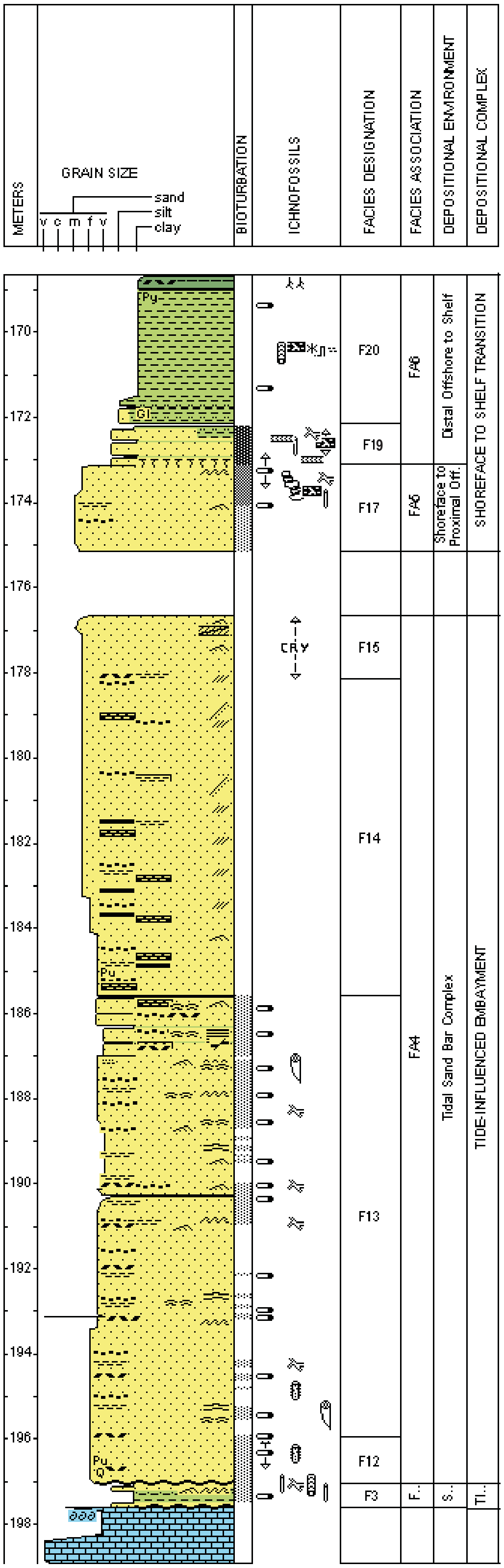

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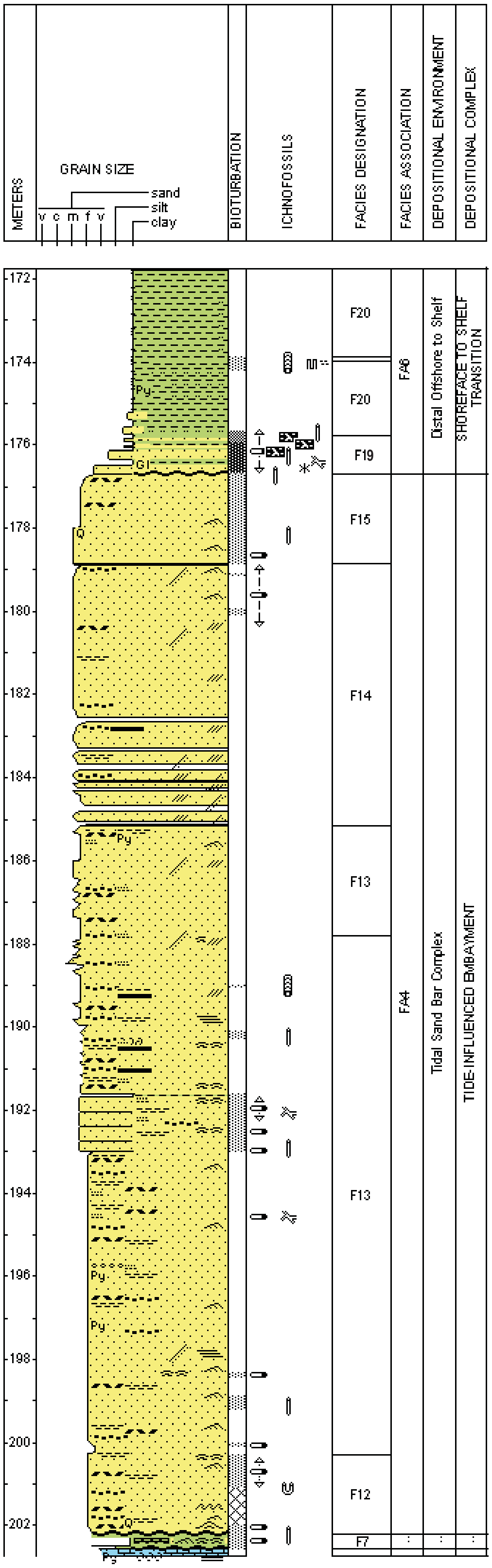

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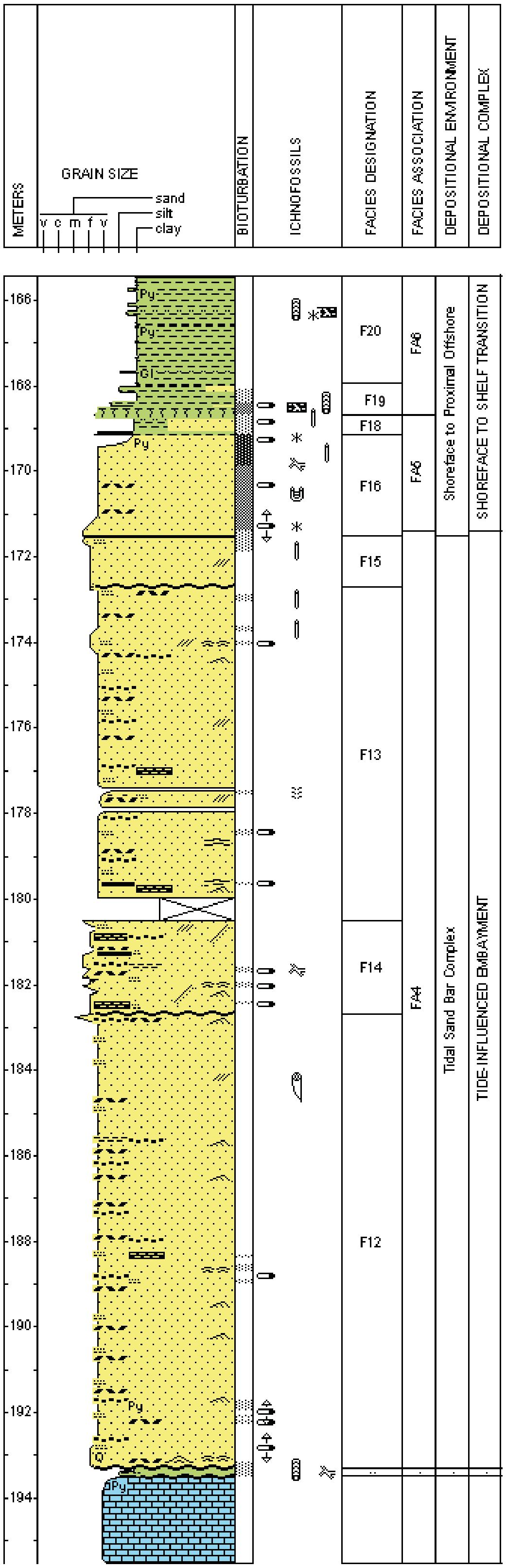

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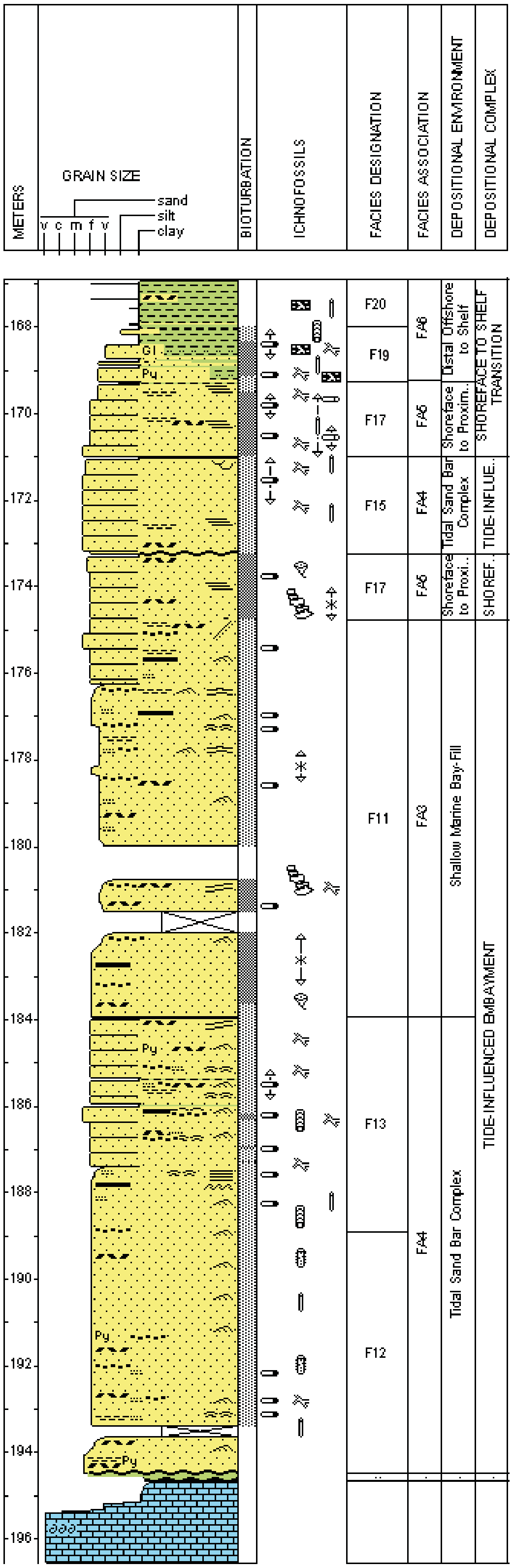

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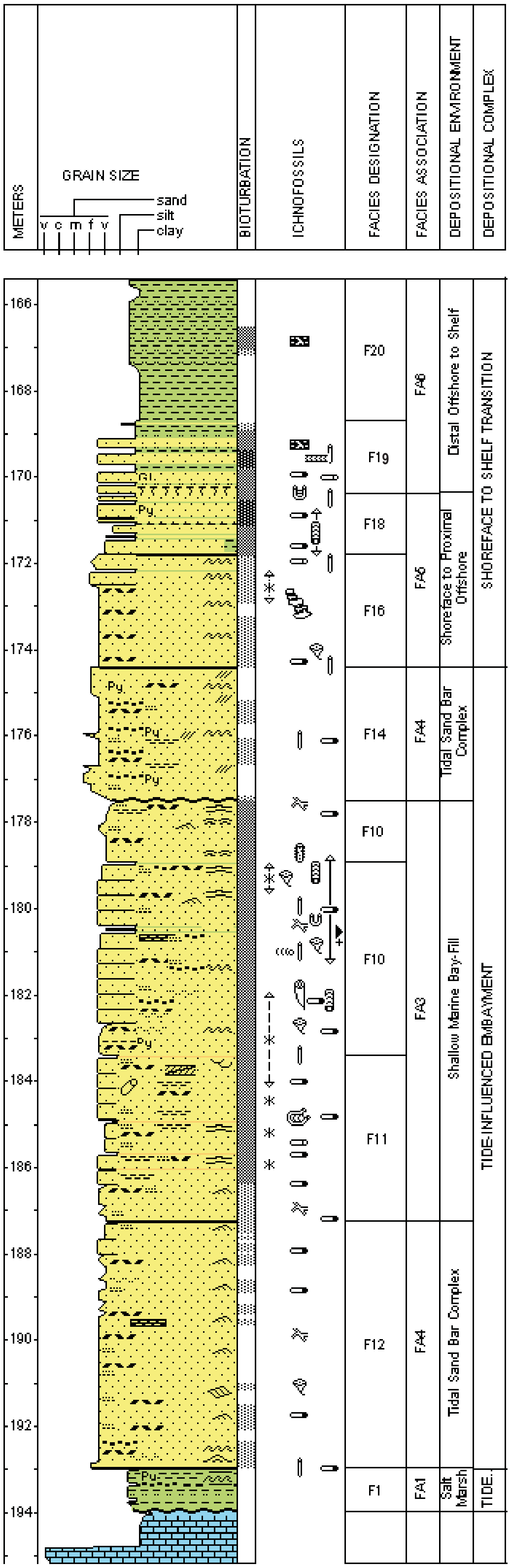

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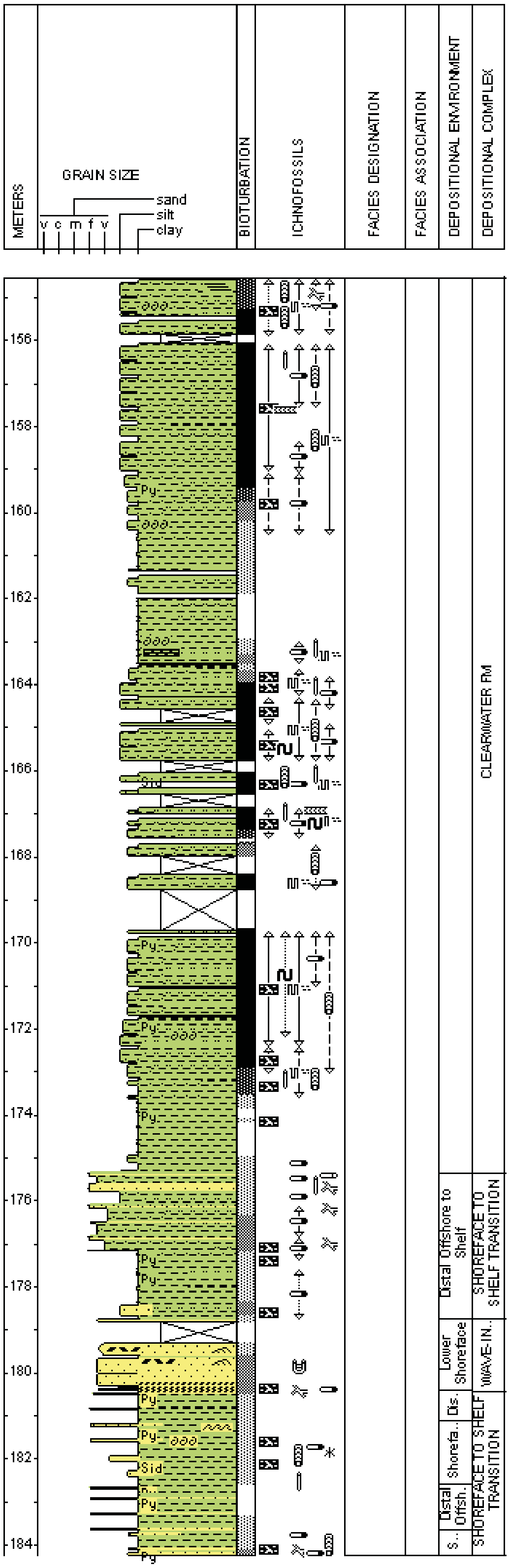

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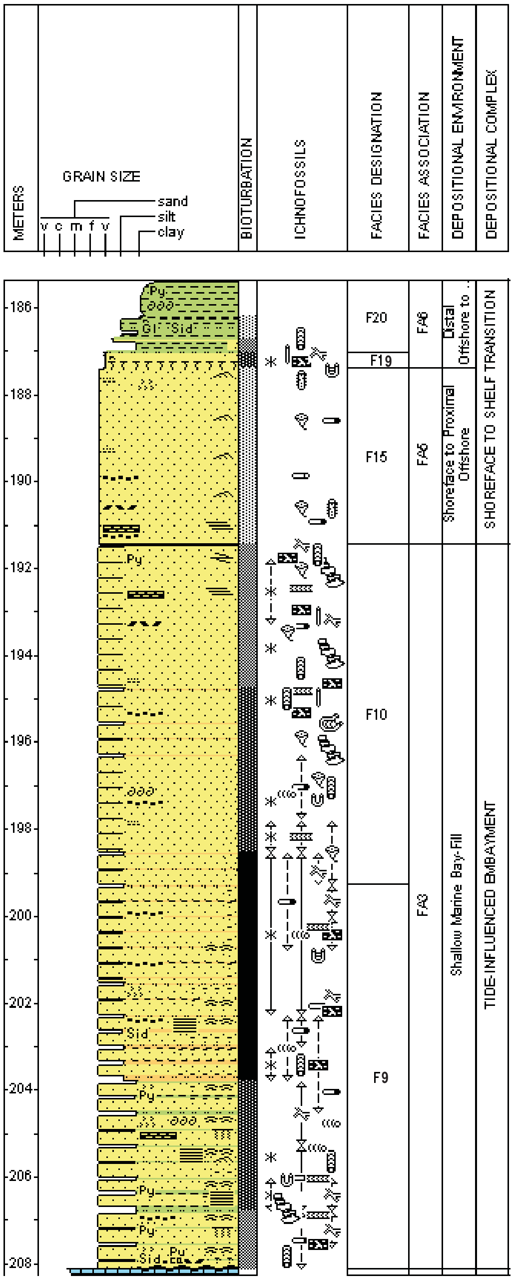

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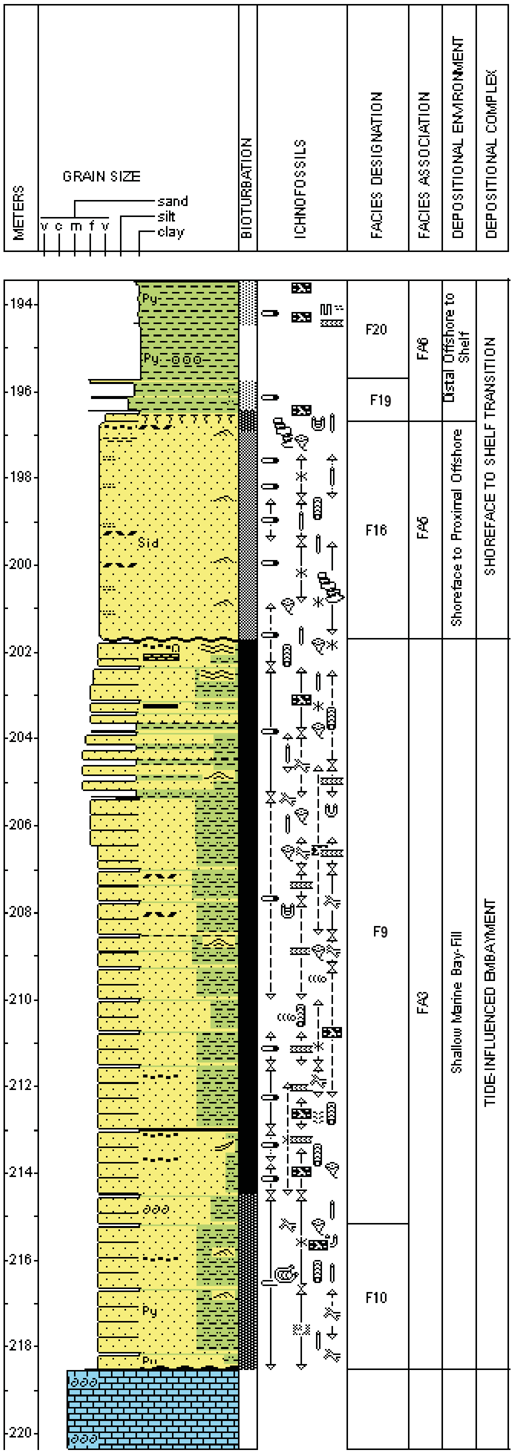

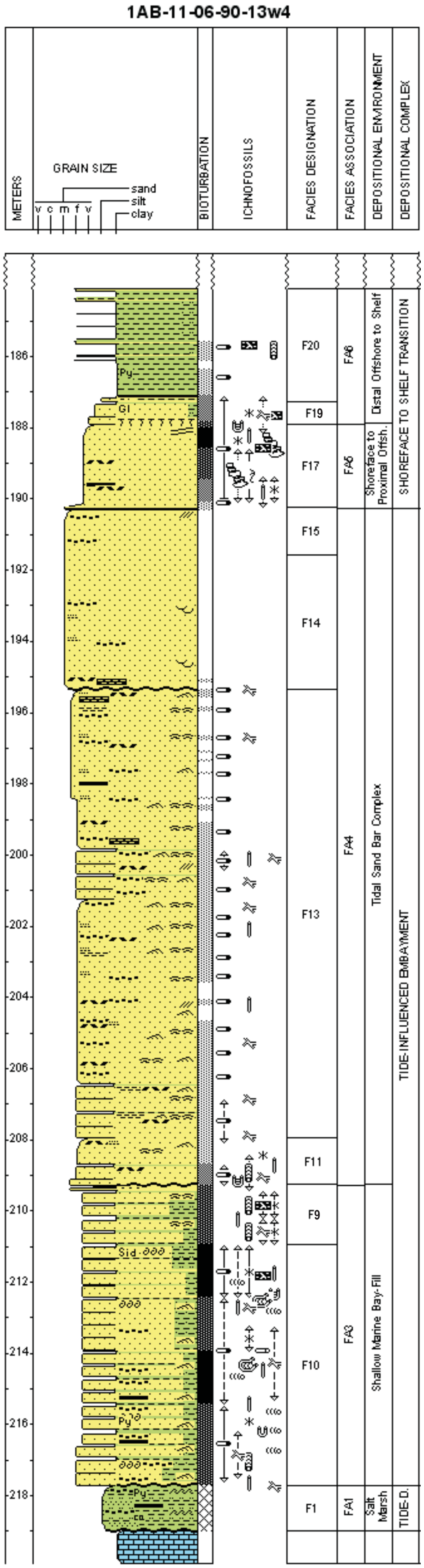
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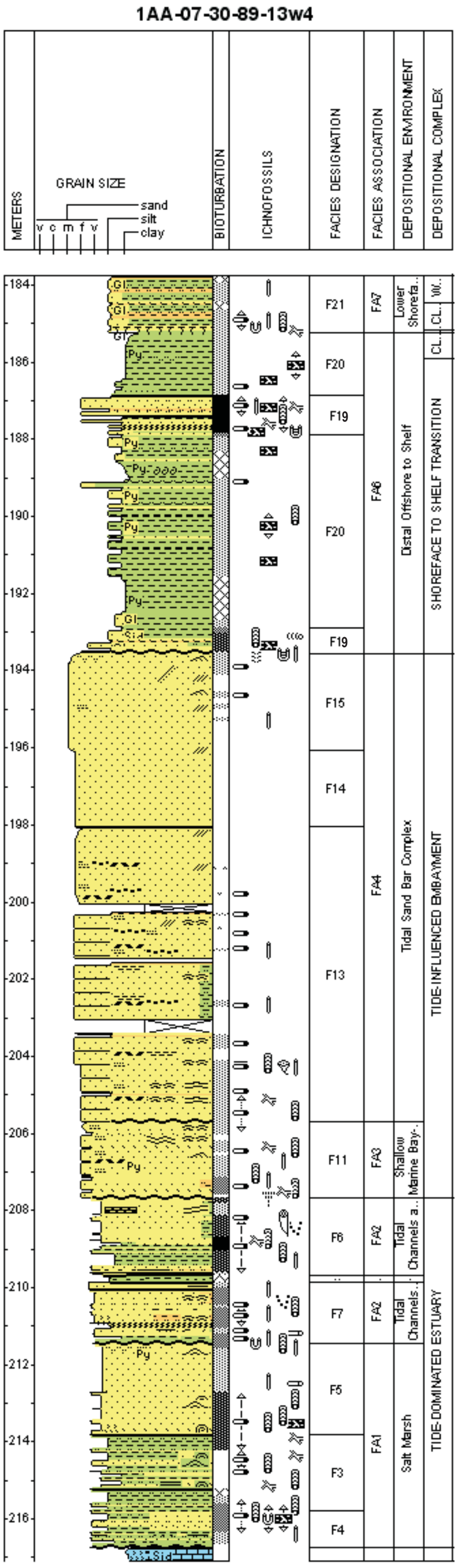
GRAIN SIZE
v c m f v
sand
silt
clay
BIOTURBATION
ICHNOFOSSILS
FACIES DESIGNATION
FACIES ASSOCIATION
DEPOSITIONAL ENVIRONMENT
DEPOSITIONAL COMPLEX
-186
-188
-190
-192
-194
-196
-198
-200
-202
-204
-206
-208
-210
-212
-214
-216
-218
Py
Gl
Sid
ca
F20
F19
F17
F15
F14
F13
F11
F9
F10
F1
FA6
FA5
FA4
FA3
FA1
Distal Offshore to Shelf
Shoreface to Proximal Offsh.
Tidal Sand Bar Complex
Shallow Marine Bay-Fill
Salt Marsh
SHOREFACE TO SHELF TRANSITION
TIDE-INFLUENCED EMBAYMENT
TIDE-D.


1AA-07-30-89-13w4
METERS
GRAIN SIZE
v c m f v
sand
silt
clay
BIOTURBATION
ICHNOFOSSILS
FACIES DESIGNATION
FACIES ASSOCIATION
DEPOSITIONAL ENVIRONMENT
DEPOSITIONAL COMPLEX
-184
-186
-188
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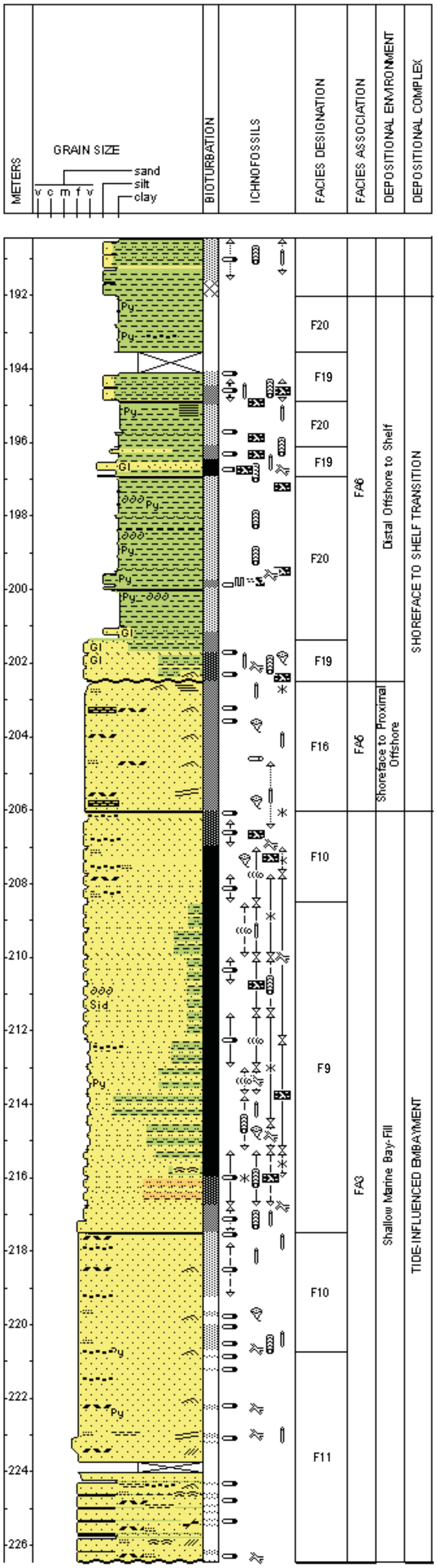
F4
FA7
FA6
FA4
FA3
FA2
FA2
FA1
Lower Shorefa.
Distal Offshore to Shelf
Tidal Sand Bar Complex
Shallow Marine Bay-
Tidal Channels a.
Tidal Channels
Salt Marsh
CL.
CL.
W.
SHOREFACE TO SHELF TRANSITION
TIDE-INFLUENCED EMBAYMENT
TIDE-DOMINATED ESTUARY

1AA-10-32-89-13w4



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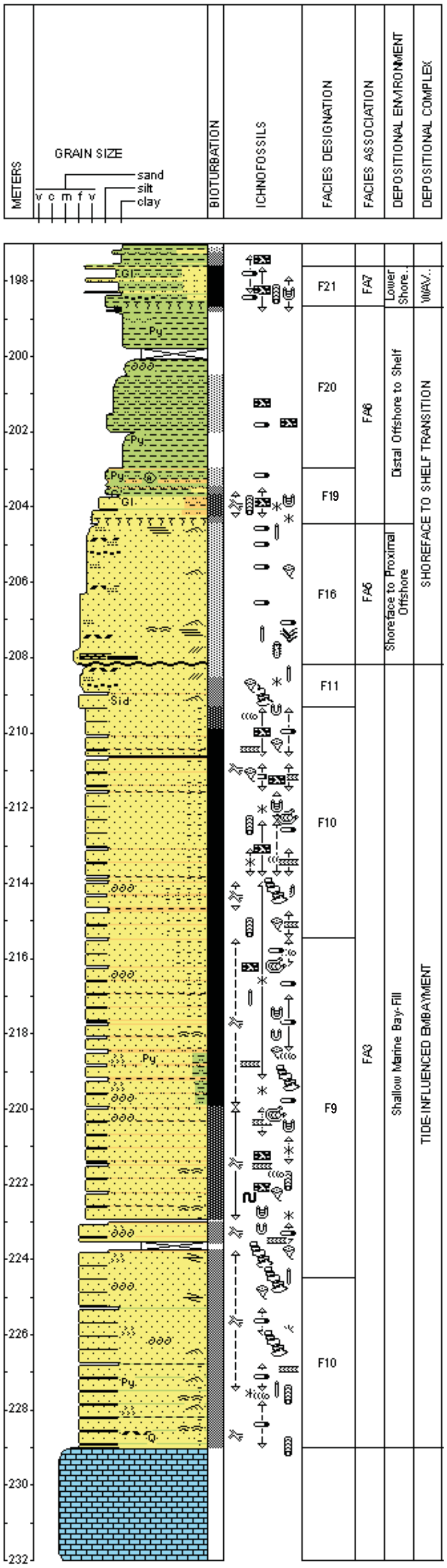

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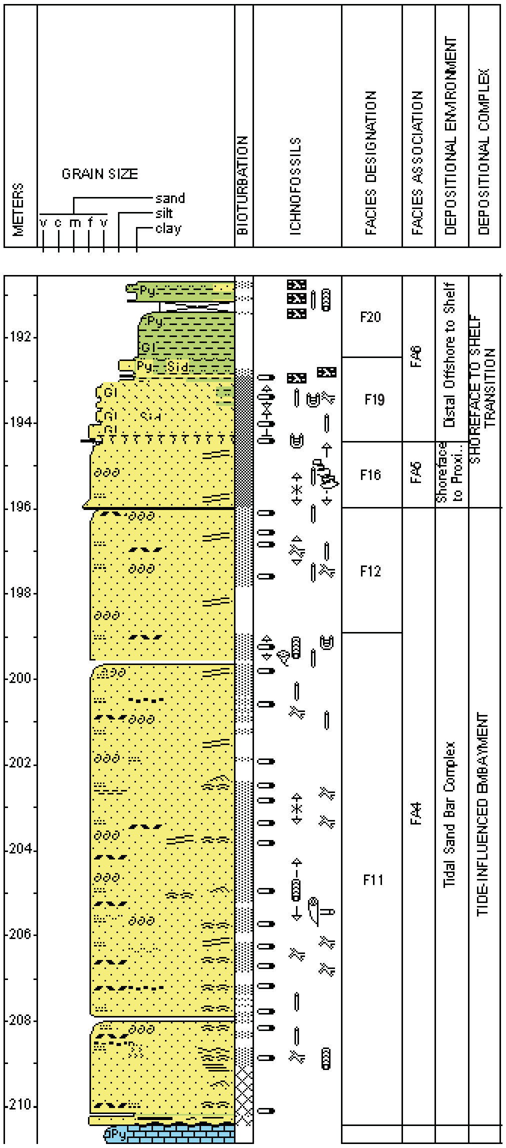

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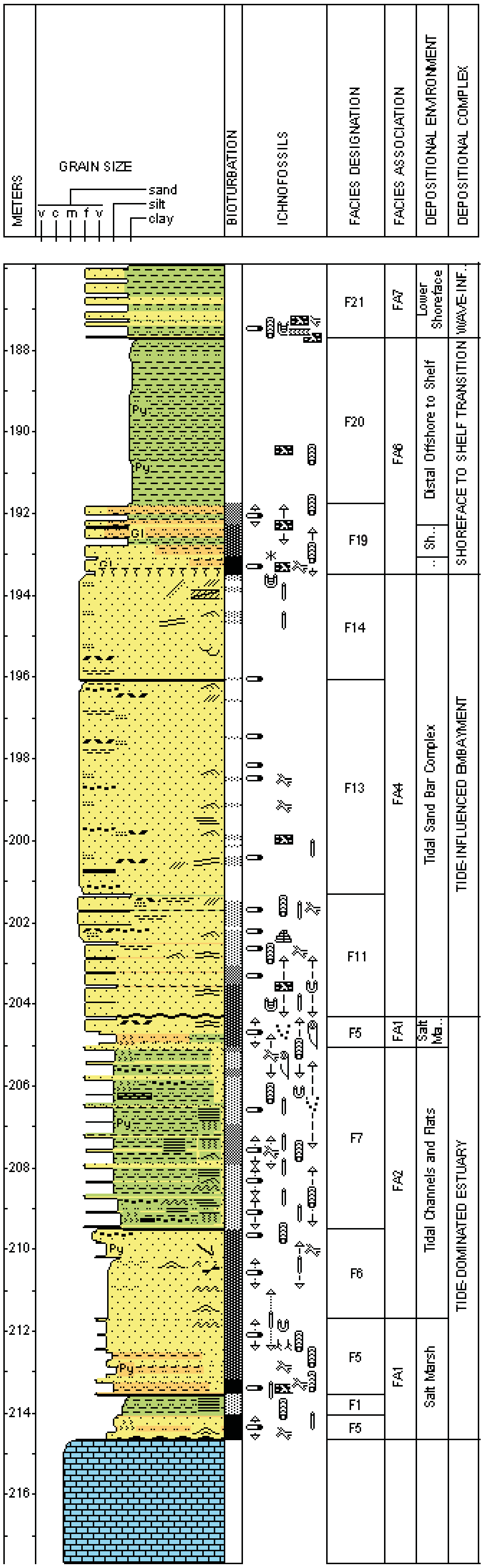

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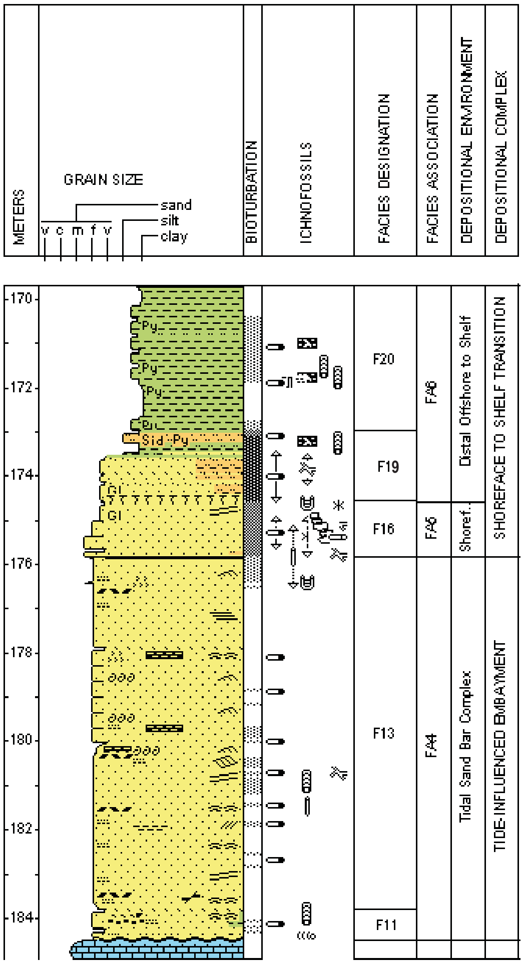

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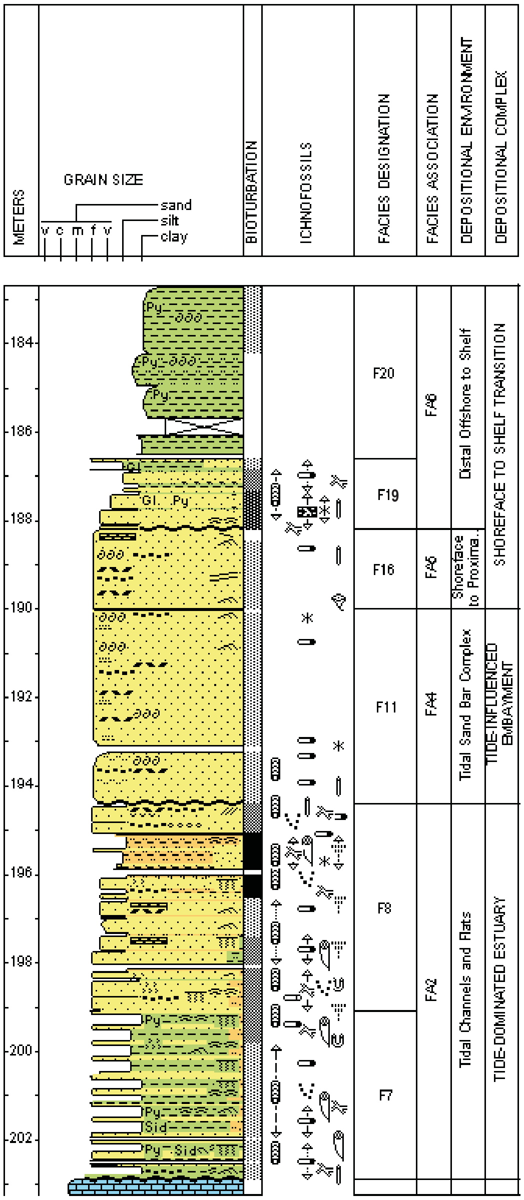

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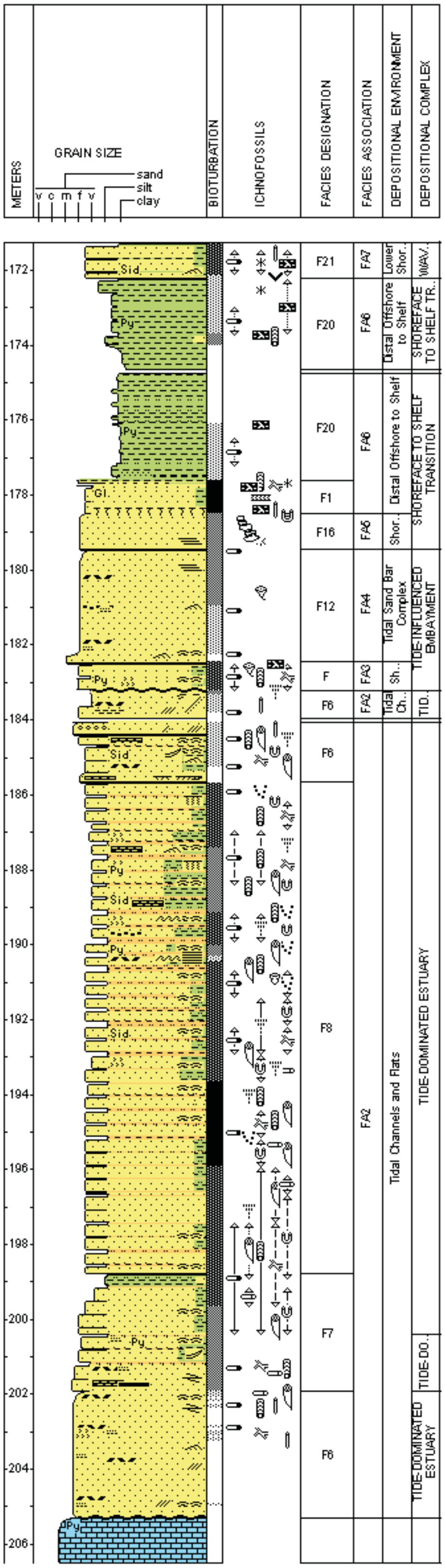

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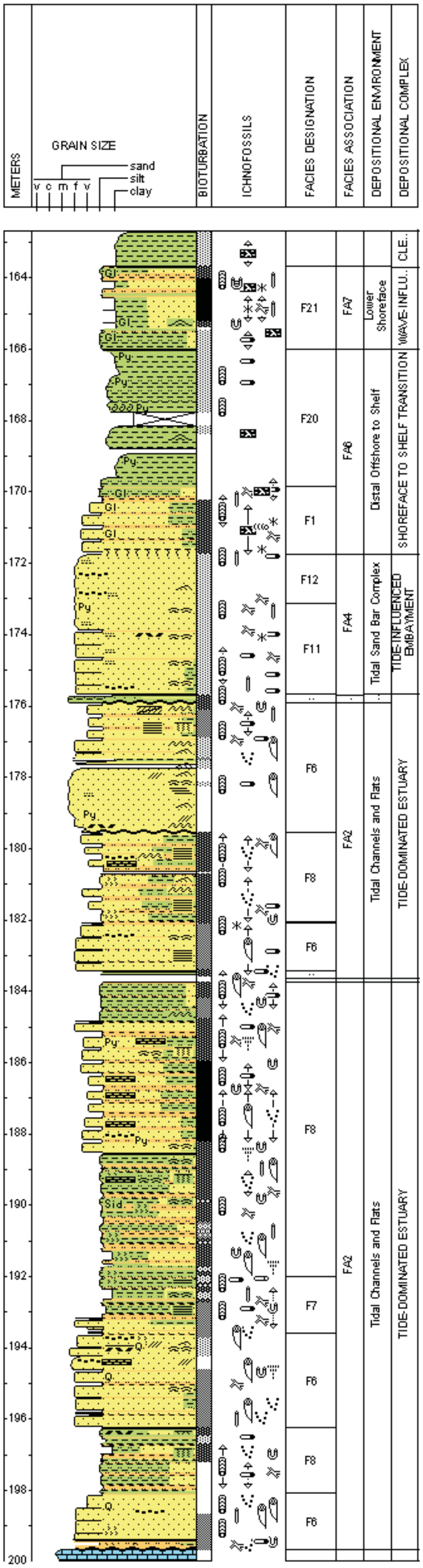

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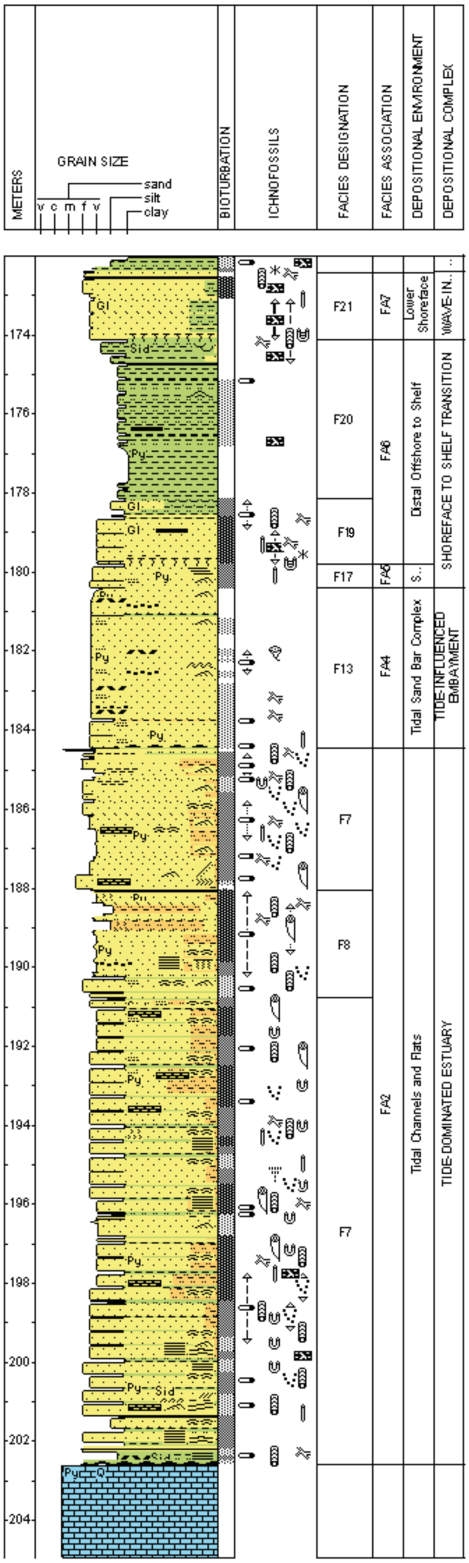

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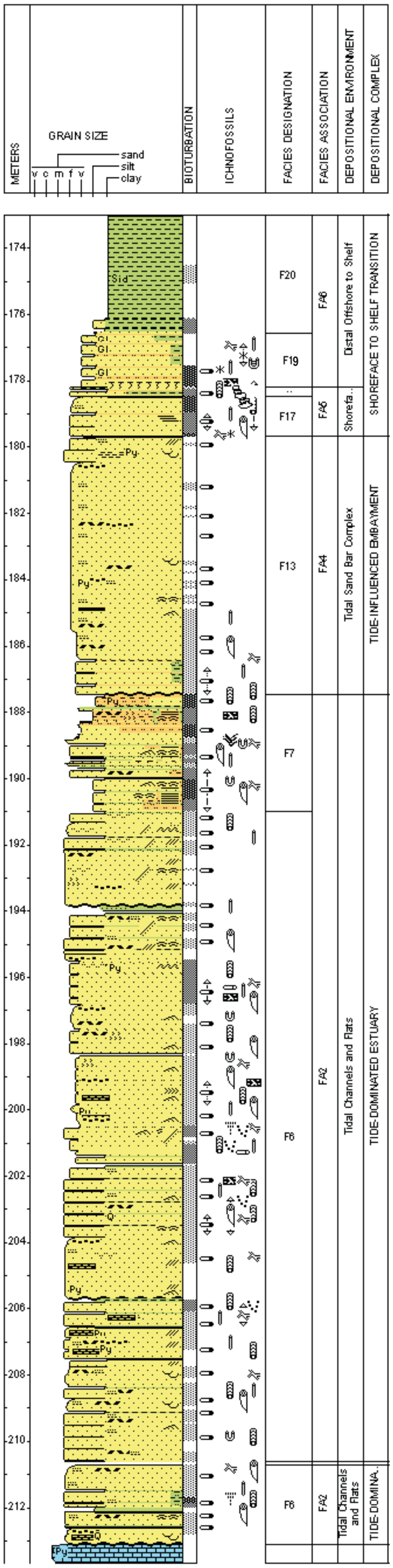

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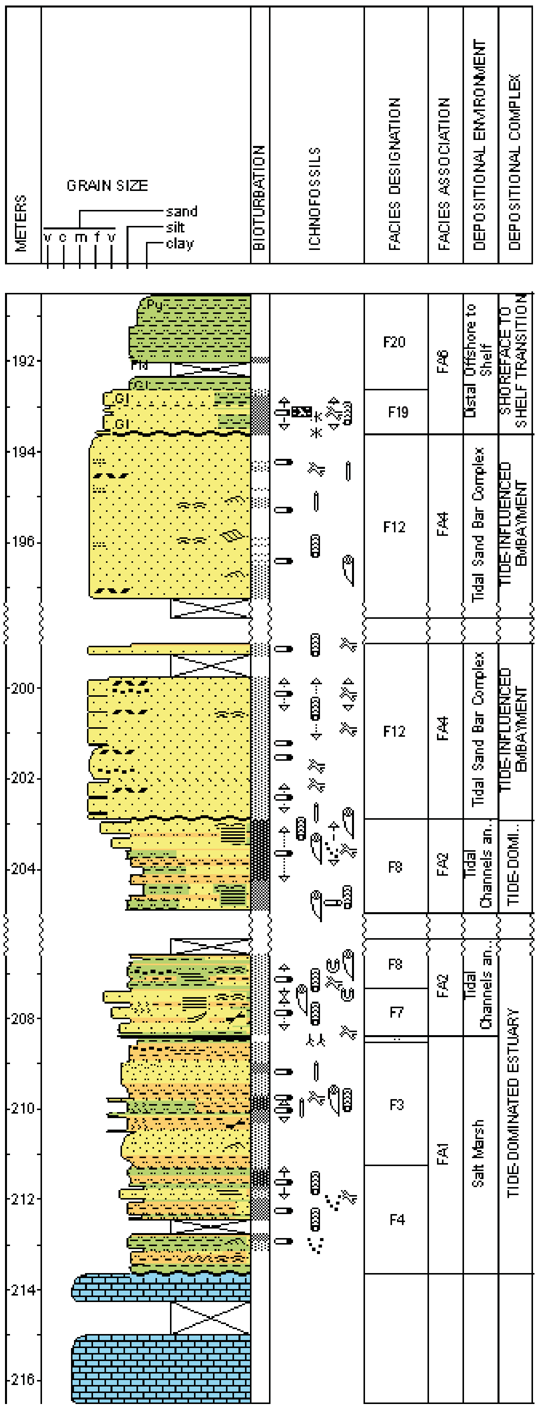

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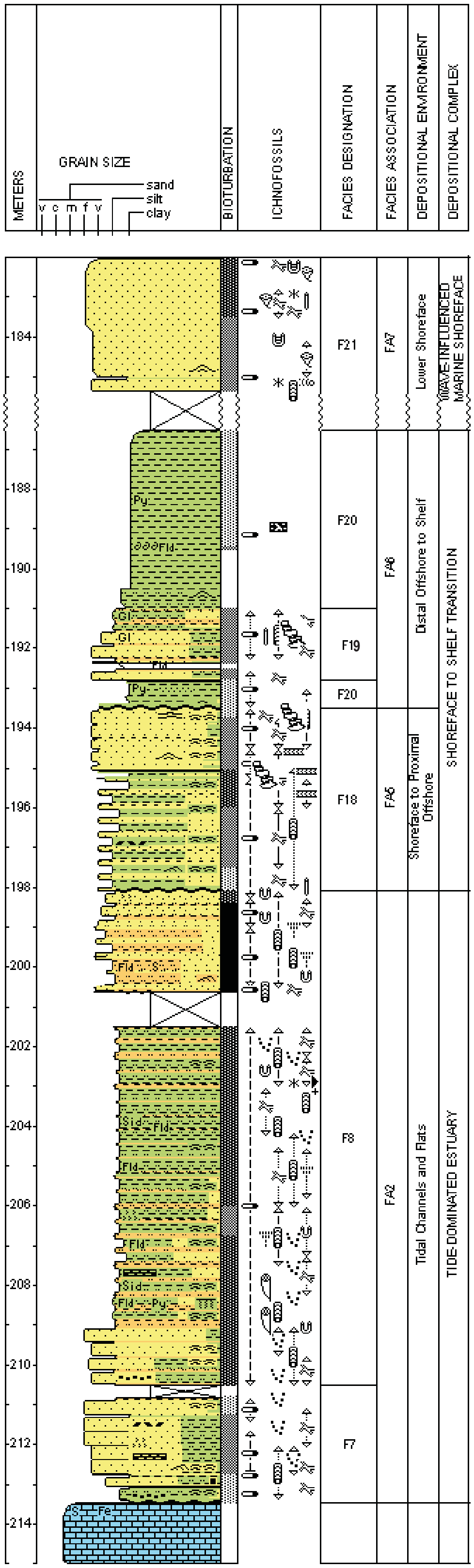

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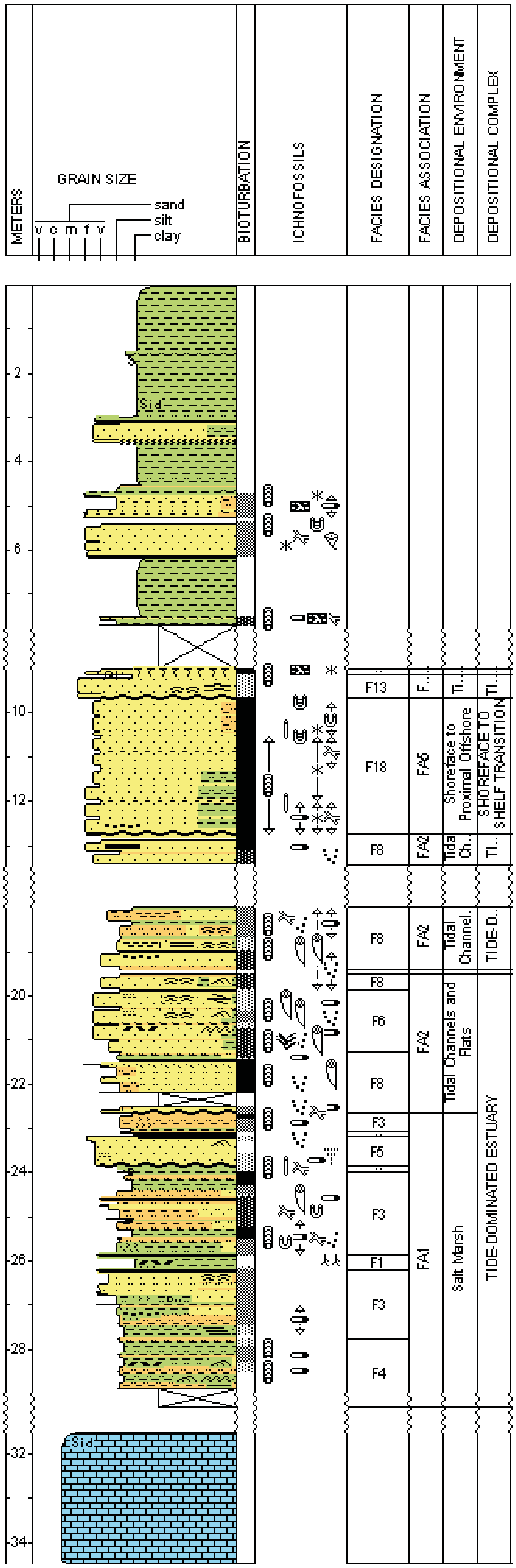

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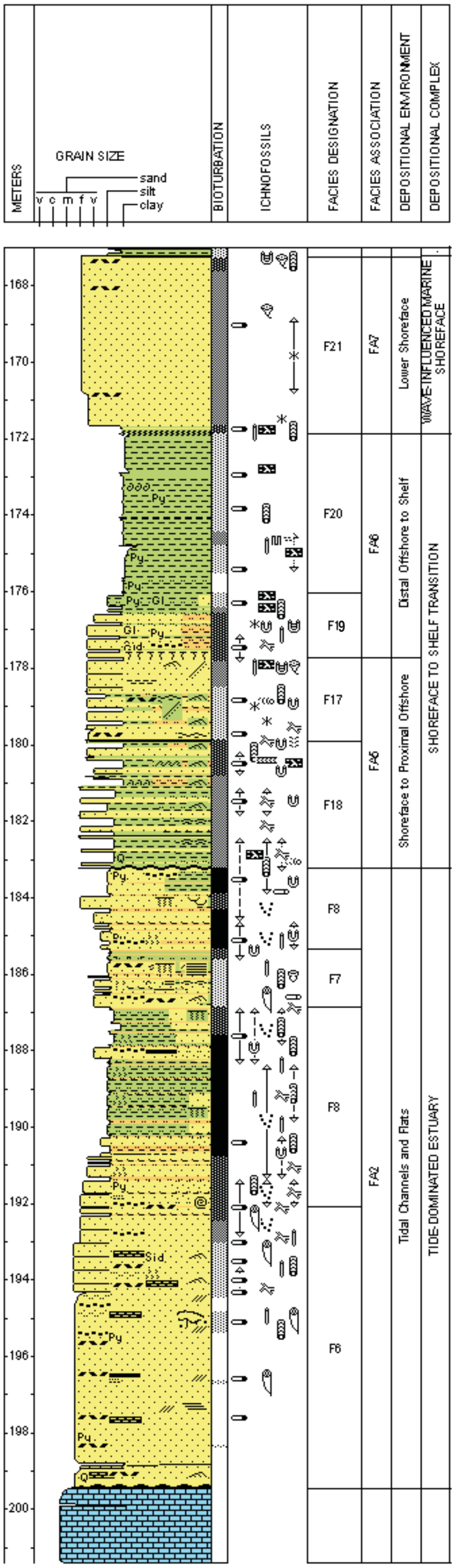

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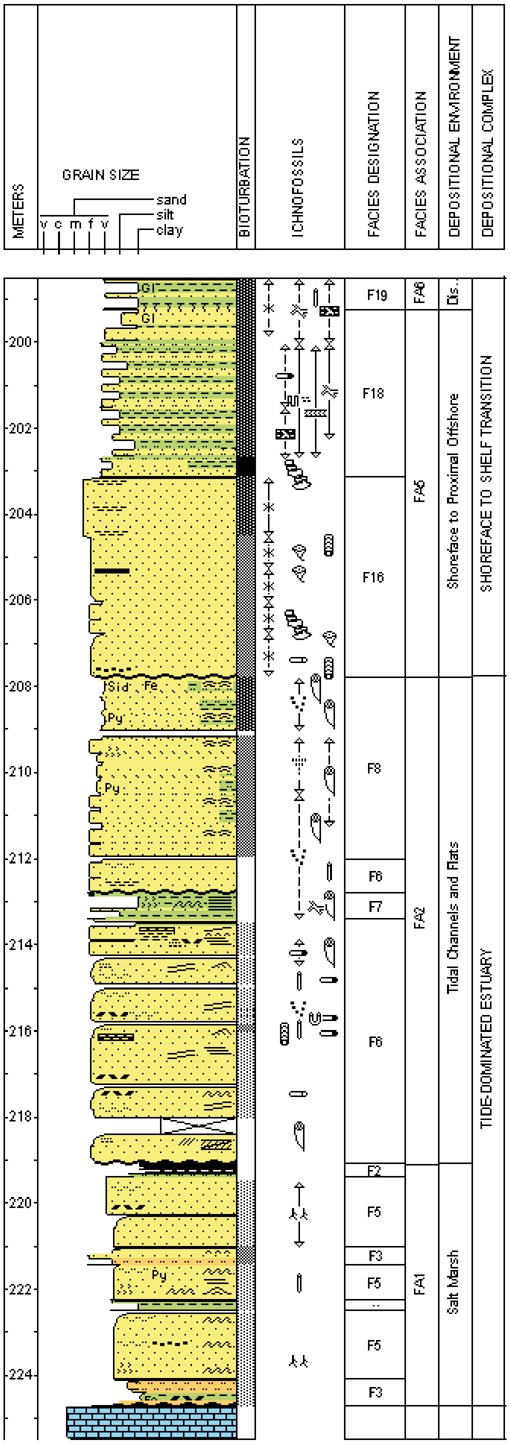

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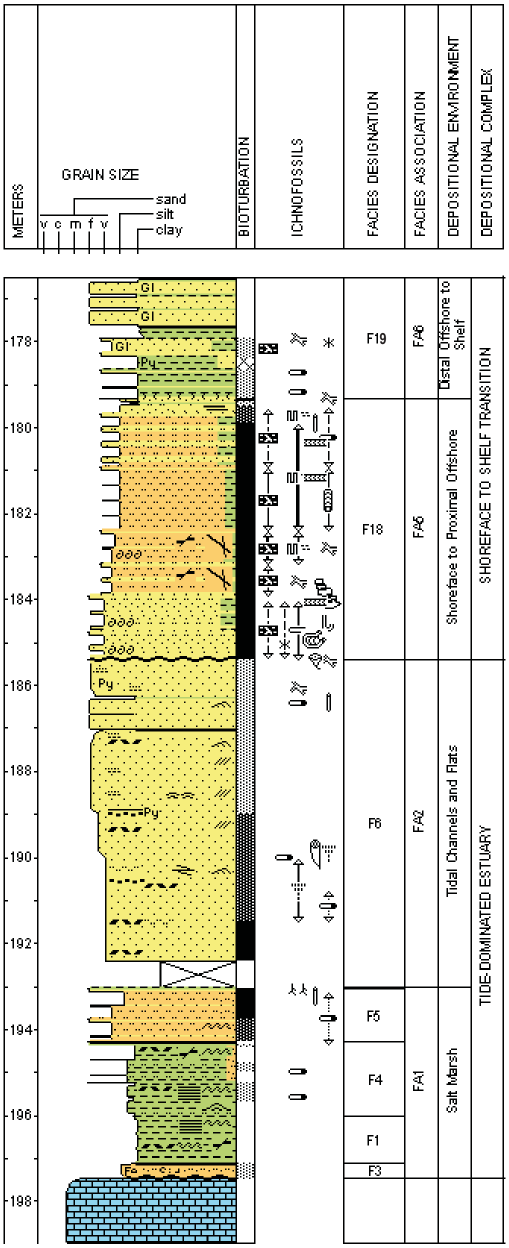

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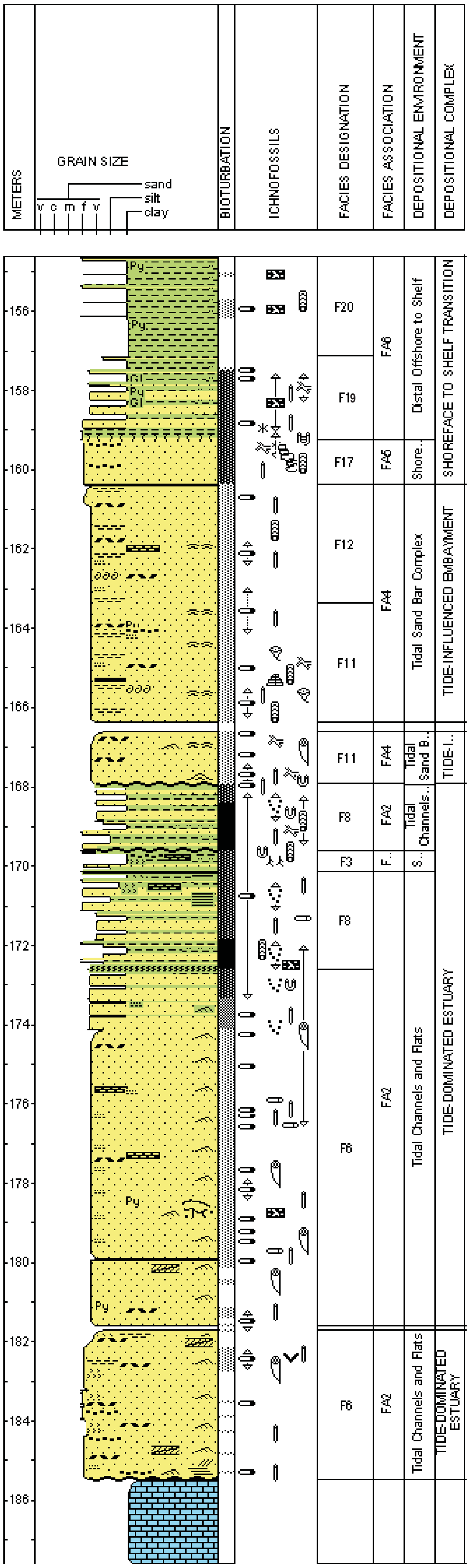

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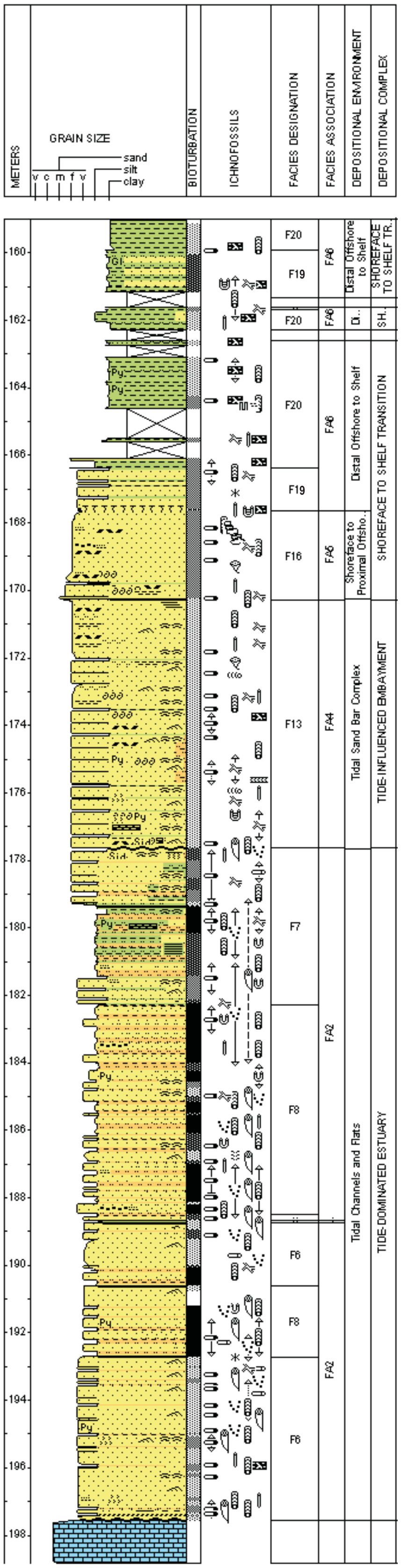

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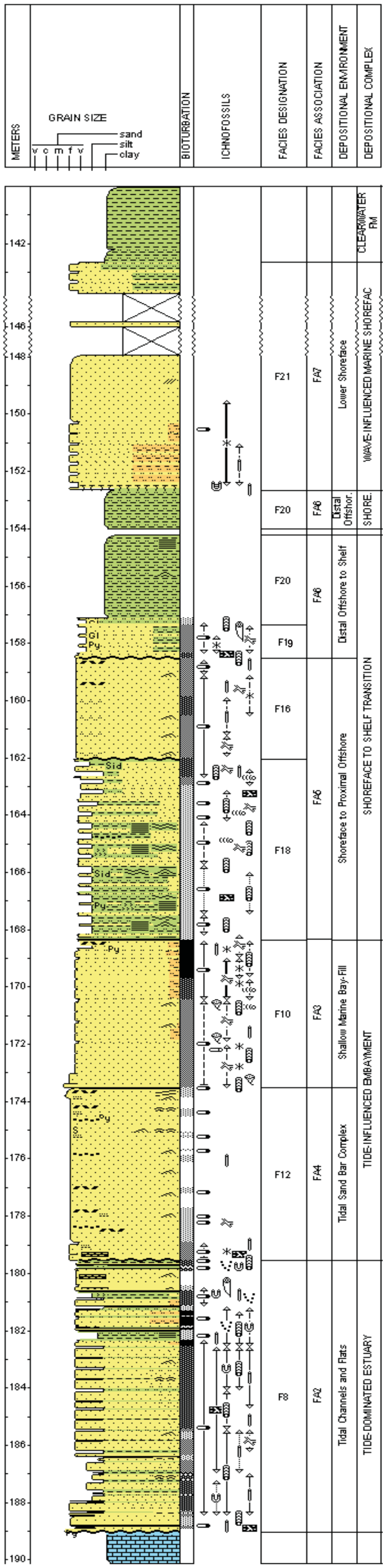

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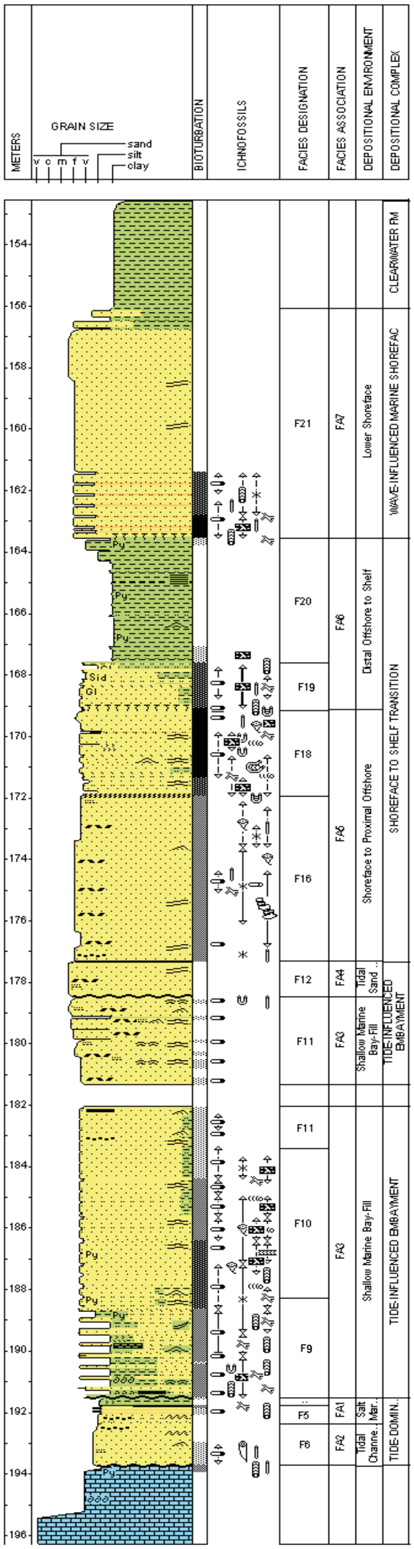

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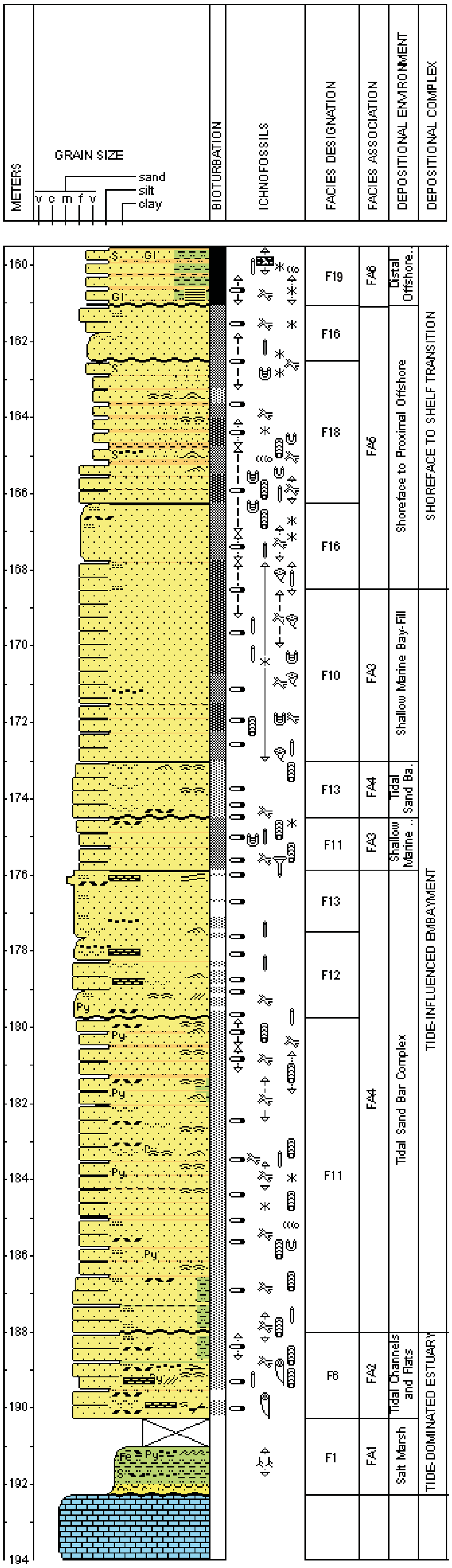

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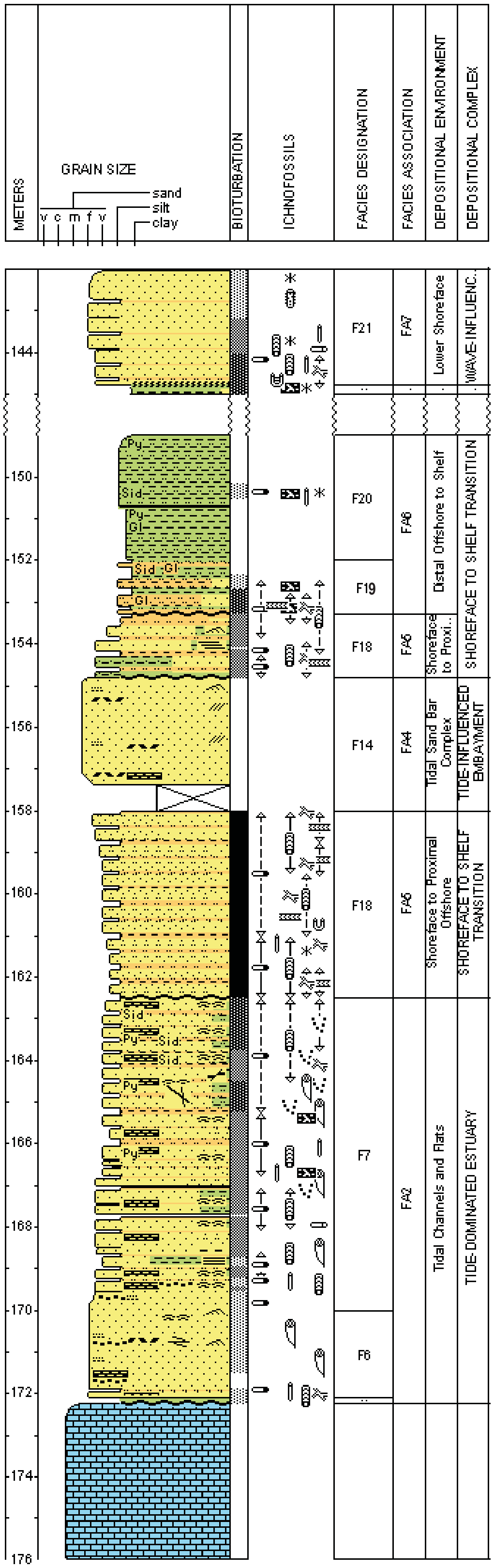

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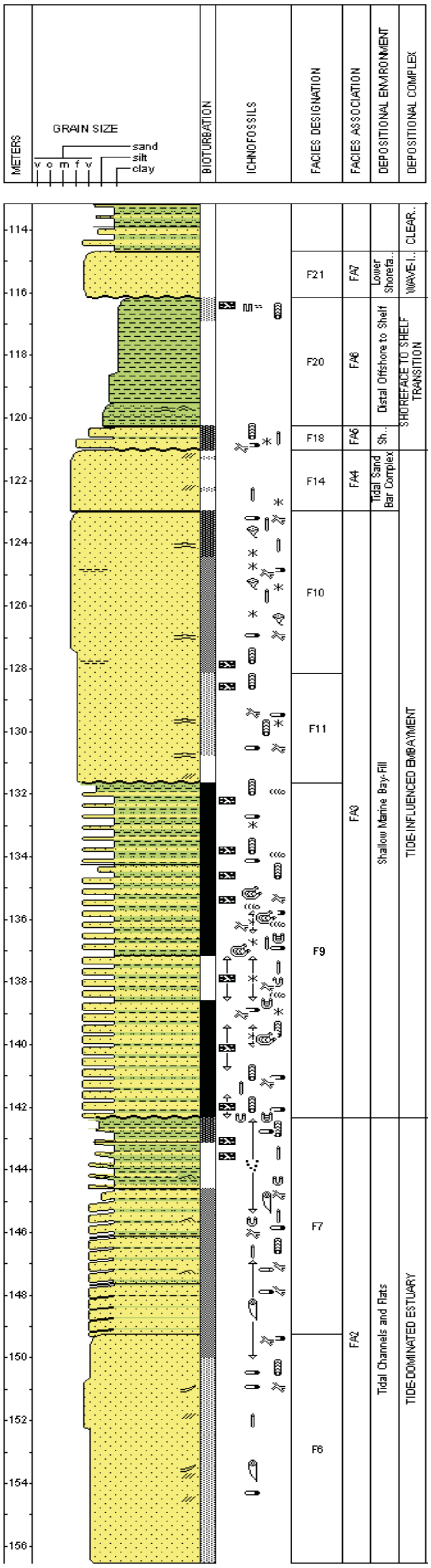

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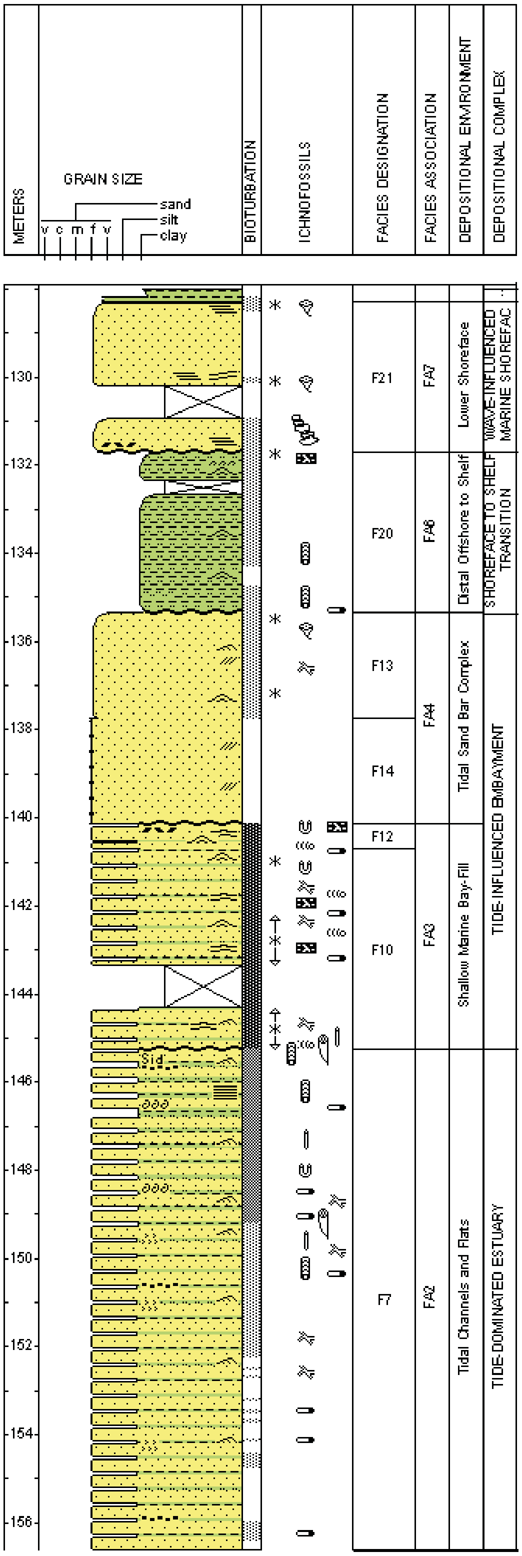

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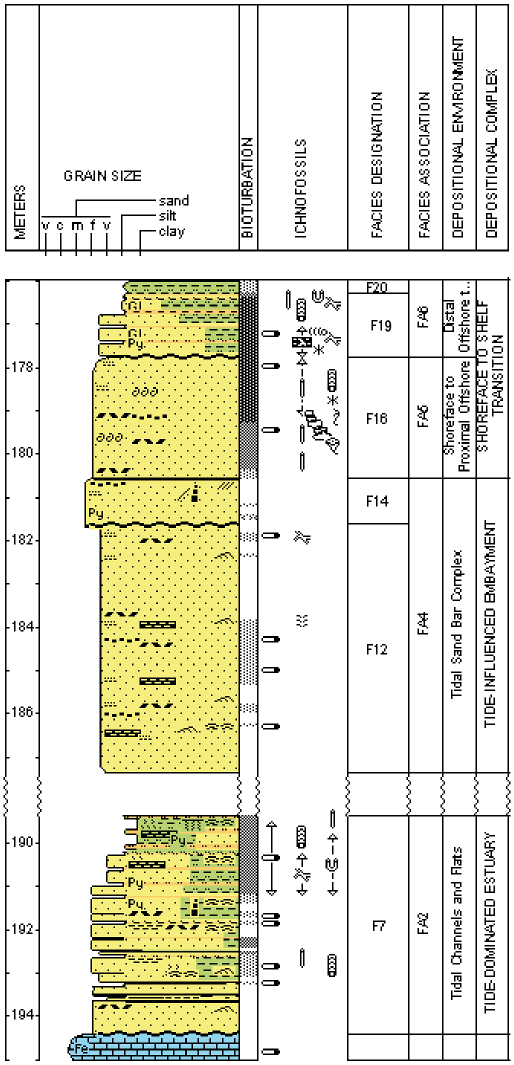

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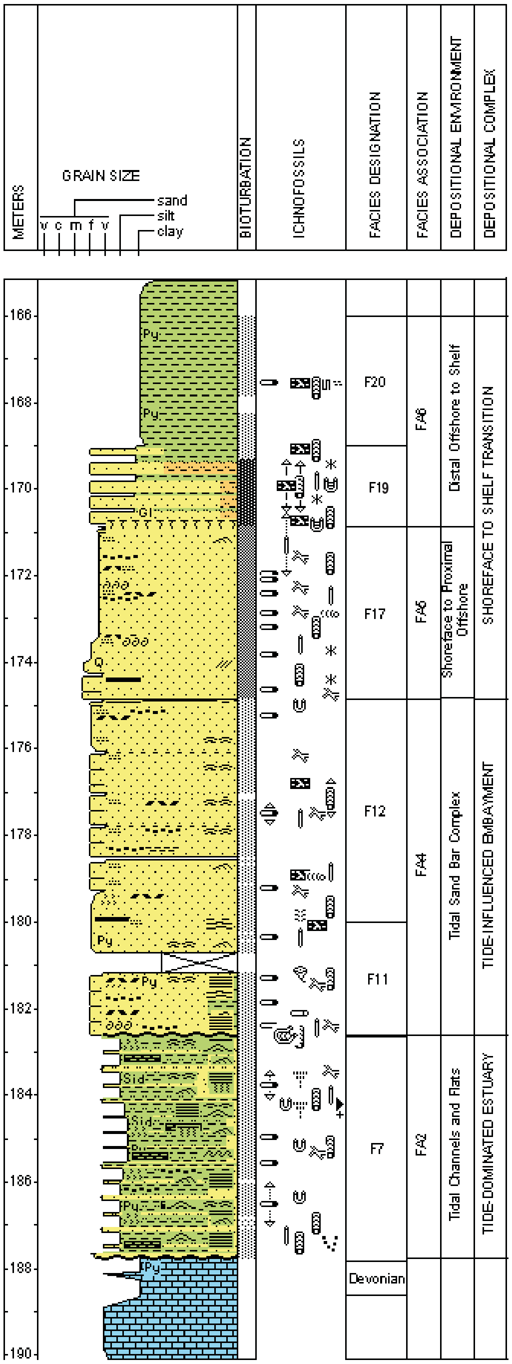

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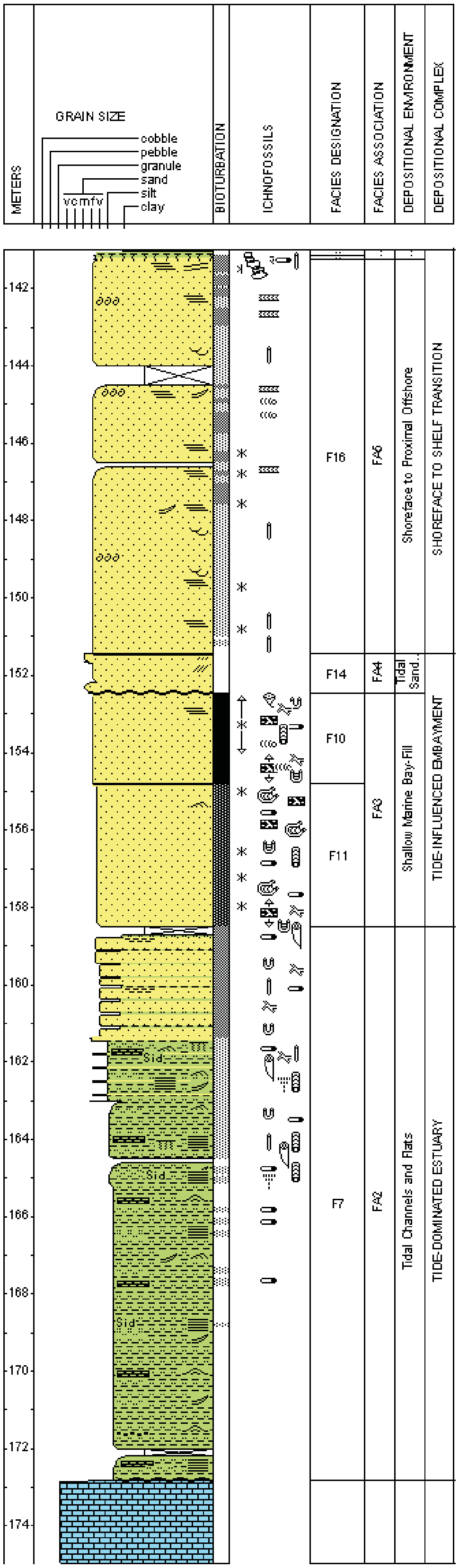

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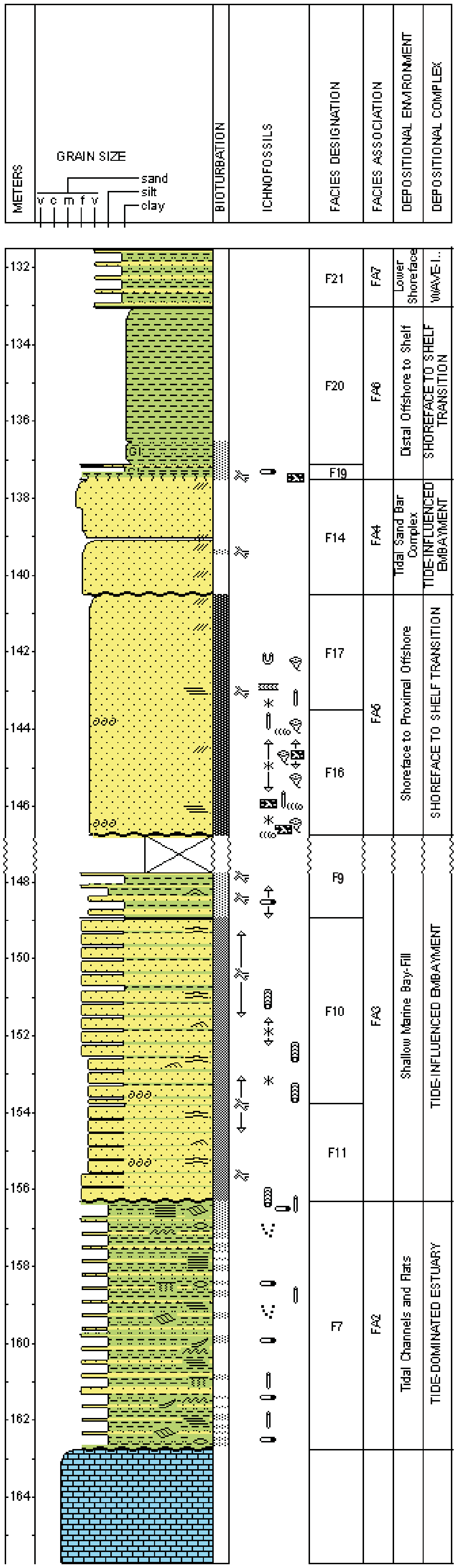

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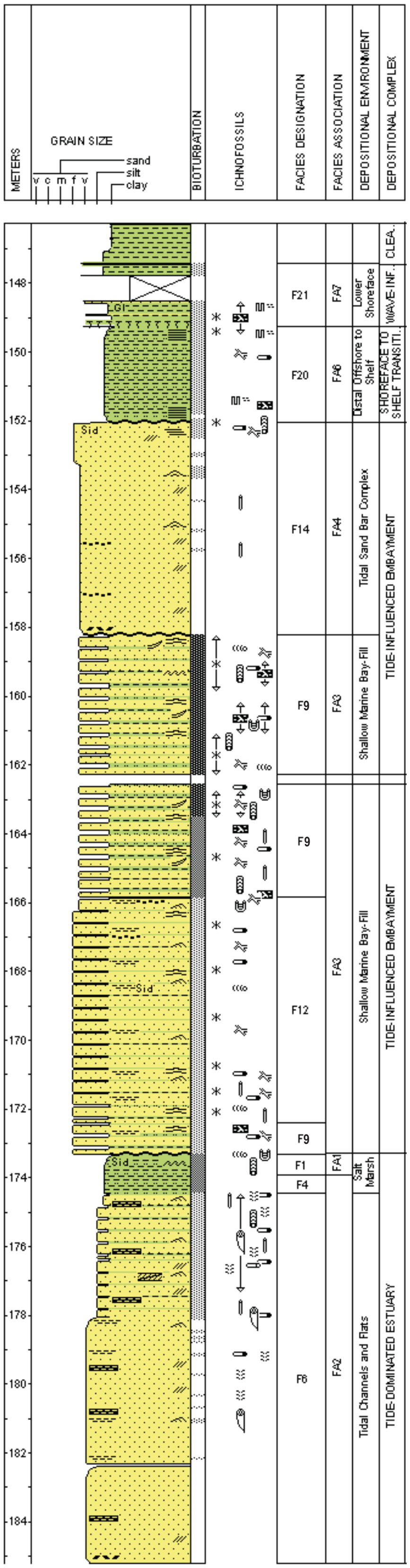

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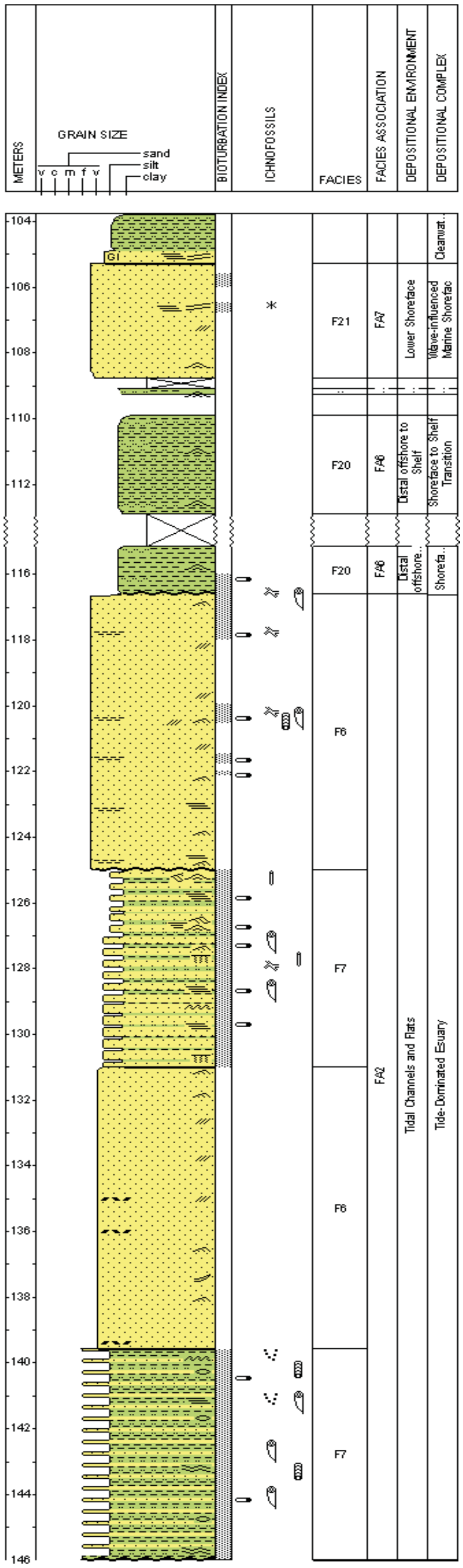

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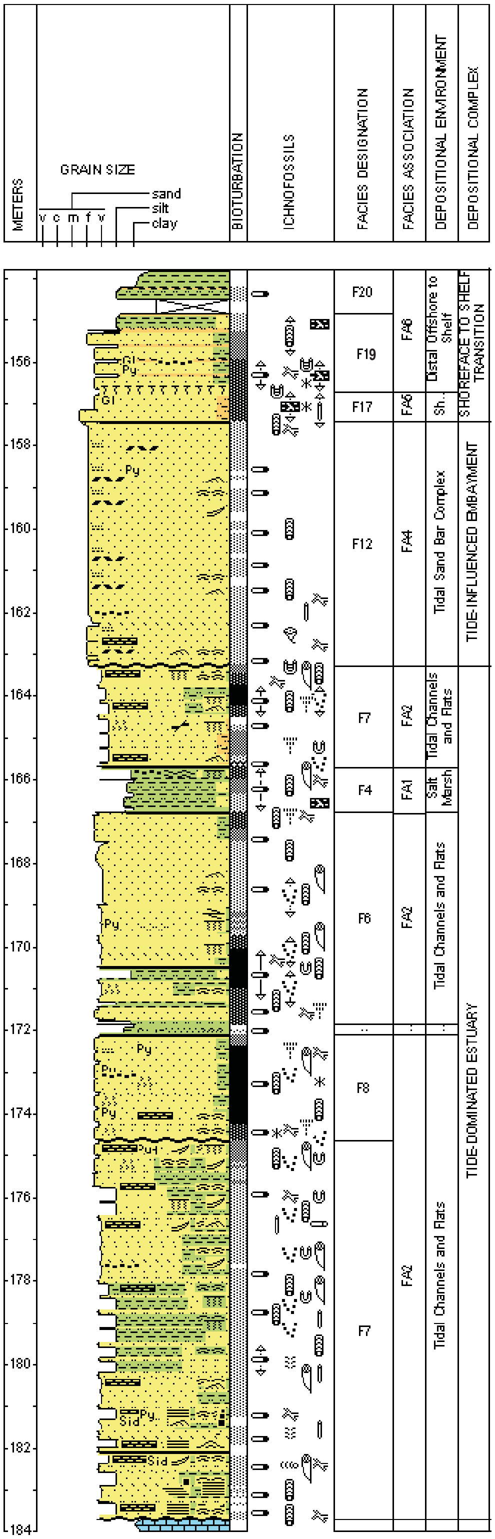

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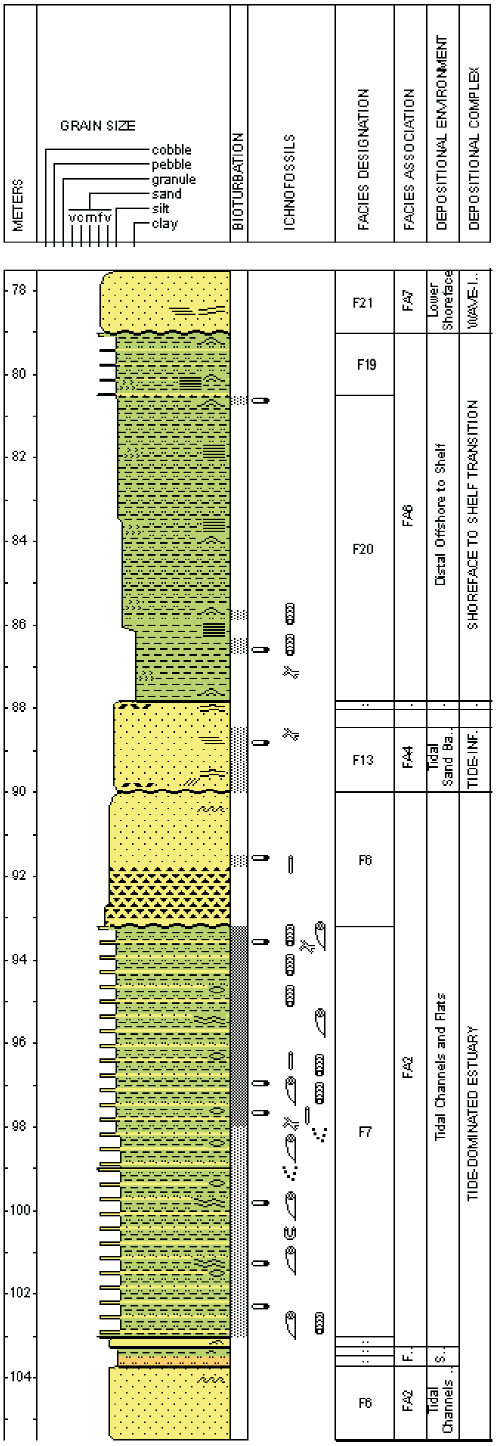

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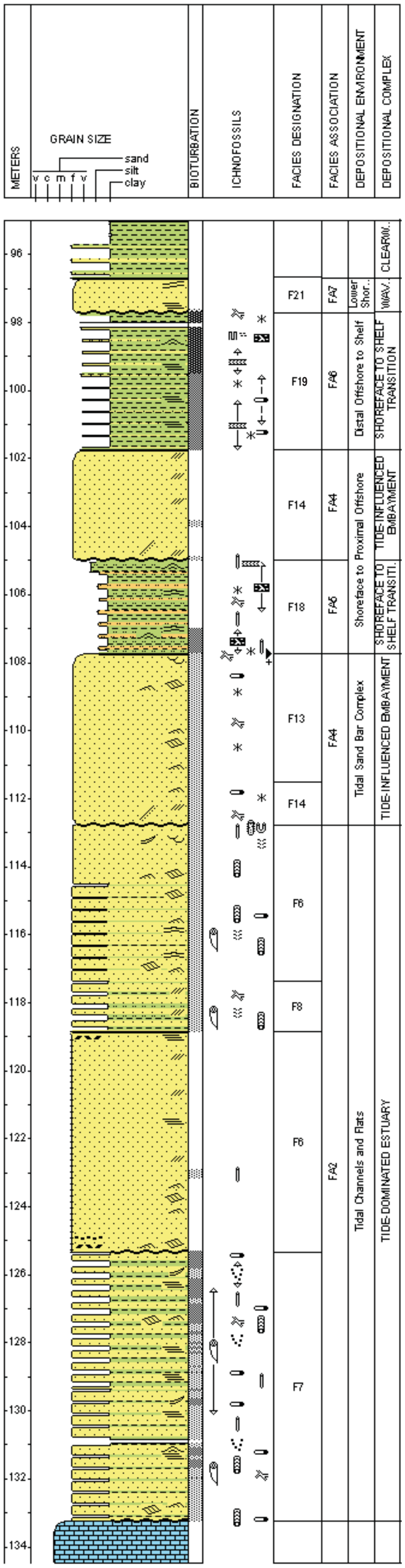

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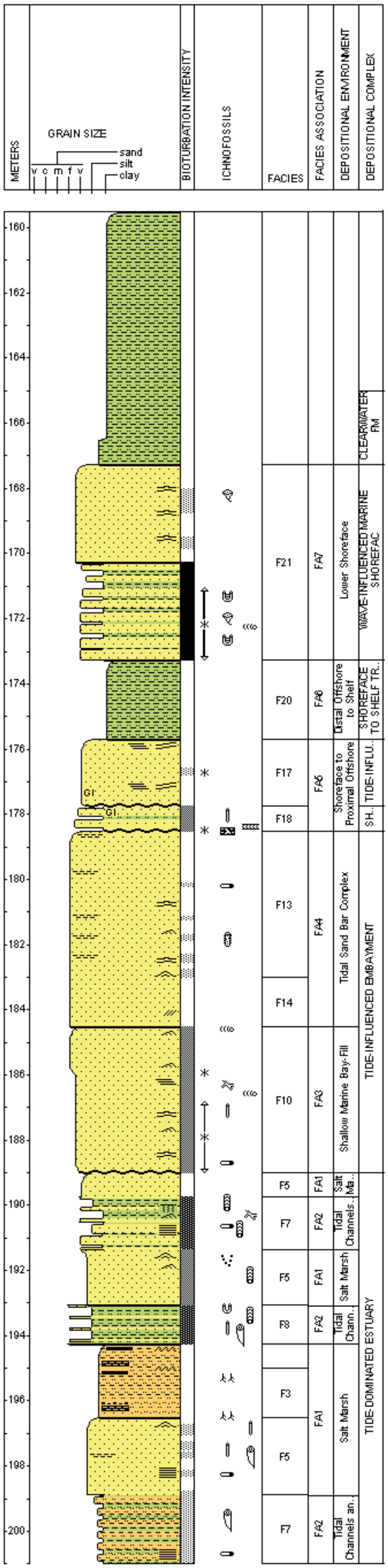

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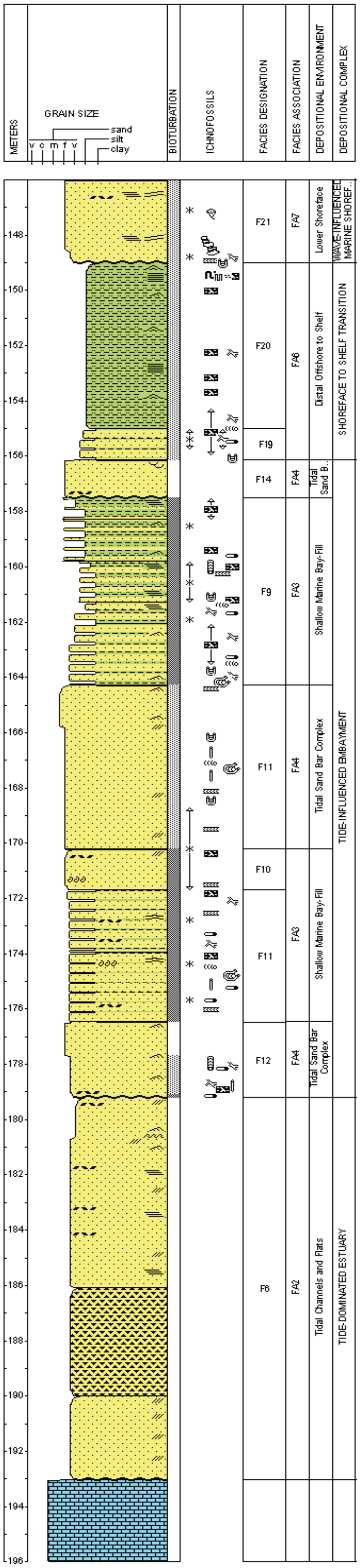

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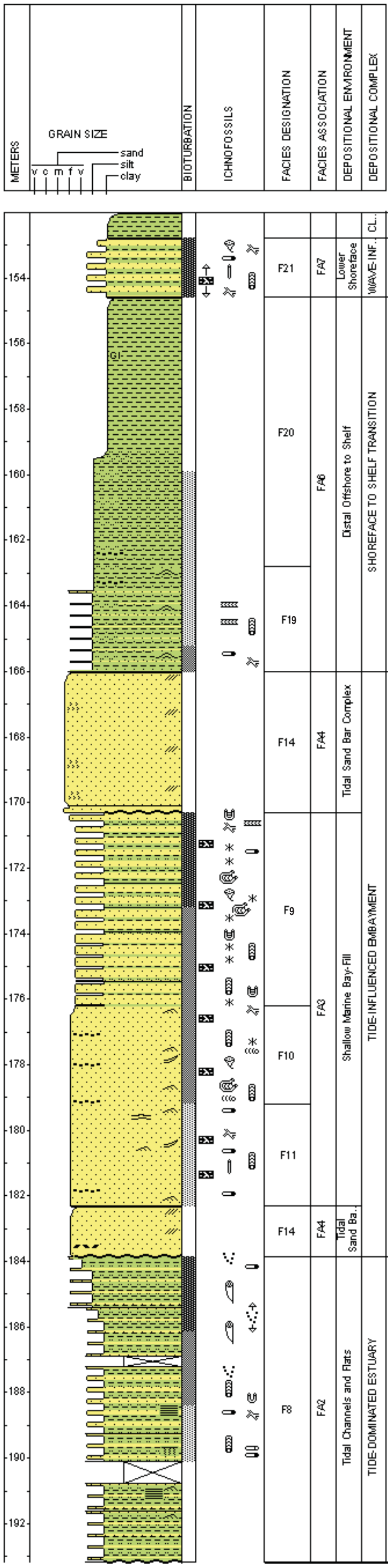

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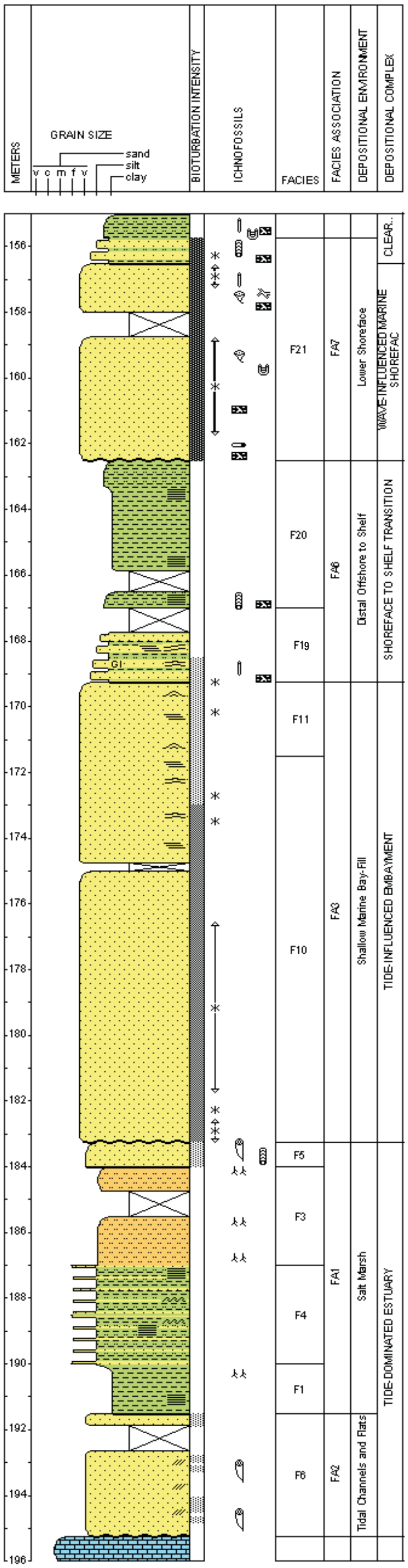

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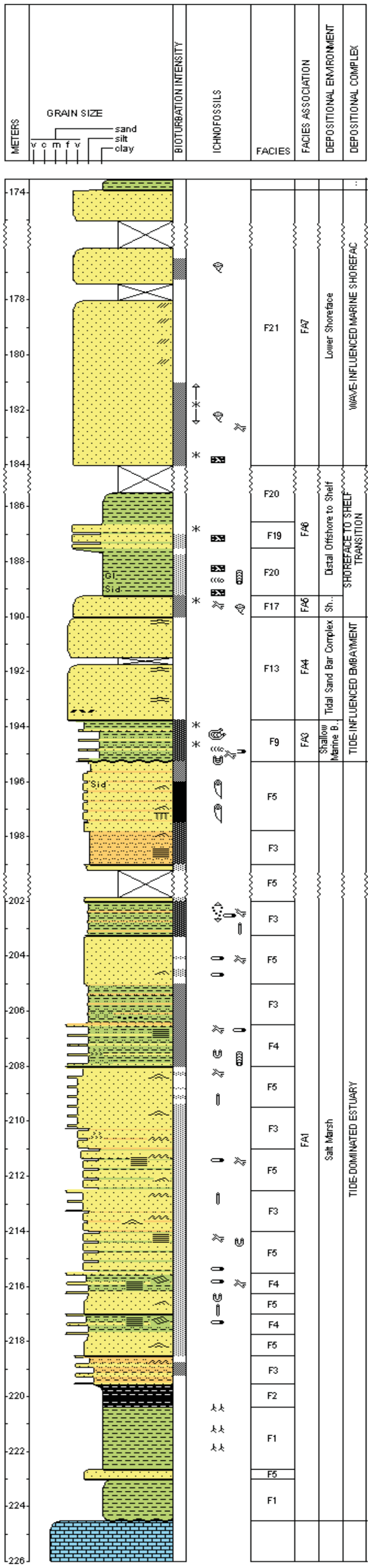

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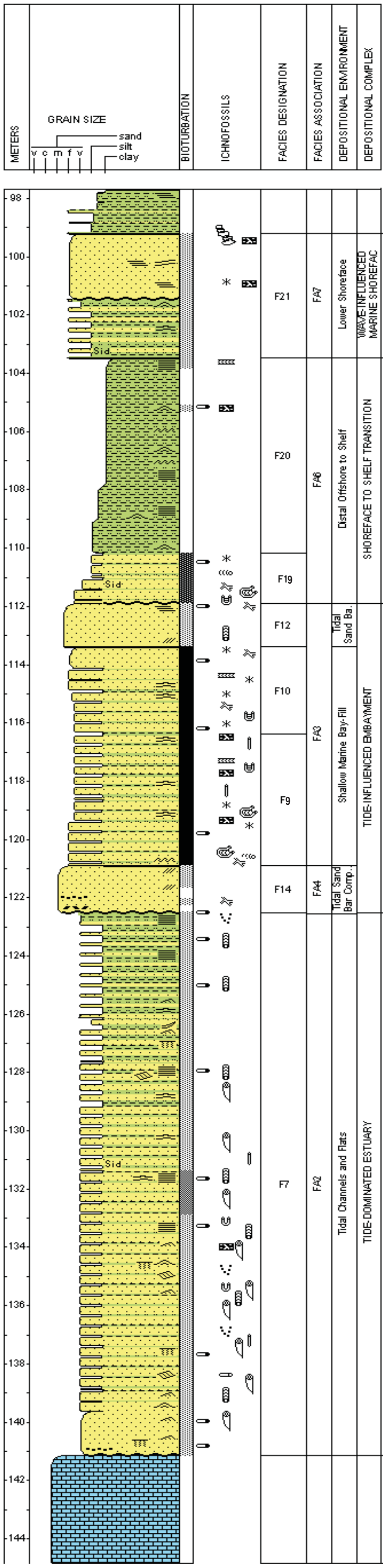

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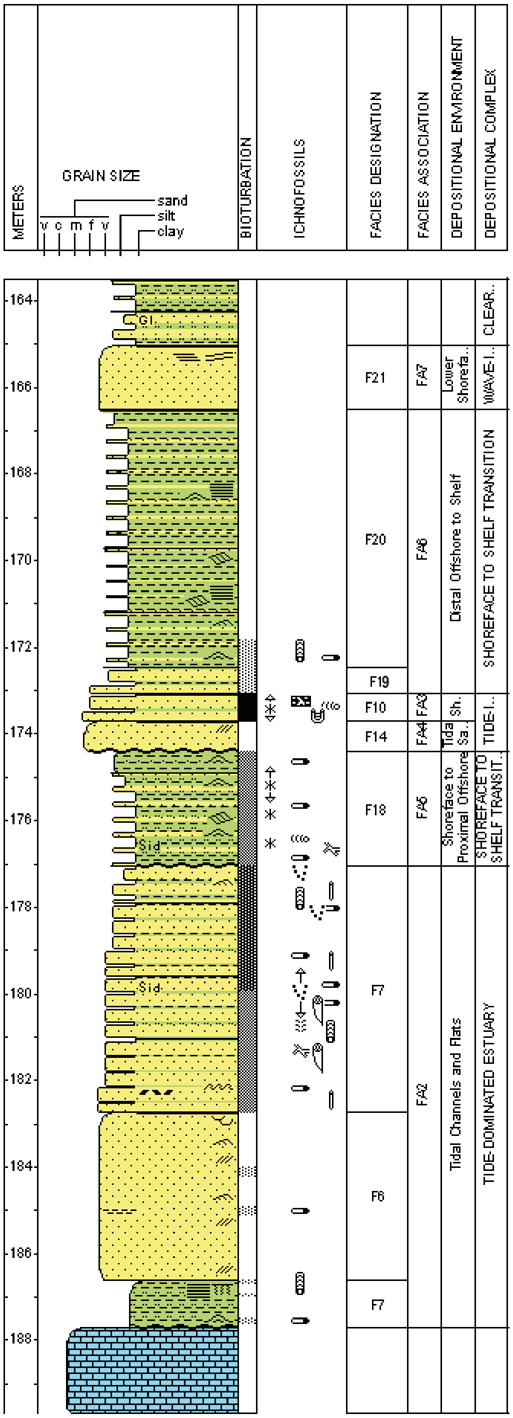

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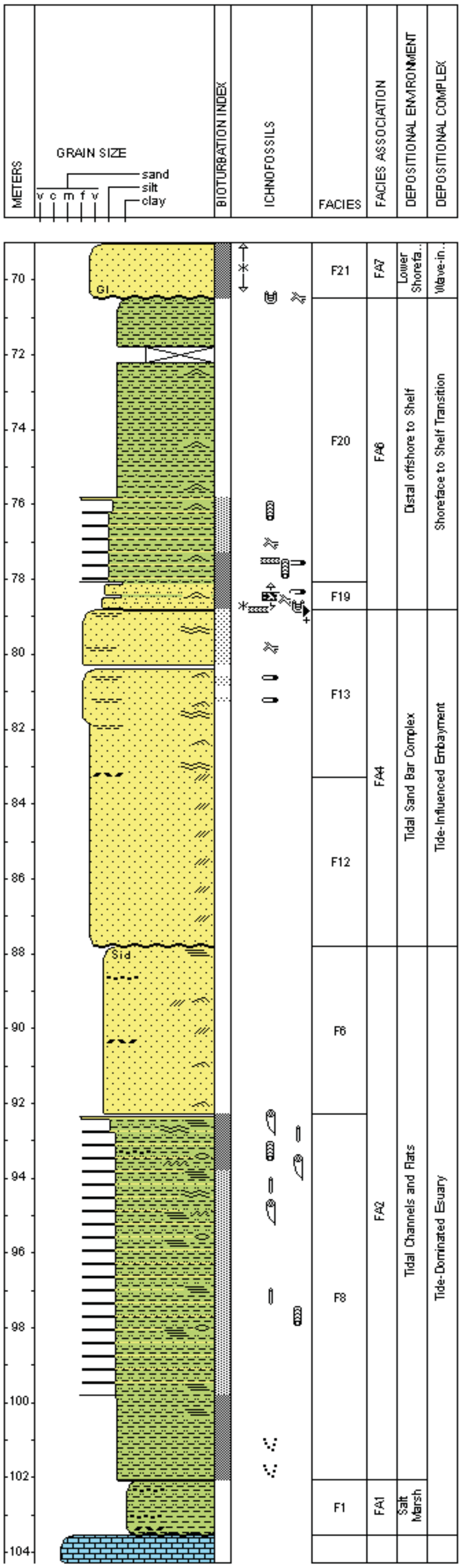

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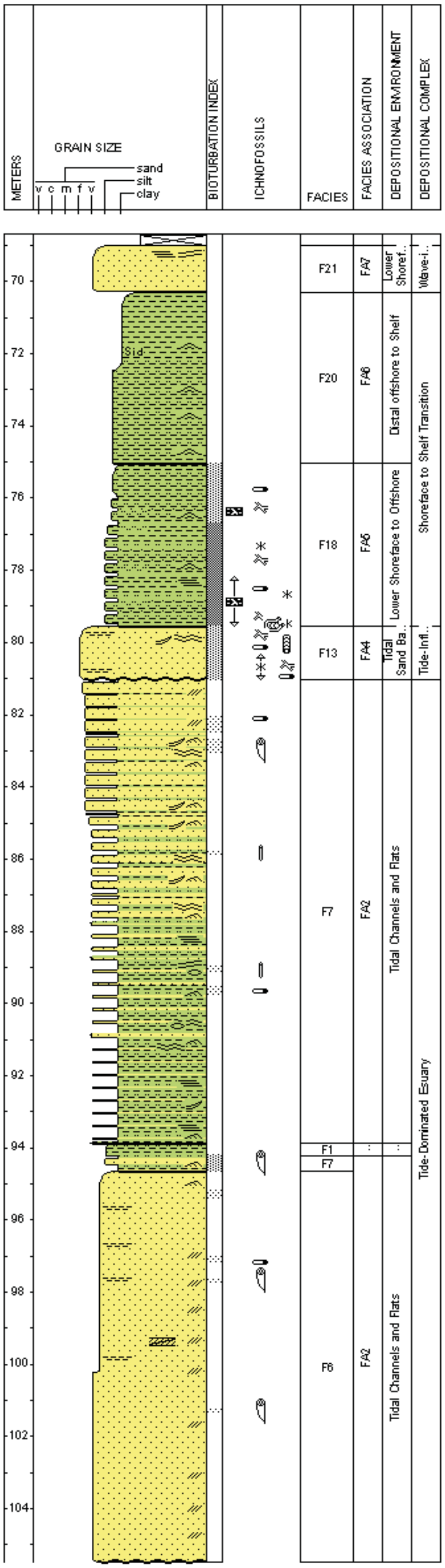

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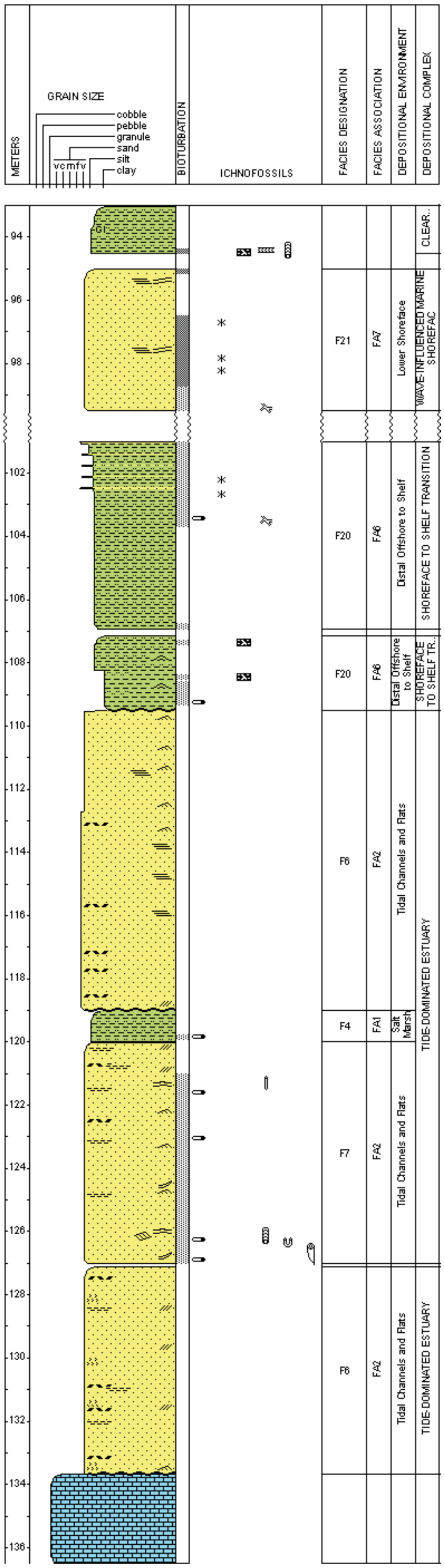

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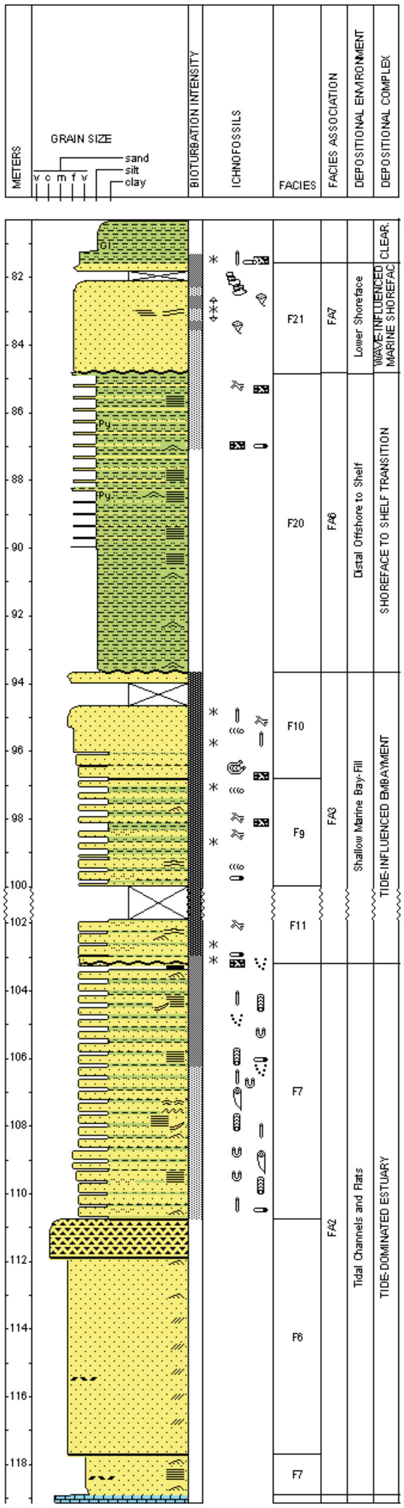

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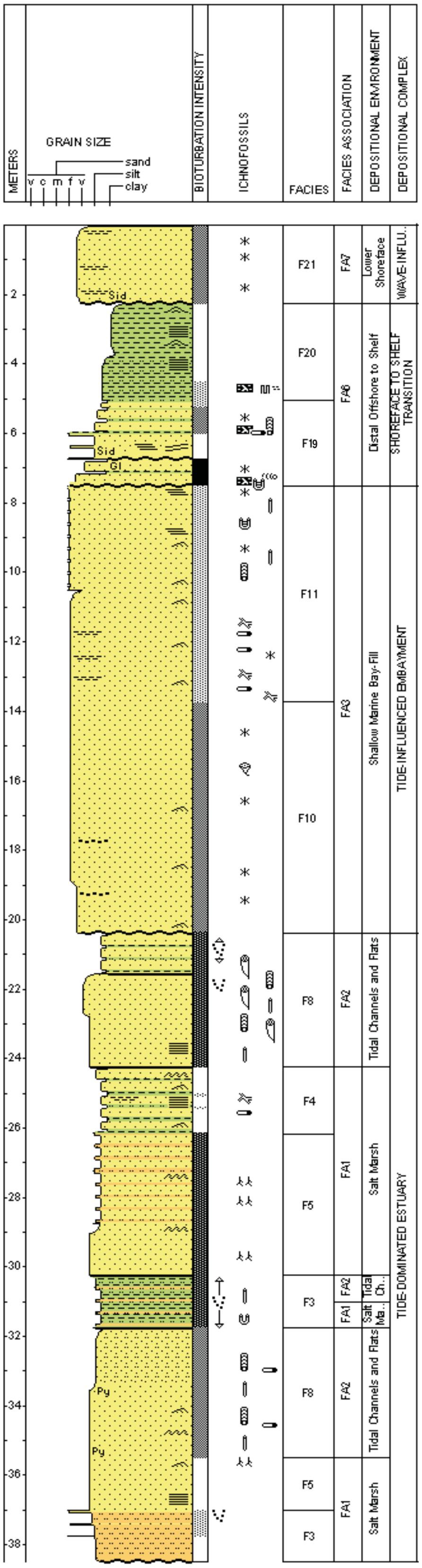

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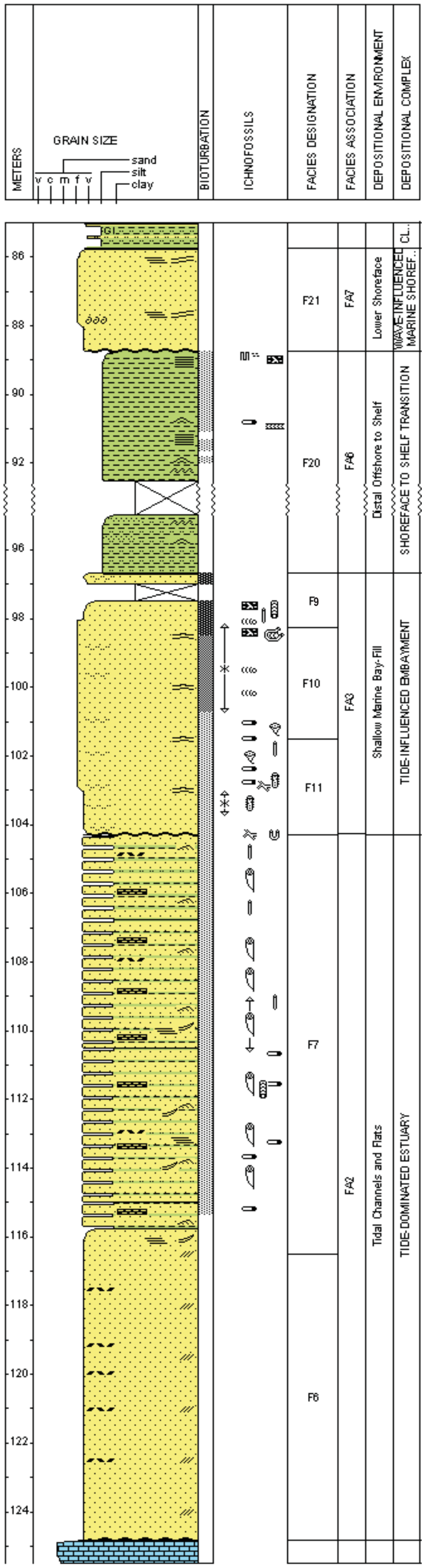
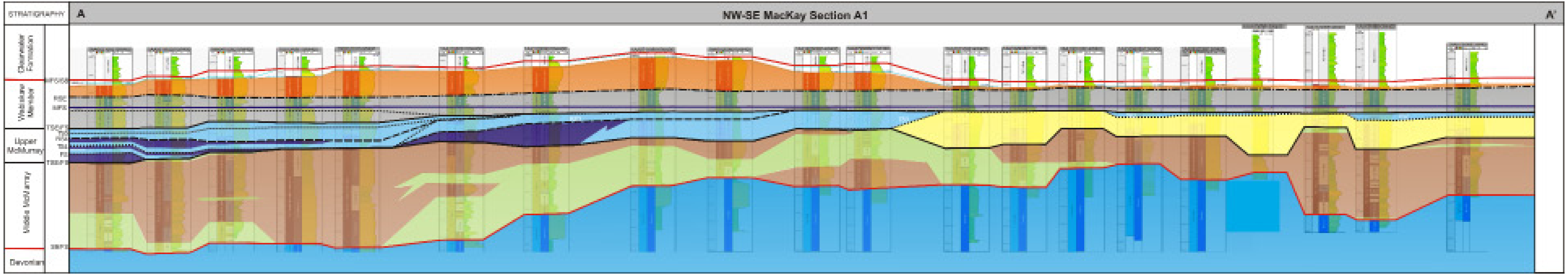
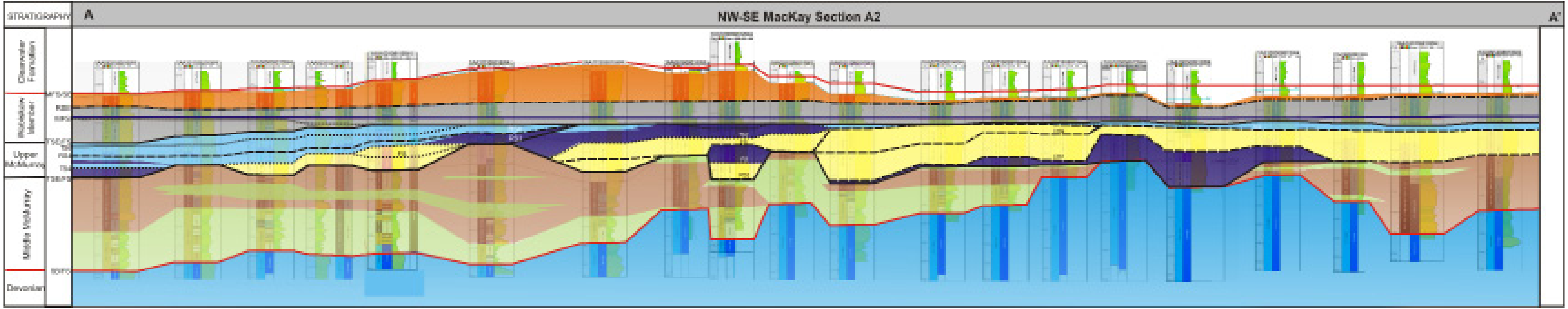
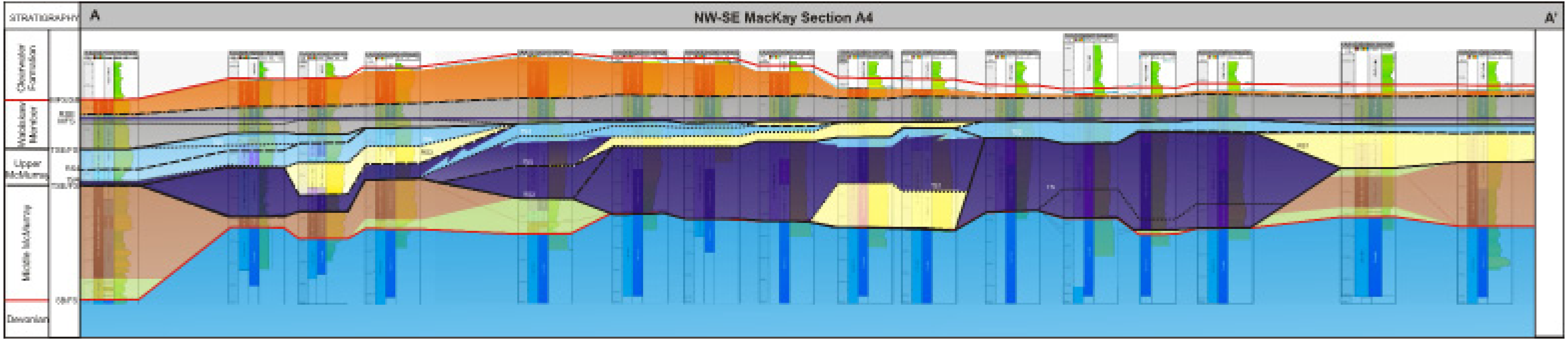


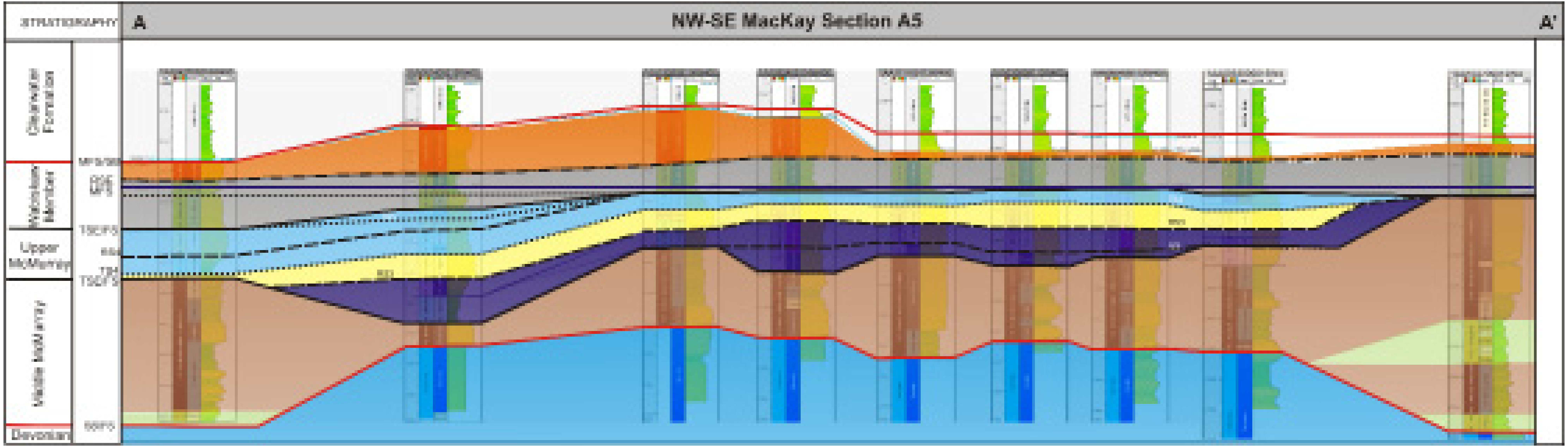
APPENDIX B

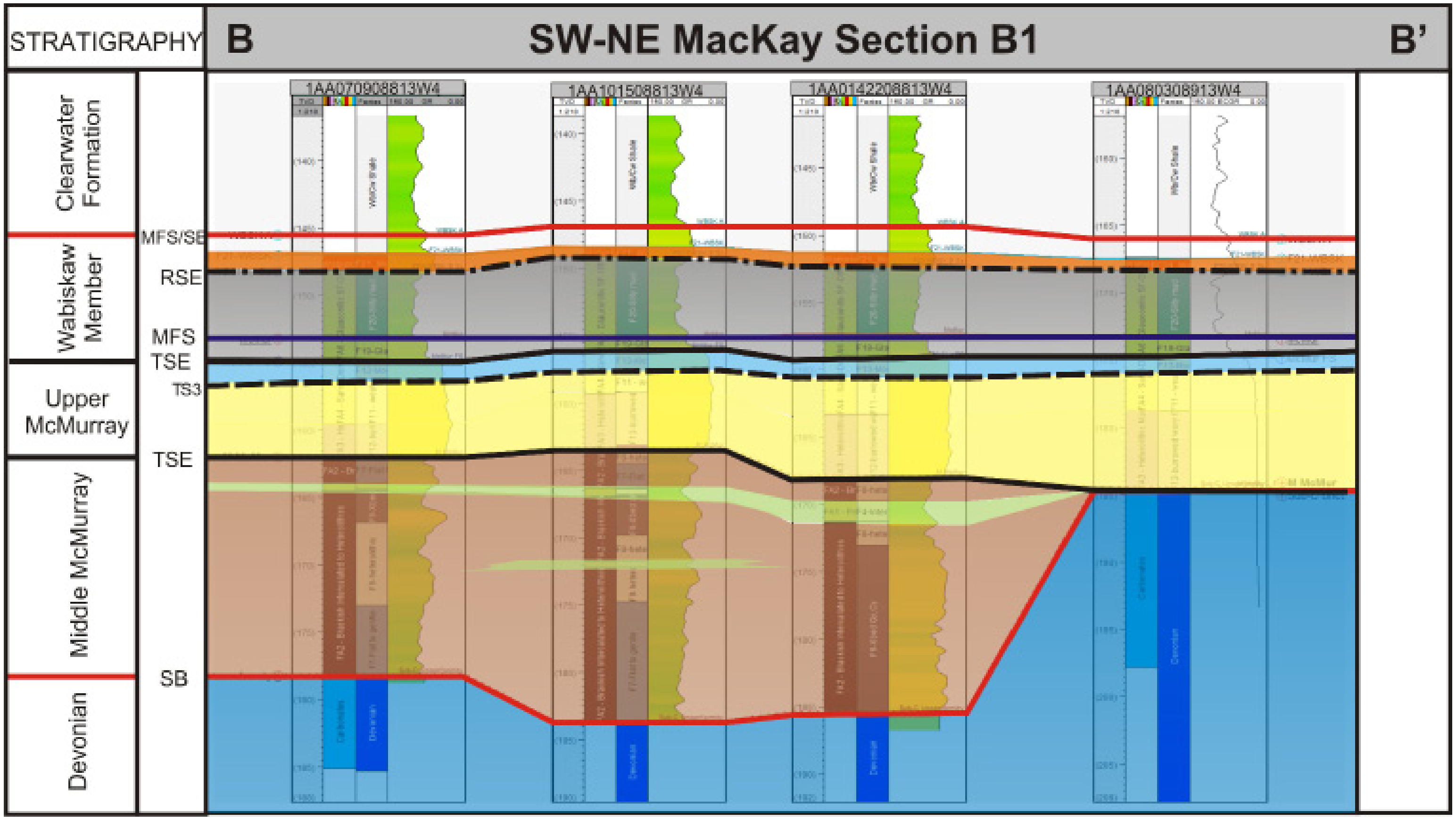

STRATIGRAPHY
A
NW-SE MacKay Section A1
A'
Clearwater Formation
Wabiskaw Member
Upper McMurray
Middle McMurray
Devonian
MFS/SB
RSE
MFS
TSE/FS
FS
TSE/FS
SB/FS

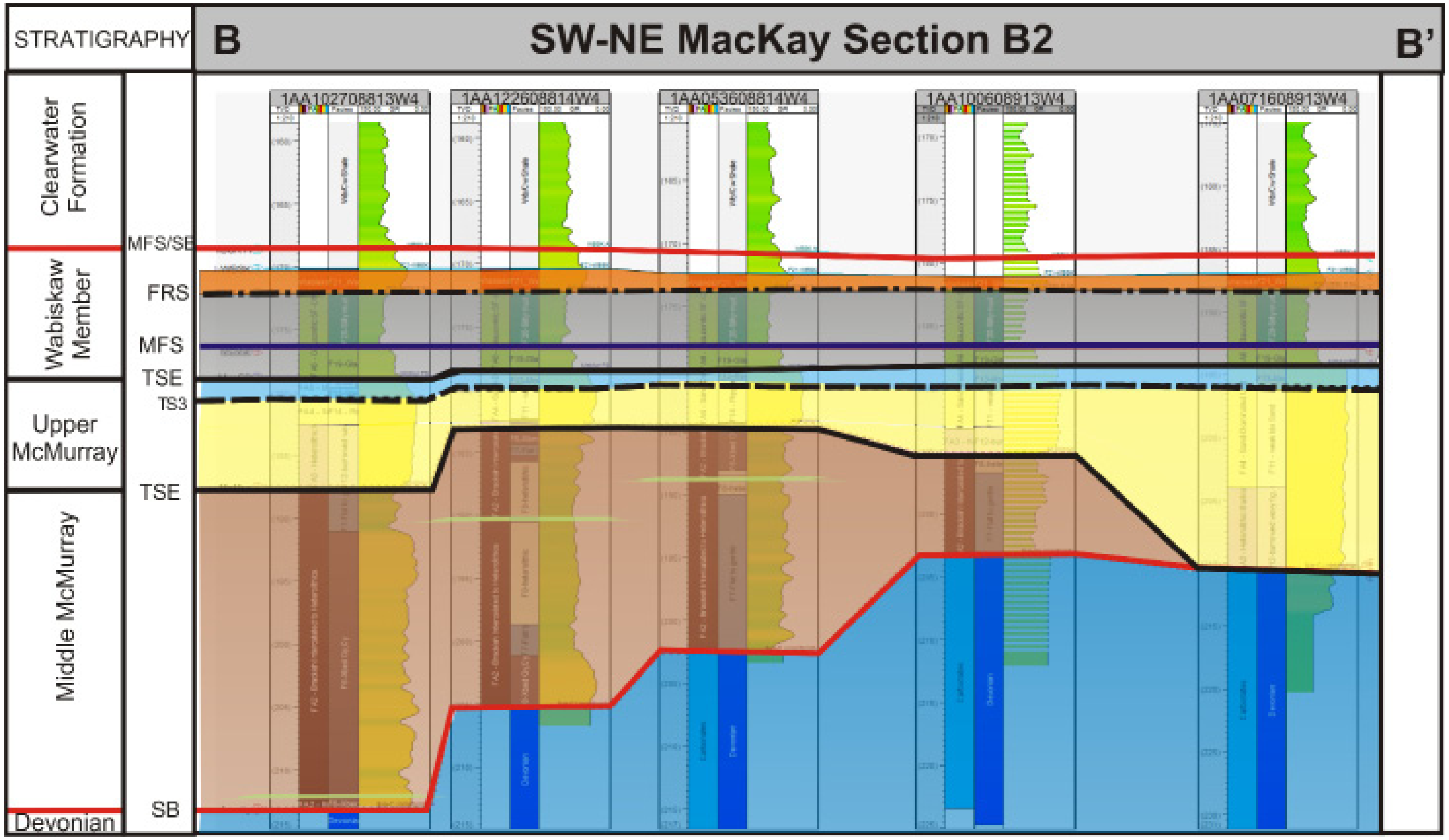

STRATIGRAPHY
A
NW-SE MacKay Section A2
A'
Clearwater Formation
Wabiskaw Member
Upper McMurray
Middle McMurray
Devonian

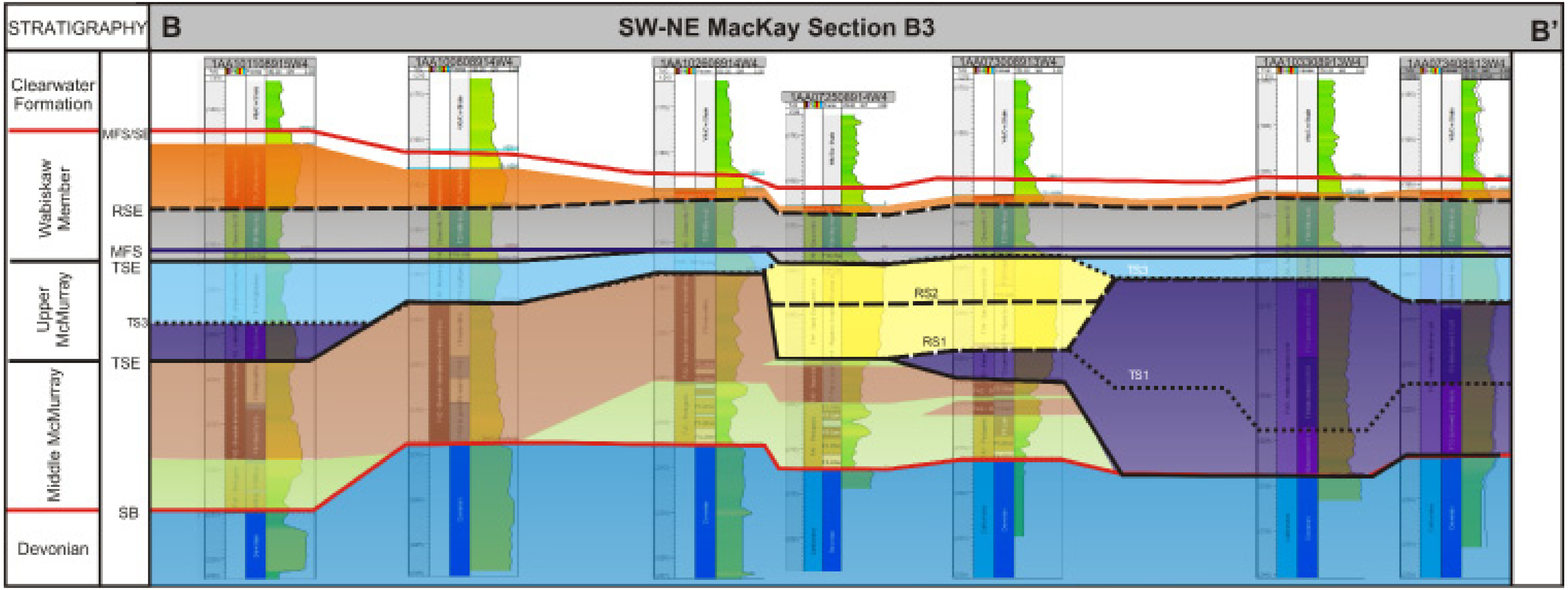

STRATIGRAPHY
A
NW-SE MacKay Section A3
A'
Clearwater Formation
Wabiskaw
Upper McMurray
Middle McMurray
Devonian
MFS
RSE
MFS
TSE
RS4
TSd
TSE/FS
SB/FS
SB/MFS
FRS
MFS
TSE
TSE
TSE/FS
SB

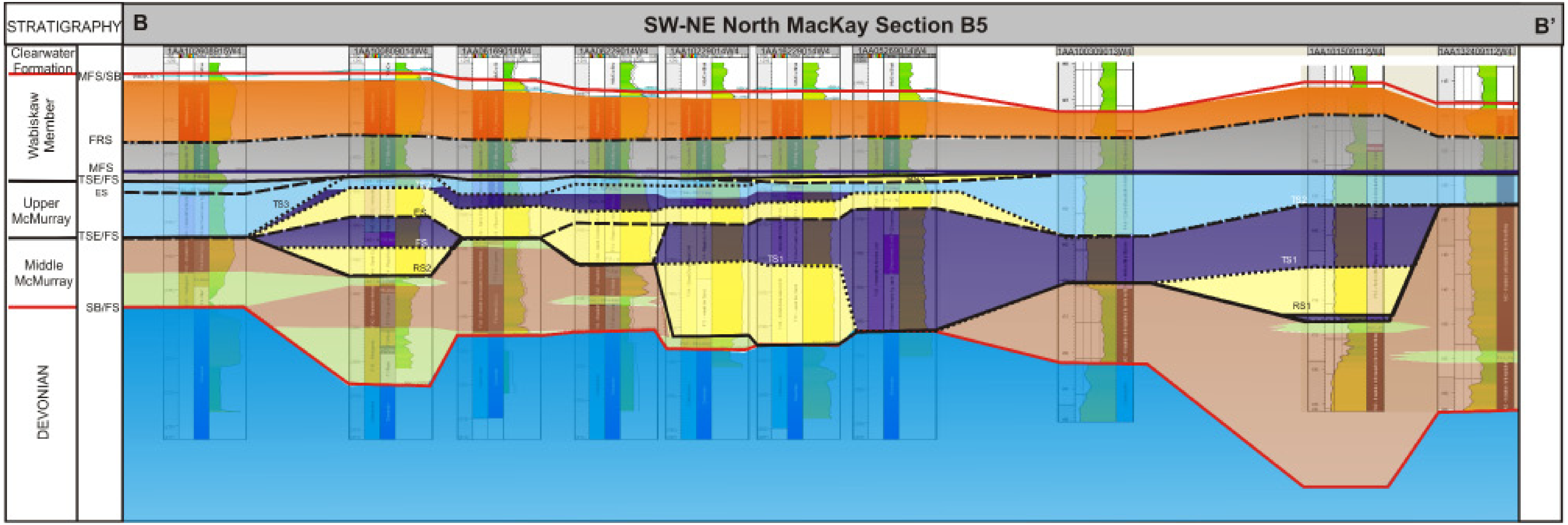

STRATIGRAPHY
A
NW-SE MacKay Section A4
A'
Clearwater Formation
Wabiskaw Member
Upper McMurray
Middle McMurray
Devonian

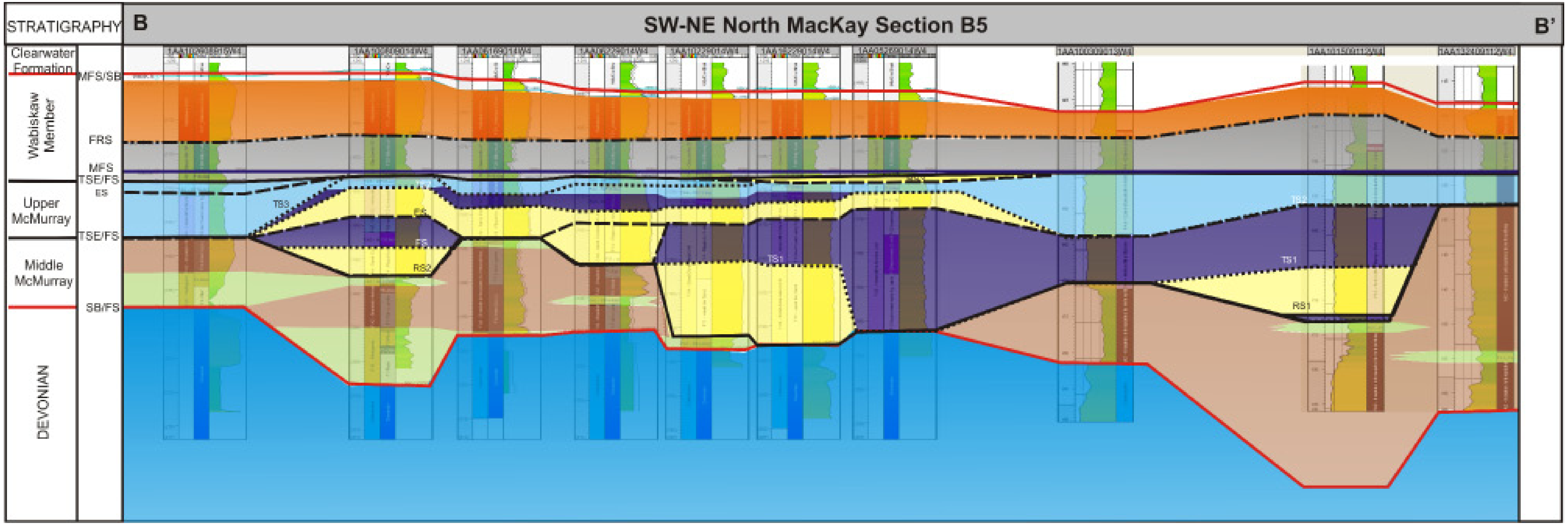

STRATIGRAPHY
A
NW-SE MacKay Section A5
A'
Clearwater Formation
Wabiskaw Member
Upper McMurray
Middle McMurray
Devonian
MFS/SB
TSCFS
TSDFS
SBFS

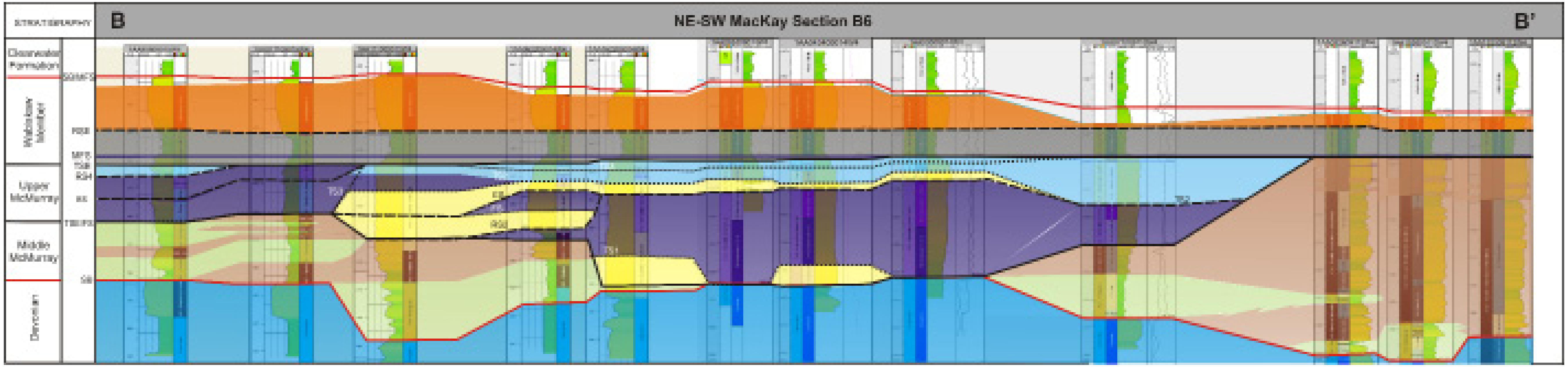

STRATIGRAPHY
B
SW-NE MacKay Section B1
B'
Clearwater Formation
Wabiskaw Member
Upper McMurray
Middle McMurray
Devonian
MFS/SE
RSE
MFS
TSE
TS3
TSE
SB
1AA070908813W4
1AA101508813W4
1AA0142208813W4
1AA080308913W4

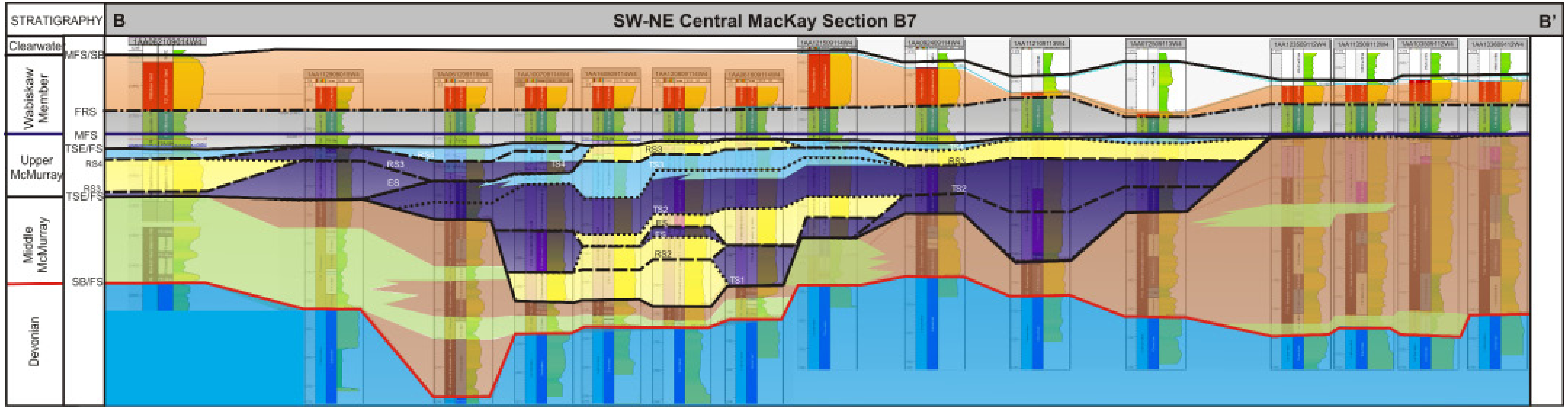

STRATIGRAPHY
B
SW-NE MacKay Section B2
B'
Clearwater Formation
Wabiskaw Member
Upper McMurray
Middle McMurray
Devonian
MFS/SB
FRS
MFS
TSE
TS3
TSE
SB
1AA102708813W4
1AA122608814W4
1AA053608814W4
1AA100608913W4
1AA071608913W4

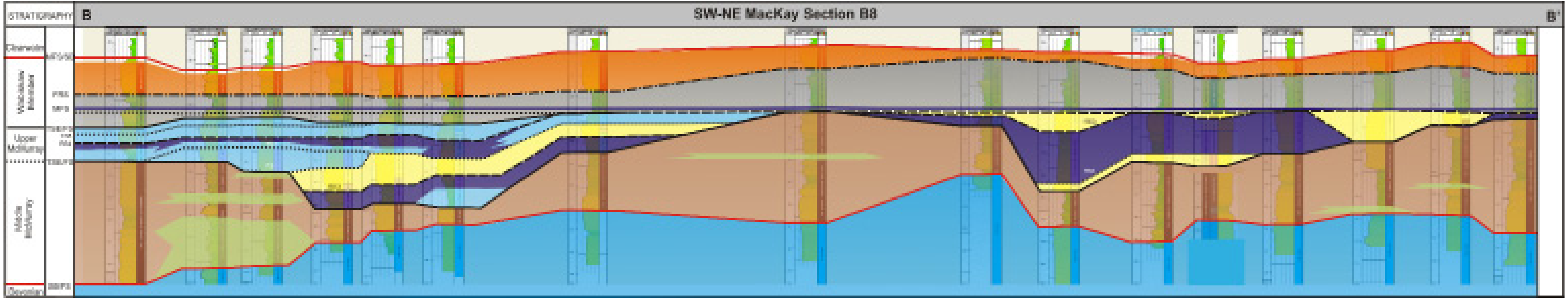

STRATIGRAPHY
B
SW-NE MacKay Section B3
B'
Clearwater Formation
Wabiskaw Member
Upper McMurray
Middle McMurray
Devonian
MFS/SB
RSE
MFS
TSE
TS3
TSE
SB
1AA101108915W4
1AA100608914W4
1AA102608914W4
1AA072508914W4
1AA073508913W4
1AA103308913W4
1AA073608913W4
TS3
RS2
RS1
TS1


STRATIGRAPHY
B
SW-NE North MacKay Section B5
B'
Clearwater Formation
Wabiskaw Member
Upper McMurray
Middle McMurray
DEVONIAN
MFS/SB
FRS
MFS
TSE/FS
ES
TSE/FS
SB/FS
TS3
TS2
ES
FS
RS2
TS1
TS1
TS2
RS1


STRATIGRAPHY
B
SW-NE North MacKay Section B5
B'
Clearwater Formation
Wabiskaw Member
Upper McMurray
Middle McMurray
DEVONIAN
MFS/SB
FRS
MFS
TSE/FS
ES
TSE/FS
SB/FS
TS3
TS2
TS1
FS
RS2
RS1


STRATIGRAPHY
B
NE-SW MacKay Section B6
B'
Clearwater Formation
Wabiskaw Member
Upper McMurray
Middle McMurray
Devonian
SB
RSE
MFS
TSE
RSH
RS
SB


STRATIGRAPHY
B
SW-NE Central MacKay Section B7
B'
Clearwater
Wabiskaw Member
Upper McMurray
Middle McMurray
Devonian
MFS/SB
FRS
MFS
TSE/FS
RS4
RS3
TSE/FS
SB/FS
RS3
RS4
ES
TS4
RS3
TS3
TS2
FS
FS
RS2
TS1
RS3
TS2


STRATIGRAPHY
B
SW-NE MacKay Section B8
B'
Clearwater
MFS/SB
Wabiskaw Member
FRS
MFS
Upper McMurray
TSE/FS
Middle McMurray
SB/FS
Devonian

APPENDIX C

UWI	Combined Depth	Trace Fossils	Diversity (#)	Largest Burrow Size	Average Burrow Size (mm)	BI
Well	1AA101508813W4					
1AA101508813W400	156.75	*Th, As, Ch, Pl,*	4	17	<2	BI 3-4
1AA101508813W400	157.50	*Te, Sk, As, Ch, Th, Pl*	6	15	3	BI 4
1AA101508813W400	158.60	*Pl, Th, Te, Pa, Sk*	5	10	3	BI 2-3
1AA101508813W400	160.10	*Th, Te, Pl, Se*	4	5	3	BI 1
1AA101508813W400	160.80	*Oph, Ro, Pl Sk*	4	5	2	BI 1
1AA101508813W400	161.50	*Sk, Pl, Te*	3	4	2	BI 0-1
1AA101508813W400	163.00	*Ro, Pl, Th, Sk Pa*	5	12	3	BI 1
1AA101508813W400	163.75	*Mgy, Gy, Te, Cy Sk, Th, Pa*	7	16	2	BI 4
1AA101508813W400	164.50	*Mgy, Gy, Te, Cy Sk,*	7	10	2	BI 5
1AA101508813W400	165.25	*Mgy, Gy, Te, Cy Sk,*	5	10	<2	BI 3
1AA101508813W400	166.00	*Mgy, Gy, Te, Cy Sk,*	6	10	<2	BI4
1AA101508813W400	166.75	*Cy, Gy, Mgy, Te Pl Th*	6	14	<2	BI 2-3
1AA101508813W400	167.50	*Cy, Gy, Mgy, Te Pl Th*	6	17	<2	BI 2-3
1AA101508813W400	168.25	*Cy, Gy, Mgy, Te Pl*	5	3	<2	BI 0-1
1AA101508813W400	169.00	*Cy, Gy, Mgy, Te Pl*	5	5	<2	BI 0-1
1AA101508813W400	169.75	*Cy, Mgy, gy, Ar,*	4	9	<2	BI 1, 2-3 local
1AA101508813W400	170.50	*Gy, Mgy, Te, Cy, Th, Sk, Ar*	7	15	<2	BI 5-6 to BI 4
1AA101508813W400	171.25	*Gy, Mgy, Te, Cy, Th*	5	17	<2	BI 4-5
1AA101508813W400	172.00	*Mgy, Gy, Te, Pl, Th*	6	15	<2	BI 4
1AA101508813W400	172.75	*Mgy, Gy, Cy, Te, Th Sk, Pa*	7	35	<2	BI 4
1AA101508813W400	173.50	*Mgy, Gy, Cy, Te, Th Sk, Pa*	7	26	<2	BI 5
1AA101508813W400	174.25	*Cy, Mgy, Gy, Te, Th*	5	35	<2	BI 5
1AA101508813W400	175.00	*Cy, Mgy, Gy, Te, Th*	5	15	<2	BI 3, BI 4-5
1AA101508813W400	175.75	*Cy, Mgy, Te, Th, Pl, Ar, Pa*	7	8	<2	BI 2
1AA101508813W400	176.50	*Cy, Mgy, Te, Th, Sk, Ar, Pl*	7	20	<2	BI 2
1AA101508813W400	177.25	*Cy, Pl, Te, Mgy, Sk*	6	13	<2	BI 2
1AA101508813W400	178.00	*Cy, Pl, Te, Mgy, Sk*	5	6	<2	BI 1-2
1AA101508813W400	178.75	*Gy, Cy, Te, Mgy, Pl,*	6	5	<2	BI 1-2
1AA101508813W400	179.50	*Te, Sk, Cy, Zoo, Th, Mgy, Pl*	7	10	<2	BI 1-2
1AA101508813W400	180.25	*Cy, Pl, Te, Mgy, Sk*	5	10	<2	BI 1-2
1AA101508813W400	181.00	*Cy, Pl, Te, Mgy, Sk*	5	10	<2	BI 1
1AA101508813W400	181.75	*Pl, Gy, Th, Sk, Cy,*	5	14	<2	BI 0-1
1AA101508813W400	182.50	*Pl, Mgy, Cy, Th, Te*	5	10	<2	BI 0-1
1AA101508813W400	183.10	*Mgy, Cy, Th, Te, Pl,*	5	11	<2	BI 0-1
1AA101508813W400	183.70	*Pl, Te, Mgy, Th*	4	10	<2	BI 0-1
Well	1AA151908813W4					
1AA151908813W400	163.10	*Ch, Th, Te, Sk*	4	15	<2	BI 0-1, 3

1AA151008813W400	164.60	Ch, Pl, Te, Phy	4	2	<2	Bl 3, Bl 0-1
1AA151008813W400	167.50	Te, Th, Pl, Sk, Ch	5	16	4	Bl 3
1AA151008813W400	169.00	Te, Sk, Pl, Th, Sh, As	6	12	3	Bl 2-3
1AA151008813W400	169.75	Te, Th, Pl, Rz As, Sc	5	20	3	Bl 1-2
1AA151008813W400	170.50	Te, Th, Pl, Sk Ch?	5	10	3	Bl 1-2
1AA151008813W400	171.25	Te, Th, Pl, As, Cy	5	17	8	Bl 1-2
1AA151008813W400	172.00	Th, Sk, Te, Pl	4	14	3	Bl 1-2
1AA151008813W400	172.75	Th, Te, Zoo, Pl, Rz,	6	13	3	Bl 2
1AA151008813W400	173.50	Te, Th, Pl, Ar, Sk	5	12	3	Bl 2
1AA151008813W400	174.25	Th, Pl, Ch, Sk , Zoo	5	20	3	Bl 2-3
1AA151008813W400	175.00	Th, Pl, Te, Sk, Rz, Sh Pa,	7	13	2	Bl 2
1AA151008813W400	175.75	Th, Pl, Te, Sk, Zoo	5	15	5	Bl 2-3
1AA151008813W400	176.50	Th, Te, Pl, Sh, Sc, Sk	6	16	4	Bl 2-3
1AA151008813W400	177.25	Th, Pl, Pa, Sc, As, Te, Sk	7	57	4	Bl 2-3
1AA151008813W400	178.00	Te, Pl, Th	3	11	4	Bl 3
1AA151008813W400	178.70	Cy, Pl, Gy, Te, Mgy,	5	11	2	Bl 3-4
1AA151008813W400	179.40	Cy, Pl, Gy, Te, Mgy,	5	11	2	Bl 3-4
1AA151008813W400	180.15	Gy, Mgy, Cy, Te, Sk, Ar, Th, Pa, Pl	9	15	<2	Bl 5-6
1AA151008813W400	180.90	Gy, Mgy, Cy, Te, Sk, Ar, Th, Pa, Pl	9	21	2	Bl 4
1AA151008813W400	181.70	Cy, Gy, Mgy, Ar, Sk, Pl Te	7	8	<2	Bl 4
1AA151008813W400	182.50	Cy, Mgy, Te, Th, Pl,	6	11	<2	Bl 3
1AA151008813W400	183.25	Gy, Mgy, Cy, Te, Sk, Ar, Th, Pa, Pl	9	35	2	Bl 5-6
1AA151008813W400	184.00	Gy, Mgy, Cy, Te, Sk, Ar, Th, Pa, Pl	9	10	<2	Bl 5-6
1AA151008813W400	184.75	Gy, Mgy, Cy, Te, Sk, Ar, Th, Pa, Pl	9	8	2	Bl 5-6
1AA151008813W400	185.50	Gy, Mgy, Cy, Te, Sk, Ar, Th, Pa, Pl	9	14	<2	Bl 5
1AA151008813W400	186.25	Gy, Te, Ar, Mgy, Cy,	6	8	<2	Bl 4-5
1AA151008813W400	187.00	Cy, Mgy, Lg, Te, Pl, Sk, Ar,	7	9	<2	Bi 4-5, 1 local
1AA151008813W400	187.75	Te, Mgy, Gy, Sk, Cy,	6	12	2	Bl 5-6
1AA151008813W400	188.50	Cy, Te, Mgy, Gy, Pl, Ar, Sk, Th	8	10	2	Bl 5
1AA151008813W400	189.25	Cy, Mgy, Te,	3	4	<2	Bl 4
1AA151008813W400	190.00	Cy, Mgy, Sk,	3	3	<2	Bl 1, 2-3 local
1AA151008813W400	190.75	Cy, Mgy, Gy, Te, Pl, Ar, Th,	7	28	2	Bl 5
1AA151008813W400	191.50	Cy, Mgy, Te, Pl, Th, Ar	6	9	<2	Bl 5-4, Bl 0
1AA151008813W400	192.25	Mgy, Gy, Te, Cy, Th,	6	7	<2	Bl 5-4
1AA151008813W400	193.00	Cy, Mgy, Gy, Te, Pa, Ar, Pl	7	9	<2	Bl 5-6

1AA151908813W400	193.70	*Cy, Mgy, Pl, SK, Te, Pa*	6	12	<2	BI 0, 2-3 local
1AA151908813W400	194.40	*Sk, Gy, MgyCy,*	4	5	2	BI 0, 2-3 local
1AA151908813W400	195.15	*Cy, Mgy, Pl, Sk,*	4	4	<2	BI 0, 2-3 local
1AA151908813W400	195.90	*Cy, Mgy, Te,*	3	6	<2	BI 0, 2-3 local
1AA151908813W400	197.40	*Cy, Mgy, Te, Pl, Sk*	5	4	<2	BI 0, 2-3 local
1AA151908813W400	197.50	*Mgy, Cy,*	2	3	<2	BI 1
Well	**1AA142208813W400**					
1AA142208813W400	157.50	*Ch, Pl*	2	<2	<2	BI 0-1
1AA142208813W400	157.50	*Ch, Sk, As, Th, Pl*	5	16	<2	BI 3
1AA142208813W400	159.00	*Pl, Th, Ch, As,*	4	20	3	BI 2-3
1AA142208813W400	159.70	*Rs, Pl, Sk, Th, Sh,*	6	11	3	BI 3
1AA142208813W400	160.40	*As, Th/Para, Sk Pa*	5	14	3	BI 2-3
1AA142208813W400	161.15	*Sk, Rs*	2	<2	<2	BI 0-1
1AA142208813W400	161.90	*Sk*	1	<2	<2	BI 0-1
1AA142208813W400	162.65	*Th, Pl, Sk*	3	10	<2	BI 0-1
1AA142208813W400	163.40	*PL*	1	3	<2	BI 0-1
1AA142208813W400	164.15	*Pl, Sh, Sk*	2	6	<2	BI 1
1AA142208813W400	164.90	*Pl, Rs, Th*	3	8	2	BI 1
1AA142208813W400	165.60	*Pl, Th, Te*	3	11	3	BI 1
1AA142208813W400	166.30	*Sc, Th, Pl, Te, Rs, Sk*	6	10	3	BI 1-2
1AA142208813W400	167.20	*Pl, Th, Rs*	3	14	3	BI 2
1AA142208813W400	168.10	*Te, Pl, As, Th, Sc,*	5	16	3	BI 2
1AA142208813W400	168.85	*Th, Pl, Ar, Gy, Cy, Mgy, Te*	7	9	2	BI 4-5
1AA142208813W400	169.60	*Gy, Mgy, Ar, Te, Pl,*	6	10	2	BI 4-5
1AA142208813W400	170.35	*Mgy, Pl, Non-m: Th, Te, Ar*	4	4	2	BI 4-5
1AA142208813W400	171.10	*Pl, Sk, Mgy, Cy?, Non-*	5	3.5	<2	BI 4-5
1AA142208813W400	171.85	*Mgy, Te, Sk,Cy,*	4	3	<2	BI 4
1AA142208813W400	172.60	*Mgy, Te, Cy, Gy, Ar,*	6	7	<2	BI 4-5
1AA142208813W400	173.35	*Cy, Mgy, Gy, Ar,*	4	4	<2	BI 3
1AA142208813W400	174.10	*Cy, Mgy, Sk, GY*	4	5	<2	BI 2-3
1AA142208813W400	174.85	*Cy, Mgy, Gy,*	3	2	<2	BI 1-2
1AA142208813W400	175.60	*Mgy, Cy, Pl,*	3	5	<2	BI 0, 1 local
1AA142208813W400	176.35	Pa, *Cy, Pl,*	3	3	<2	BI 0, 1 local
1AA142208813W400	177.10	*Cy, Mgy, Gy*	3	<2	<2	BI 0, 1 local
1AA142208813W400	177.85	*Cy, Mgy*	2	3	<2	BI 0, 1 local
1AA142208813W400	178.60	*Cy, Mgy*	2	3	2	BI 1
1AA142208813W400	179.40	*Cy, Mgy, Sk*	3	6	2	BI 1-2
1AA142208813W400	180.20	*Cy, Mgy, Sk*	3	2	<2	BI 1
1AA142208813W400	181.70	*Cy*	1	3	<2	BI 0, 1 local

1AA142208813W400	182.70	*Pl, Cy, Mgy*	3	3	<2	BI 0, 1 local
1AA142208813W400	183.70	*Pl, Cy*	2	3	<2	BI 0, 1 local
1AA142208813W400	184.20	*Sk*	1	<2	<2	BI 0, 1 local
1AA142208813W400	184.70	*Sk, Gy*	2	2	<2	BI 0, 1 local
1AA142208813W400	185.50	*Sk, Pl, Cy*	3	<2	<2	BI 0, 1 local
Well	1AA103008813W400					
1AA103008813W400	169.00	*Ch*	1	<2	<2	BI 0-1
1AA103008813W400	169.75	*Th, OSk, Ch, As, Pl,*	6	28	4	BI 3-1
1AA103008813W400	170.50	*Th, Op, Sk, Ch, Pl, As, Te Rs*	8	25	4	BI 4
1AA103008813W400	171.25	*Sh, Sk, Th, As, Ch, Pl, Rs*	6	40	2	BI 1-2, 4
1AA103008813W400	172.00	*As, Te, Sk, Th, Pl*	5	20	2	BI 2
1AA103008813W400	172.75	*Rs, Pl, Th, Sh, Sk*	5	12	2	BI 2
1AA103008813W400	173.50	*Sh, Rs, Pl, Rz, As, Th, Te*	7	13	4	BI 2
1AA103008813W400	174.25	*Pl, Te, As, Sk, Ar, Ch, Th*	7	12	4	BI 2-3
1AA103008813W400	175.00	*Pl, Te, As, Sk, Th, Ar, Sc*	7	10	4	BI 2-3
1AA103008813W400	176.00	*Te, Sh, Sk, Pl, Th*	5	10	<2	BI 1
1AA103008813W400	177.00	*Sh, Pl, Te, Sk, Th*	5	22	2	BI 1
1AA103008813W400	177.75	*Pl, Te, Sk, Th*	4	11	2	BI 1
1AA103008813W400	178.50	*Pl, Te, Sk, Th*	4	30	4	BI 1-2
1AA103008813W400	179.25	*Te, Pl, Sk, Sc,*	4	14	3	BI 1-2
1AA103008813W400	180.00	*Te, Pl, Th, Sk*	4	14	2	BI 1
1AA103008813W400	180.40	*Th, Pl, Ch, Te, Sk*	5	12	2	BI 1
1AA103008813W400	181.10	*Rs, Te, Pl, Th, As*	5	15	3	BI 1
1AA103008813W400	182.70	*Rz, Th, Pl, Sk, As, Gy, Pa, Sc*	8	14	3	BI 2
1AA103008813W400	183.40	*Sk, Gy, Mgy, Cy, Pl,*	6	9	<2	BI 2
1AA103008813W400	184.10	*Sk, Gy, Mgy, Cy, Pl,*	6	10	<2	BI 1-2
1AA103008813W400	184.85	*Cy, Mgy, Te, Th, Gy,*	5	9	<2	BI 1
1AA103008813W400	185.60	*Pl, Mgy, Cy, Th Te*	5	9	<2	BI 1
1AA103008813W400	186.35	*Te, Pl, Sk, Ar, Mgy, Cy, Sc, Gy,*	8	8	<2	BI 1-2
1AA103008813W400	187.10	*Te, Pl, Sk, GY*	4	3	<2	BI 1
1AA103008813W400	187.80	*Te, Pl, Sk, GY, Mgy*	4	7	<2	BI 1
Well	1AH113108813W400					
1AH113108813W400	177.80	*Th, Te, Pl, Sk, Ch, As, Zoo*	5	17 mm	4 mm	BI 3-4
1AH113108813W400	178.55	*Sk, Te, As, Sh*	4	4	2	BI 4
1AH113108813W400	179.30	*Rs, Pl, Sk, Para, Sh,*	5	20	3	BI 4
1AH113108813W400	183.80	*Sh, Rs, Pl, Sk*	4	13	2	BI 2
1AH113108813W400	182.30	*Th, Sh, Ch, Pl, ?Oph*	5	20	3	BI 1

1AH113106813W400	185.30	*Sk, Rs, As, Pl, Th, Te*	6	9	4	BI 1
1AH113106813W400	186.80	*Rs, As, Pl,*	3	3	2	BI 1
1AH113106813W400	190.30	*Pl, Sk, Te, Ar, Gy, Th, Cy*	7	20	3	BI 3
1AH113106813W400	191.80	*Pl, Mgy, Gy, Ar, TH*	5	10	3	BI 2-3, BI 1 local
1AH113106813W400	193.30	*Pl, Gy, Sk*	3	6	2	BI 2-3, BI 1 local
1AH113106813W400	193.80	*Th*	1	9	<2	BI 0-1
1AH113106813W400	194.50	*Sk*	1	<2	<2	BI 0-1
Well	**1AA132406814W400**					
1AA132406814W400	170.20	*Ch*	1	< 2	<2	BI 0-1
1AA132406814W400	171.00	*Th, Ch, Pa, As Te, Pl, Sk,*	7	40	3	BI 4
1AA132406814W400	171.80	*Th, Pl, Ch, As, Te,*	5	27	4	BI 4-5
1AA132406814W400	173.20	*Pl, Sk, Th, Te, Pa*	5	10	2	BI 1
1AA132406814W400	174.00	*Pl, Th, Te, Sk, Ar*	4	12	2	BI 1-2
1AA132406814W400	174.80	*Te, Pl, Th, Sk, As*	5	18	2	BI 1-2
1AA132406814W400	175.45	*Te, Pl, Sk, Th, Sc*	5	7	3	BI 1
1AA132406814W400	176.10	*Te, Pl, Th, Sk*	4	10	3	BI 4, BI 1
1AA132406814W400	176.95	*Mgy, Te, Pl, Th, Sk,*	6	17	2	BI 3
1AA132406814W400	177.80	*Gy, Mgy, Cy, Pl, Th*	6	17	2	BI 2
1AA132406814W400	179.10	*Mgy, Cy, Pl, Pl*	5	< 2	2	-
1AA132406814W400	180.70	*Mgy, Gy, Cy, Pl, Te, TH*	5	4	<2	BI 0-1, BI 2
1AA132406814W400	181.40	*Mgy, Gy, Cy, Pl, Th, Te*	6	10	<2	BI 4-5, BI 0-1
1AA132406814W400	182.10	*Mgy, Cy, Te, Pl*	4	20	2	BI4-5
1AA132406814W400	182.90	*Mgy, Cy, Pl, Te, Th*	5	28	2	BI 3-4
1AA132406814W400	183.70	*Cy, Mgy, Gy, Pl, Te,*	6	20	2	BI 3-4
1AA132406814W400	184.45	*Mgy, gy, Cy, Pl, Te, Th, Ar*	7	20	<2	BI 3-4
1AA132406814W400	185.20	*Gy, Mgy, cy, Pl, Te, Th*	6	18 mm	less than 2 m to 2	BI 4-3
1AA132406814W400	186.00	*Cy, Gy, Mgy. Pl, Te, Th, Ar*	7	14mm	3 mm	BI 4-5
1AA132406814W400	186.80	*Cy, Mgy, Gy, Pl, Te, Th, Ar*	7	14 mm	3 mm	BI 5-6
1AA132406814W400	188.20	*Cy, Gy, Mgy, Te, Pl,*	6	19 mm	2 mm	BI 4-5
1AA132406814W400	189.00	*Gy, Mgy, Cy, Te, Pl, Th, Sk, Ar, Ch?*	8	19 mm	2 mm	BI 4-5
1AA132406814W400	189.80	*Gy, Mgy, Te,Cy, Pl, Th, Sk Ch?*	7	10 mm	2 mm	BI 4
1AA132406814W400	190.50	*Gy, Mgy, Cy, Te, Pl, Ar, Th*	7	14 mm	less than 2 m to 2	BI 4
1AA132406814W400	191.20	*Mgy, Gy, Cy, Pl, Te, Th, Sk*	7	20 mm	less than 2 mm	BI 3-4
1AA132406814W400	192.00	*Gy, Mgy, Cy, Te, Pl, Ar, Th*	7	15 mm	less than 2 m to 2	BI 3-4

1AA132408814W400	192.80	Gy, Mgy, Cy, Pl, Te, Ar, Sk, Th	8	10 mm	less than 2 mm to 2 mm	BI 1-2, BI 4
1AA132408814W400	193.50	Gy, Mgy, Te, Cy, Pl, Ar, Th	7	15 mm	2 mm	BI 3
1AA132408814W400	194.20	Gy, Mgy, Cy, Pl, Te	5	5 mm	2 mm	BI 1, BI 3
1AA132408814W400	195.00	Mgy, Gy, Cy, Te, Pl, Ar,	5	5 mm	less than 2mm	BI 3, BI 0-1
1AA132408814W400	195.80	Gy, Mgy, Cy, Te, Pl, Th	6	10 mm	less than 2mm	BI 3
1AA132408814W400	196.50	Gy, Mgy, Te, Pl, Sk, Ar, Th, Ch?	7	11 mm	2 mm	BI 4-3
1AA132408814W400	197.20	Gy, Mgy, Te, Pl, Sk, Ar, Ch?	6	15 mm	3 mm	BI 4, BI 1
1AA132408814W400	198.00	Gy, Mgy, Te, Pl, Th, Sk, Ar	7	23 mm	3 mm	BI-4
1AA132408814W400	198.80	Gy, Mgy, Cy, Te, Pl, Sk, Pa, Ch?	7	14 mm	less than 2mm	BI3-4
1AA132408814W400	199.30	Mgy, Te, Pl, Sk, Cy, Ar, Ch?	6	15 mm	less than 2mm	BI-3
1AA132408814W400	199.80	Pl, Th, Te, Mgy	3	12 mm	2 mm	BI 2-3
Well	1AA122608814W400					
1AA122608814W400	176.50	-	-999	-	-	-
1AA122608814W400	177.25	Ch, Te, Th, Sk, Pl, As, Ar	7	28	3	BI 5
1AA122608814W400	178.00	Ch, Th, Te, Sk, Pl, As, zoo	7	37	4	BI 5
1AA122608814W400	178.75	Th, Te, Pl, Ch, Rz, As Pa, Sk	9	50	5	BI 4-5
1AA122608814W400	179.50	Sk, As, Sh, Ra Th	5	18	3	BI 2
1AA122608814W400	181.00	Pl, As, Ra, Th	3	30	4	BI 1-2
1AA122608814W400	182.50	Sk, As, Pl, Th	3	2 mm	less than 2 mm	BI 1
1AA122608814W400	183.25	Gy, pl, Cy Thc Th, Sc, Te, Pl, Ra, Zoo, Rz	1	28 mm	3-4 mm	BI 4
1AA122608814W400	184.00	Pl, Th, Te, Mgy, Cy,	5	12	2	BI 0-2
1AA122608814W400	184.70	Cy, Mgy, Pl, Te,	4	5	<2	BI 0, 1 local
1AA122608814W400	185.40	Pl, Cy, Te,	3	4	<2	BI 0, 1 local
1AA122608814W400	186.15	GY, Mgy, TH, Ar,	4	20	<2	BI 3-4, BI 0-1
1AA122608814W400	186.90	Gy, Mgy, Te, Th, Sk,	6	15	<2	BI 3-4
1AA122608814W400	187.65	Te, Mgy, Gy, Th, Pl, Cy Sk	7	13	<2	BI 3-4
1AA122608814W400	188.40	Gy, Mgy, Te, Th, Cy, Pl, Sk	7	27	<2	BI 3-4
1AA122608814W400	189.15	Mgy, Gy, Te, Pl, Sk,	5	18	<2	BI 3-4
1AA122608814W400	189.90	Mgy, Te, Pl, Th, Cy,	5	22	<2	BI 4-3
1AA122608814W400	190.65	Mgy, Gy, Th, Cy,Sk, Te, Pl	7	12	<2	BI 4-3

1AA122608814W400	191.40	*Gy, Mgy, Cy, Th, Pl,*	6	30	<2	BI 5
1AA122608814W400	192.15	*Mgy, Gy, cy, Te, Pl, Th, Ar, Pa*	8	18	<2	BI 5
1AA122608814W400	192.90	*Mgy, Gy, cy, Te, Pl, Th, Ar,*	7	20	<2	BI 5
1AA122608814W400	193.65	*Mgy, Gy, Pl, Te, Th, Ar, Sk, Pa Cy*	9	30	2	BI 5
1AA122608814W400	194.40	*Mgy, Gy, Cy, Sk, AR, Te, Th Pa, Pl*	9	28	2	BI 4-5
1AA122608814W400	195.15	*Mgy, Gy, Cy, Sk, AR, Te, Th Pl*	8	30	2	BI 4-5
1AA122608814W400	195.90	*Mgy, Gy, Cy, Sk, AR, Te, Th Pl*	8	35	3	BI 4-5
1AA122608814W400	196.65	*Gy, Mgy, Cy, Sk, Te, Th, Ar,*	7	18	2	BI 4-5
1AA122608814W400	197.40	*Gy, Mgy, Cy, Sk, Te, Th, Ar,*	7	20	2	BI 4
1AA122608814W400	198.15	*Gy, Mgy, Th, Cy, sk,*	6	28	2	BI 3-4
1AA122608814W400	198.90	*Te, Ar, Gy, Pl, Th, Cy*	6	40	3	BI 3-4
1AA122608814W400	199.65	*Pl, Te, Th, Gy, Mgy, Cy Sk*	7	28	3	BI 3-4
1AA122608814W400	200.40	*Gy, Mgy, Cy, Te, Ar, Th, Pl*	7	45	3	BI 3-4
1AA122608814W400	201.15	*Cy, Gy, Pl, Th*	4	20	2	BI 2
1AA122608814W400	201.90	*Gy, Th, Cy, Te,*	4	30	2	BI 2
1AA122608814W400	202.70	*Pl, Sk, Cy*	3	4	<2	BI 0-1
1AA122608814W400	203.50	*Cy, pl, Sk Th*	4	14	2	BI 0-1
Well	**1AA102708814W400**					
1AA102708814W400	177.50	-	-999	-	-	-
1AA102708814W400	178.25	*Ch, Th, Te, As Pl, Sh*	7	14	<2	BI 4
1AA102708814W400	179.00	Para, *Sh, Pl, Te, TH*	5	18	3	BI 3-4
1AA102708814W400	179.75	*Pl, Sk, Ra, Te, Th, SH*	6	15	2	BI 4-3
1AA102708814W400	180.50	*Pl Th*	2	9	<2	BI 0-1
1AA102708814W400	182.00	*Pl, Sk, Th*	3	10	2	BI 0-1
1AA102708814W400	183.50	*Pl, SK*	2	2	2	BI 0-1
1AA102708814W400	185.00	*Pl, sk, Th*	3	13	2	BI 1
1AA102708814W400	186.40	*Th, Sk, Pl, Ra*	4	10	2	BI 1
1AA102708814W400	187.20	*Pl, sk, Th, As, Gy, Te*	6	10	2	BI 1
1AA102708814W400	188.00	*Gy, Pl, Th, Sk, Cy, Te, Te*	7	15	2	BI 1
1AA102708814W400	188.70	*Mgy, Pl, Te, Gy, Th,*	6	20	2	BI 2-3
1AA102708814W400	189.40	*pl, te, Lg, Gy, Cy,*	6	15	<2	BI 3-2
1AA102708814W400	190.20	*Mgy, Gy, Cy, Pl, Ar,*	6	15	2	BI 2-3
1AA102708814W400	191.00	*Gy, Pl, Te, Ar, Mgy, cy, Th*	7	10	<2	BI 2-3
1AA102708814W400	192.50	*Pl, Te, Sk, Cy*	4	5	<2	BI 0-1
1AA102708814W400	194.00	*Pl, Cy*	2	3	<2	BI 0-1
1AA102708814W400	195.30	*Pl, Te, Gy, Cy*	2	5	<2	BI 0-1
1AA102708814W400	196.05	*Gy, Mgy, Cy, Pl*	4	6	<2	BI 0-1
1AA102708814W400	196.80	*Cy, Mgy, Gy, Pl, Sk*	6	15	<2	BI 1-2
1AA102708814W400	197.55	*Cy, Mgy, Gy, Sk,*	4	10	<2	BI 0-1

1AA102708814W400	198.30	*Cy, Mgy, Gy, Th*	4	10	<2	Bl 1
1AA102708814W400	200.00	*Cy, Gy, Mgy, Ar, Te,*	6	20	<2	Bl 1
1AA102708814W400	200.75	*Gy, mgy, Cy, Th , Sk*	4	13	<2	Bl 1
1AA102708814W400	201.50	*Gy, mgy, Cy, Th*	4	10	<2	Bl 1-2
1AA102708814W400	201.60	*Cy, Gy, Mgy, Ar*	4	10	2	Bl 1-2
1AA102708814W400	202.30	*Gy, Mgy, Cy, Th, Te,*	6	10	2	Bl 1-2
1AA102708814W400	203.00	*Gy, Mgy, Cy*	3	5	<2	Bl 1-2
1AA102708814W400	203.75	*Cy, Gy, Mgy, Pl, Th*	5	10	2	Bl 1-2
1AA102708814W400	204.50	*Mgy, Th, Cy,*	3	5.5	<2	Bl 0-1, 1 local
1AA102708814W400	205.25	*Cy, Te, Sk*	3	6	<2	Bl 0-1, 1 local
1AA102708814W400	206.00	*Mgy, Th, Te, Cy*	4	12	<2	Bl 0-1, 1 local
1AA102708814W400	206.90	*Gy, Mgy, Cy, Th, Pl*	5	11	<2	Bl 0-1, 1 local
1AA102708814W400	207.80	*Mgy, Sk, Th*	3	10	<2	Bl 0-1, 1 local
1AA102708814W400	208.40	*Th, Pl, Mgy , cy*	4	15	<2	Bl 0-1, 1 local
1AA102708814W400	209.00	*Mgy, Pl, Cy, Te, sk*	5	13	<2	Bl 0-1, 1 local
1AA102708814W400	209.75	*Pl, Mgy, Cy, Te, Ar*	5	5	<2	Bl 0-1, 1 local
1AA102708814W400	210.50	*Cy, Mgy, Te, Pl*	4	6.5	<2	Bl 0-1, 1 local
1AA102708814W400	211.25	*cy, pl, mgy, th, sk*	5	10	<2	Bl 0-1, 1 local
1AA102708814W400	212.00	*Cy, Pl, Mgy, Gy, Th, Te, SK*	7	20	<2	Bl 0, Bl 4-2
1AA102708814W400	213.00	*Cy, Pl*	2	3	<2	Bl 0-1, 1 local
Well	1AA053608814W400					
1AA053608814W400	177.35	-	-999	30	<2	Bl 1
1AA053608814W400	178.10	*Ch, Pl, Te, th*	4	15	< 2	Bl 1
1AA053608814W400	179.00	*Te, Pl, Th, Pa, Ch*	4	11	2	Bl 4-3
1AA053608814W400	179.90	*Pl, ch, As, SK*	4	12	2 3	Bl 4
1AA053608814W400	181.10	*Ch, Dp, Sk, Te, As, Pl, Th*	6	11	<2	Bl 0, Bl 2-3
1AA053608814W400	182.90	*Th, Pl, SK, Rs*	4	8	2	Bl 1
1AA053608814W400	183.80	*Pl, Th, sk*	3	5	2	Bl 0-1
1AA053608814W400	185.10	*Pl, Th, sk*	3	12	3	Bl 0-1
1AA053608814W400	185.45	*Th, Pl, Mgy, Gy*	4	14	2	Bl 0-1
1AA053608814W400	185.80	*Gy, Pl, Te, Th*	4	10	2	Bl 3
1AA053608814W400	187.10	*Gy, Pl, Ar, Sk*	3	3	2	Bl 3-2
1AA053608814W400	188.00	*Gy, Cy, Pl, Th*	4	11	2	Bl 2-3
1AA053608814W400	188.90	*Gy, Mgy, Te, Th, Sk,*	6	15	2	Bl 2-3
1AA053608814W400	188.90	*Gy, Mgy, Pl, Te, Cy, Th*	6	18	2	Bl 0-1, Bl 3
1AA053608814W400	188.90	*Gy, Mgy, Cy, Pl, Te,*	6	22	2	Bl 4

1AA053608814W400	189.50	*Gy, Mgy, Cy, Te, Pl, Th, Ch?*	4	15	2	Bl 4
1AA053608814W400	190.10	*Cy, Gy, Mgy, Pl, Te*	5	11	2	Bl 3-4
1AA053608814W400	191.00	*Pl, Te, Th*	3	13	2	Bl 3, Bl 0-1
1AA053608814W400	191.90	*Gy, Mgy, Pl, Te, Cy, Ar, Ch?*	7	7	2	Bl 3-4
1AA053608814W400	192.50	*Cy, Gy, Mgy, Pl, Te,*	6	7	<2	Bl 3-4
1AA053608814W400	193.10	*Gy, Cy, Pl, Te, Ar, sk*	5	8	<2	Bl 4
1AA053608814W400	194.00	*Gy, Mgy, Cy, Pl, Te, Ar, Sk, Th*	8	11	<2	Bl 3-4
1AA053608814W400	194.90	*Gy, Mgy, Cy, Sk, Ar, Te, Pl, Th*	8	7	<2	Bl 3-4
1AA053608814W400	195.50	*Gy, Mgy, Pl, Te, Cy, Ar, Sk, Th*	8	10	<2	Bl 2-3
1AA053608814W400	196.10	*Gy, Mgy, Cy, Pl, Te, Ar, Sk, Th*	8	10	<2	Bl 4
1AA053608814W400	197.00	*Pl, Gy, Cy, Te, Ar*	3	7	2	Bl 1-2
1AA053608814W400	197.90	*Gy, Mgy, Pl, Te, Ar, Sk, Th, Cy, Ch?*	8	10	2	Bl 3
1AA053608814W400	198.50	*Gy, Mgy, Cy, Te, Pl, Sk, Ar, Ch?*	8	9	3	Bl 3-4
1AA053608814W400	199.10	*Gy, Te, Pl, Sk, Ar*	5	5	2	Bl 2-3
1AA053608814W400	200.20	*Pl, Te, Ar, Ch*	4	6	<2	Bl 2-3
1AA053608814W400	201.30	*Pl, Te, GY, Ar*	4	5	<2	Bl 2-3
1AA053608814W400	201.70	*Pl, Te, Sk, Gy*	4	5	<2	Bl 1-2
1AA053608814W400	202.10	*Pl, Te, Sk, Mgy, Gy*	4	4	<2	Bl 3-4
1AA053608814W400	202.50	*Pl, Te, Th, ch?*	3	11.5	<2	Bl 2
Well	**1AA080308813W400**					
1AA080308813W400	170.30	-	-999	-	-	-
1AA080308813W400	171.80	*Pl, Ch, Phy, Te*	4	4	<2	Bl 2-1
1AA080308813W400	173.30	*Pl, Ch, Te*	3	8	2	4
1AA080308813W400	174.80	*Pl, Th, Te, Ch, As*	5	15	3	Bl 3-4
1AA080308813W400	175.55	*Sh, Dp, As, Pl, Pa, Th*	6	15	3	Bl 3-4
1AA080308813W400	176.30	*Pl, Te, Sk, Ra, Sh, Th, As, Ur*	7	10	3	2
1AA080308813W400	177.80	*Ra, Sh, Pl*	3	3	<2	2
1AA080308813W400	179.30	*Pl, Te*	1	10	<2	1
1AA080308813W400	180.05	*Pl, Sh*	2	4	<2	Bl 0-1
1AA080308813W400	180.80	*Pl, Th, Sh*	3	11	<2	Bl 0-1
1AA080308813W400	181.55	*Pl, Sk, Sh*	3	4	<2	Bl 0-1
1AA080308813W400	182.30	*Pl, Sh, Sk*	3	<2	<2	Bl 0-1
1AA080308813W400	183.80	*Pl*	1	3	<2	Bl 0-1
1AA080308813W400	184.60	*Pl, Zoo*	3	3	<2	Bl 0-1
Well	**1AB100808813W400**					
1AB100808813W400	188.00	*Sk, Th, Ch, As, Pl,*	5	20	3	Bl 4
1AB100808813W400	188.50	*As, Ch, Th Sk*	4	30	<2	Bl 2-3
1AB100808813W400	189.25	*Sh, Para*	2	10	4	Bl 2
1AB100808813W400	190.00	*Para, Sh, Ra, Th,*	5	14	4	Bl 2-3
1AB100808813W400	190.80	*Pl, Ra, Sk Sh*	4	10	2	Bl 2-3

1AB100608913W400	191.60	*Pl, Ra, Sr Sh*	4	10	2	BI 2-3
1AB100608913W400	192.35	*As, Ra, Pl Th*	4	22	2	BI 2
1AB100608913W400	193.10	*As, Pl*	2	17	2	BI 2
1AB100608913W400	193.80	*Te, Pl, Th*	-999	-	-	BI 2-3
1AB100608913W400	194.50	*Ra, Th, Te, Pl, As,*	6	30	3	BI 3
1AB100608913W400	194.75	*Te, As, Th, ArSk, Pl, Rz,*	7	30	5	BI 3-4
1AB100608913W400	195.00	*Mgy, GY, Th, Sk, Te,*	6	23	<2	BI 5
1AB100608913W400	196.50	*Mgy, Te, Th ,Gy, Cy*	5	13	<2	BI 5-6
1AB100608913W400	197.25	*Gy, Mgy, Te, Th, SK*	5	14	<2	BI 2-3
1AB100608913W400	198.00	*Mgy, Gy, Pl,Sk, Te, Th, Cy*	7	18	<2	BI 3
1AB100608913W400	198.55	*Gy, Cy, Mgy, Th, Te*	5	11	3	BI 3
1AB100608913W400	199.10	*Cy, Sk, Gy, Mgy, Th, Pa, Te*	7	23	3	BI 3
1AB100608913W400	199.80	*Cy, Gy, Mgy, te, Th,*	6	40	3	BI 3
1AB100608913W400	200.50	*Cy, Te, Mgy, Pl,*	4	8	2	BI 2
1AB100608913W400	201.20	*Mgy, Pl, Cy, Te*	4	10	2	BI 3
1AB100608913W400	201.90	*Mgy, Cy, Pl, Sk, Te*	6	10	<2	BI 3
1AB100608913W400	202.90	*Te, Gy, Cy, Mgy, Pl, Th, Sr*	7	13	2	BI 2
Well	**1AB071608913W400**					
1AB071608913W400	190.65	Ch	1	2	<2	BI 0-1
1AB071608913W400	191.40	*Ch, Te, Sr*	3	7	<2	BI 1
1AB071608913W400	192.15	Ch	1	<2	<2	BI 0-1
1AB071608913W400	192.90	Ch	1	<2	<2	BI 0-1
1AB071608913W400	194.40	*Pl, Th*	2	12	3	BI 2-3
1AB071608913W400	195.90	*Pl, Sk, Th, Pa*	2	8	2	BI 0-1
1AB071608913W400	197.40	*Pl, Sk, Th, Para, Sh,*	6	30	3	BI 2-3
1AB071608913W400	198.90	*Pl, Sk, Th, Para, Lg,*	6	11	3	BI 2
1AB071608913W400	199.65	*Pl, Sk. Dp, Ra, Sh, Lg*	6	7	3	BI 3
1AB071608913W400	200.40	*Pl, Sk, Sh, As, Sc/Te*	6	12	2	BI 0-1, 3
1AB071608913W400	201.15	*Pl, Th, Sk*	3	9	2	BI 0-1
1AB071608913W400	201.90	Pl	1	6	2	BI 0-1
1AB071608913W400	202.65	Pl	1	5	2	BI 0-1
1AB071608913W400	203.40	*Pl, Th, Sh*	3	15	2	BI 0-1
1AB071608913W400	204.90	*Pl, Sh*	2	3	>2	BI 0-1
1AB071608913W400	205.65	*Pl, Pa, Zoo, Sh, Th*	3	8	2	BI 1
1AB071608913W400	206.40	*Pl, Th, Ar*	2	30	2	BI 0-1
1AB071608913W400	207.15	*Pl, Th, Te*	3	10	2	BI 0-1
1AB071608913W400	207.90	*Pl, Sk*	2	6	3	BI 0-1
1AB071608913W400	208.65	*Pl, Sk, Ar*	3	3	2	BI 0-1
1AB071608913W400	209.40	*Pl, Th, Te*	3	10	3	BI 0-1
1AB071608913W400	210.50	Pl	1	3	<2	BI 0-1
Well	**1AA071908913W400**					
1AA071908913W400	192.20	*Te, Ch*	2	<2	<2	BI 0-1
1AA071908913W400	193.70	*Sk, Pl: Ch, As, Te, Th, Rz, Ar*	3	2	<2	BI 1, BI 4
1AA071908913W400	195.20	*Sk, Pl, Para*	3	9	<2	BI 0-1
1AA071908913W400	196.70	*Sk*	1	<2	<2	BI 0-1

1AA071908813W400	198.20	*Pl*	1	3	<2	BI 0-1
1AA071908813W400	199.70	*Te, Th, Pl, SH, Sc*	2	13	2	BI 0-1
1AA071908813W400	200.50	*Sk*	1	<2	<2	BI 0-1
1AA071908813W400	201.30	*Sk*	1	1	<2	BI 0-1
1AA071908813W400	202.00	*P, Th, Te, Sk*	4	11	2	1
1AA071908813W400	202.70	*Pl, Te, Th*	3	20	2	1
1AA071908813W400	203.45	*Te, Th, Ar, Ch, Pl Sh,*	6	18	<2	BI 4, BI 1
1AA071908813W400	204.20	*Ch, Sk, Sh, Pa, Dp, Te, As, TH, Pl*	9	18	2	BI 4
1AA071908813W400	204.95	*Te, Th, Pl, Mgy, Sk, Sc, Rs, Ch, As,*	6	13 mm	2-3 mm	BI 4
1AA071908813W400	205.70	*Te, ?Cy, Pl, Th, Mgy*	6	18	<2	BI 2
1AA071908813W400	206.45	*Pl, Te, Mgy, Ar,*	4	7	<2	BI 2
1AA071908813W400	207.20	*Mgy, Th, Pl, Sk, Te,*	5	11	<2	BI 2
1AA071908813W400	207.95	*Te, Pl, Th, Sk, Gy*	5	18	3	BI 2-3
1AA071908813W400	208.70	*Te, Th, Pl, Sk, Gy,*	5	13	2	BI 2-3
1AA071908813W400	209.45	*Te, Pl, Sk, Th*	4	10	2	BI 2
1AA071908813W400	210.20	*Th, Te, Sk, Pl, Non-m*	5	14	2	BI 3
1AA071908813W400	210.95	*Sk, Pl, Non-m*	3	4	2	BI 2-3
1AA071908813W400	211.70	*Sk, Te, Non-m*	3	2	<2	BI 2-3
1AA071908813W400	212.45	*Sk, Te, Pl, Non-m*	4	8	2	BI 4
1AA071908813W400	213.20	*Pl, Te, Non-m*	3	12	<2	BI 4
1AA071908813W400	213.95	*Pl, Th, Te, Sk, Non-m*	5	18	3	BI 4-5, D Local
1AA071908813W400	214.70	*Te, Pl, Th, Sk, Non-m*	5	12	2	BI 4-5, D Local
Well	**1AA073008813W400**					
1AA073008813W400	190.50	*Pl, Ch, Te*	3	3	<2	BI 0-1
1AA073008813W400	193.20	*Pl, Ch, As, Te, Th*	5	9	<2	BI 1, BI 4
1AA073008813W400	194.50	*Sh, Pl, Rs, Lg, Para*	6	5	<2	BI 1
1AA073008813W400	196.00	*Sk, Pl*	2	3	<2	BI 0-1
1AA073008813W400	198.00	*Rs?*	1	-	-	BI 0-1
1AA073008813W400	198.50	*Rs?*	1	-	-	BI 0-1
1AA073008813W400	199.25	*Pl, Sh*	2	3.5	<2	BI 0-1
1AA073008813W400	200.00	*Pl*	1	<2	<2	BI 0-1
1AA073008813W400	200.75	*Pl*	1	5	<2	BI 0-1
1AA073008813W400	201.50	*Pl, Sk*	2	2	<2	BI 0-1
1AA073008813W400	203.00	*Pl, Sk*	2	2	<2	BI 0-1
1AA073008813W400	204.20	*Sh, Th, Pl,*	3	9	2	BI 1-2
1AA073008813W400	204.95	*Pl, Th, Te, Sk, As, Sh, Rs*	7	6	2	BI 2-3
1AA073008813W400	205.70	*Pl, Th, Te, Ch,*	4	8	3	BI 2-3
1AA073008813W400	206.70	*Pl, Th, Sk*	3	18	2	BI 2
1AA073008813W400	207.45	*Pl, Te, Sk, Th, Rs,*	6	10	2	BI 2
1AA073008813W400	208.20	*Mgy, Te, Sk, Cy. Sk, Th, Pl,*	7	25	<2	BI 4
1AA073008813W400	208.95	*Cy, Sk, Te, Mgy, Pl,*	6	10	<2	BI 4
1AA073008813W400	209.70	*Gy, Te, Sk, Pl, Mgy*	5	11	<2	BI 5-6
1AA073008813W400	210.45	*Th, Mgy, Pl, Sk,Pe,*	6	38	<2	BI 2-3
1AA073008813W400	211.20	*Pl, Sk, Gy, Th, Mgy Te, Cy*	7	18	<2	BI 3

1AA073008913W400	211.95	*Pl, Sk Ar, Te,*	4	9	2	BI 2, BI 2-3
1AA073008913W400	212.70	*Sk, Non-m*	2	2	<2	BI 2
1AA073008913W400	213.45	*Non-M, Sk*	2	3	<2	BI 4
1AA073008913W400	214.20	*Pl, Te, Mgy, Sk, Non-*	5	10	2	BI 4-5
1AA073008913W400	214.95	*Th, Te, Pl, Mgy, Non-*	4	30	2	BI 4-5
1AA073008913W400	215.70	*Th, Te, Non-m*	3	28	2	BI 1, BI 4-5
1AA073008913W400	216.20	*Te, Sk, Pl, Mgy, Non-*	5	5	<2	BI 4
1AA073008913W400	216.70	*Sk, Th*	2	20	<2	BI 0-1
Well	**1AA103108913W400**					
1AA103108913W400	190.45	*Pl, Ch, Th, Sk*	4	16 mm	less than 2 mm	BI 4
1AA103108913W400	191.20	*Pl, Th, Te, Sk, Pa*	5	20 mm	3-4 mm	BI 4
1AA103108913W400	191.70	*Pl, Sk, Te, Pa*	4	5 mm	2 mm	BI 2-3
1AA103108913W400	193.20	*Pl, Sk*	2	4 mm	2 mm	BI 0-1
1AA103108913W400	196.20	*Sk*	1	less than 2 mm	less than 2 mm	BI 0-1
1AA103108913W400	199.20	*Pl*	1	less than 2 mm	less than 2 mm	BI 0-1
1AA103108913W400	200.60	*Pl, Sk, Te*	3	7 mm	less than 2 mm	BI 0-1
1AA103108913W400	201.00	*Pl*	1	4 mm	less than 2 mm	BI 0-1
1AA103108913W400	201.55	*Pl, Sk*	2	4 mm	less than 2 mm	BI 0-1
1AA103108913W400	202.10	*Pl*	1	2 mm	less than 2 mm	BI 0-1
1AA103108913W400	203.80	*Pl, Th, Sk*	3	7 mm	less than 2 mm	BI 1-0
1AA103108913W400	204.55	*Pl, Te, Th, Sk*	4	10 mm	3 mm	BI 3-2
1AA103108913W400	205.30	*Pl, Te, Th, Sk, Ra*	5	13 mm	4-5 mm	BI 3
1AA103108913W400	206.05	*Pl, Te, Th, Sk, Ar*	5	11 mm	3 mm	BI 3
1AA103108913W400	206.80	*Pl, Th, Te*	3	22 mm	2-3 mm	BI 3-2
1AA103108913W400	207.55	*Pl, Te, Th, Sk, Cy*	5	19 mm	3 mm	BI 3-4
1AA103108913W400	208.30	*Pl, Te, Th, Sk, Ch*	5	15 mm	3 mm	BI 3
1AA103108913W400	209.05	*Pl, Te, Th, Sc, Cy*	5	16 mm	4-5 mm	BI 3-4
1AA103108913W400	209.80	*Pl, Te, Sk, Ar, Th, Sc*	6	15 mm	2-3 mm	BI 3-4
1AA103108913W400	210.55	*Pl, Te, Sk, Ar, Th, Oph, Sc*	7	11 mm	2-3 mm	BI 3-4
1AA103108913W400	211.30	*Pl, Sc, Te, Sk, Ar, Th, Ch*	7	15 mm	2-3 mm	BI 4
1AA103108913W400	212.05	*Pl, Th, Sc, Ar, Sk, Pa, Te, As*	8	15 mm	3-4 mm	BI 4
1AA103108913W400	212.80	*Pl, Th, Te, Sk, Sc, Cy, Pa, Ch*	8	20 mm	3 mm	BI 4
1AA103108913W400	213.55	*Pl, Th, Te, Sk, Ar*	5	17 mm	3 mm	BI 3-4
1AA103108913W400	214.30	*Pl, Th, Te, Sc, Sk, Ra, Ch*	7	18 mm	2 mm	BI 2-3

1AA103108913W400	215.80	*Pl, Th, Te, As, Cy*	5	10 mm	2 mm	BI 2-3
1AA103108913W400	217.30	*Pl, Th, Te, Sk, Rz, Ar*	6	28 mm	4 mm	BI 3-4
Well	1AA103208913W400					
1AA103208913W400	196.50	*Ch, Pl, Te, Sk*	4	6	<2	BI 3-1
1AA103208913W400	197.25	*Pl, Te, Sk*	3	5	<2	BI 0-1
1AA103208913W400	198.00	*Pl, Te, Ch*	3	10	<2	BI 2-1
1AA103208913W400	201.50	*Te, Ch*	2	3	3	BI 0-1
1AA103208913W400	201.00	*Ch, Te, Pl, Th, Ph*	5	15	2	BI 3-2
1AA103208913W400	201.75	*Pl, Th, Ch, Te*	4	18	4	BI 3-1
1AA103208913W400	202.50	*Pl, Th, Sk, Ch, Rs, As, Te*	7	21	3	BI 4
1AA103208913W400	203.25	*Pl, Pa, Rs, Sk, Sh, As*	4	8	2	BI 2
1AA103208913W400	204.00	*Rs, As, Sh*	3	3	2	BI 2
1AA103208913W400	205.50	*Rs, As, Sh*	3	4	2	BI 2
1AA103208913W400	206.25	*Pl, Th, Rs, As, Ch,*	6	13	4	BI 3-2
1AA103208913W400	207.00	*Pl, Th, Zoo, Ch, Rs, As, Sh, Te*	7	14	5	BI 4-3
1AA103208913W400	208.50	*As, Rs, Pl, Th, Ch, Te, Sk, Sc, As, Zoo*	8	17	4	BI 5-6
1AA103208913W400	209.25	*Ch, Pl, th, Te, Sc, As, Sk, Zoo, Sh, Rz*	7	13	4	BI 5
1AA103208913W400	210.00	*Ch, Pl, th, Te, Sc, As, Sk, Zoo, Sh, Rs, Rz*	7	20	5	BI 5-6
1AA103208913W400	211.50	*Ch, Pl, th, Te, Sc, As, Sk, Zoo, Sh, Rz*	7	20	5	BI 6
1AA103208913W400	213.00	*Ch, Pl, th, Te, Sc, As, Sk,Sh*	7	20	4	BI 6
1AA103208913W400	213.75	*Ch, Pl, Th, Te, Sc, As*	6	30	4	BI 5-6
1AA103208913W400	214.50	*Ch, Pl, Th, Te, Sc, As*	6	13	3	BI 5-6
1AA103208913W400	215.60	*Te, Pl, Ch, As, Th, Sh, Sc*	5	15	3	BI 5
1AA103208913W400	216.70	*Te, Pl, Ch, As, Th, Sk*	6	18	3	BI 5-6
1AA103208913W400	217.10	*Te, Pl, ch, As, Th,*	6	21	4	BI 4-5
1AA103208913W400	217.50	*Pl, Th, Sk, As, Ch, Sh*	6	11	2	BI 3
1AA103208913W400	217.70	*Pl, Sk, Sc*	3	3	2	BI 2-3
1AA103208913W400	218.45	*Pl, Sk, Rs, As, Sc*	4	10	4	BI 2
1AA103208913W400	219.20	*Pl, Sk*	2	6	2 to 3	BI 1-2
1AA103208913W400	219.95	*Pl, Sh*	2	6	2	BI 1
1AA103208913W400	220.70	*Pl, Th, Sk, Te, Sh*	5	10.5	2	BI 1
1AA103208913W400	222.20	*Pl, Te*	2	6	2	BI 0-1
1AA103208913W400	222.95	*Pl, Th*	2	20	2	BI 0-1
1AA103208913W400	223.70	*Pl*	1	4	2	BI 0-1
1AA103208913W400	225.00	*Pl*	1	7	3	BI 0-1
1AA103208913W400	226.50	*Pl, Th*	1	10	2 mm	BI 0-1
Well	1AA103308913W400					
1AA103308913W400	201.25	*Ch, Te, Th, Sk, Pl, As*	7	28 mm	2-3 mm	BI 5
1AA103308913W400	202.00	*Ch, Te, Th, Sk, Pl, As*	8	37 mm	3-4 mm	BI 5
1AA103308913W400	203.50	*Sk, As, Sh, Ch, Th, Te, Pa*	6	40	3	BI 4

1AA103308813W400	205.00	*Pl, As, Rs, Ch, Te, Th, SK*	7	40	4	BI 4-5
1AA103308813W400	206.30	*Rs, Sh, Th, Pl*	4	8	3	BI 1-2
1AA103308813W400	207.05	*Th, Te, Pl, Rs, As, Sh*	6	28	3	BI 2
1AA103308813W400	207.80	*Pl, Th, TE, Sk, Oph?*	5	12	3	BI 2
1AA103308813W400	208.55	*As, Pl, Ch, Rs Sk*	5	5	2	BI 2-3
1AA103308813W400	209.30	*Rs, Pl, Ch, As Sh Sk*	6	4	2	BI 2-3
1AA103308813W400	210.05	*Ch, SH, Rs, Ar, As, Pl, Th, Zoo*	8	20	2	BI 4-5
1AA103308813W400	210.80	*Ch, Pl, Th, Rs, As, sh, Te*	7	15	3	BI 5
1AA103308813W400	211.55	*As, ch, Rs, Te, Sk, Th, zoo, Pl, Sh,*	9	25	4	BI 5-6
1AA103308813W400	212.30	*Zoo, Ch, Te, Th, Pl, As, Sk,*	7	27	5	BI 5
1AA103308813W400	213.05	*Ch, Th, Te, Pl, As, Sk SH*	7	18	3	BI 5
1AA103308813W400	213.80	*Ch, Th, Pl, Te, Sh,*	6	35	5	BI 5
1AA103308813W400	214.65	*As, Ch, Pl, SH, Te, Rs, Zoo Th*	8	50	4	BI 5-6
1AA103308813W400	215.50	*Rs, As, Te, Sc, Sh, Pl, Th, Ch, Rz*	9	30	8	BI 5-6
1AA103308813W400	216.25	*Zoo, Ch, As, Rs, Th, Pl, Te,SK, sh,*	9	16	7	BI 5-6
1AA103308813W400	217.00	*Ch, Th, As, Te, Pl, Sk, Sc, Rs*	8	20	7	BI 5
1AA103308813W400	217.75	*Th, As, Ch, Pl, Te, Sh*	6	30	5	BI 5
1AA103308813W400	218.50	*Rs, ch, As, pl, Te, Th, Sh, Sk Sc*	9	28	5	BI 4-5
1AA103308813W400	219.25	*Ch, Sk, As, Rs, Te, Sc Pl Th*	8	30	3	BI 4-5
1AA103308813W400	220.00	*As, Sh, Pl, Te, Th, Ch Sc*	7	35	3	BI 4-5
1AA103308813W400	220.75	*Pl, Th, As, ch, Te Sk*	6	16	2	BI 3-4
1AA103308813W400	221.50	*As, Pl, Te, Th, Sk, ch*	6	20	2	BI 3-4
1AA103308813W400	222.25	*As, Ch, Zoo, Pl, Th, Op, Te RS*	8	28	4	BI 3-4
1AA103308813W400	223.00	*As, Rs, Pl, Te, Th, Ar, ?Ch*	7	40	3	BI 3-4
1AA103308813W400	223.75	*Pl, Th, Te, Rs, Ar, Ch*	6	28	3	BI 3-4
1AA103308813W400	224.50	*Th, Pl, As, Rs, Te*	6	45	3	BI 3
1AA103308813W400	225.00	*TH, Pl, As, Para Te, ?Ch Sh, Rs, Sk*	9	15	3	BI 2-3
1AA103308813W400	225.50	*Th, As, Pl, Sh, Rs*	5	30	3	BI 3
1AA103308813W400	226.00	*Ch, Th, Pl, Te, Sh, As*	6	30	3	BI 2-3
1AA103308813W400	226.75	*Pl, Sk, te, Th Sh, Rz, As, Ch*	8	30	4	BI 3-4
1AA103308813W400	227.50	*Pl, Sk, Th, As, Ch*	5	20	4	BI 2-3
Well	1AA100808914W400					
1AA100808914W400	186.50	*teich, astero, plano, scolicia*	4	16 mm	5 mm	BI 3

1AA1D0808814W400	189.50	*plano, chondrites*	2	3 mm	less than 2mm	BI 0-1
1AA1D0808814W400	191.25	*thalass, teich, skolithos, plano,*	5	16 mm	2-3 mm	BI 3
1AA1D0808814W400	193.00	*teich, plano, thalass, shrub*	4	10 mm	3 mm	BI 2-1
1AA1D0808814W400	193.75	*thalass, plano, teich, shrub?*	4	20 mm	4 mm	BI 2-3
1AA1D0808814W400	194.50	*thalass, plano, zoophycos, shrubcyl, teich*	5	22 mm	5-8 mm	BI 3-4
1AA1D0808814W400	196.00	*thalass, plano, zoophycos, teich*	4	20 mm	4-5 mm	BI 3-4
1AA1D0808814W400	197.50	*thalass, plano, teich*	3	18 mm	3-4 mm	BI 3
1AA1D0808814W400	198.25	*plano, teich, thalass, skolithos*	4	13 mm	4 mm	BI 3-4, BI 2
1AA1D0808814W400	199.00	*plano, teich, thalass, aren*	4	16 mm	2 mm	BI 4-5
1AA1D0808814W400	199.50	"	5	15 mm	2 mm	"
1AA1D0808814W400	200.00	"	4	12 mm	2-3 mm	"
1AA1D0808814W400	200.50	*plano, teich, thalass, gyro*	4	13 mm	2 mm	BI 4
1AA1D0808814W400	201.75	*plano, teich, thalass, gyro, aren, astero*	6	28 mm	2 mm	BI 4
1AA1D0808814W400	203.00	*plano, teich, thalass, gyro*	4	15 mm	less than 2 mm to 2 mm	BI 3-4
1AA1D0808814W400	203.75	*plano, teich, thalass, gyro*	4	15 mm	less than 2 mm to 2 mm	BI 3-4
1AA1D0808814W400	204.50	*plano, teich, thalass, microgyro*	4	11 mm	2-3 mm	BI 3-4
1AA1D0808814W400	205.25	*plano, teich, thalass, microgyro*	4	13 mm	2 mm	BI 4-3
1AA1D0808814W400	206.00	*plano, teich, thalass, gyro-microgyro, cylind, aren*	6	10 mm	less than 2mm	BI 3-4
1AA1D0808814W400	206.75	*plano, teich, thalass, gyro-microgyro, cylind, aren*	6	12 mm	2-3 mm	BI 4-3
1AA1D0808814W400	207.50	*plano, teich, thalass, gyro, cylind, aren*	6	31 mm	2 mm	BI 4
1AA1D0808814W400	208.25	*plano, teich, thalass, gyro, cylind, aren*	6	11 mm	2 mm	BI 4
1AA1D0808814W400	209.00	*plano, teich, thalass, gyro, cylind, aren*	6	13 mm	2 mm	BI 4
1AA1D0808814W400	209.75	*plano, teich, thalass, gyro*	4	11 mm	2 mm	BI 3-4
1AA1D0808814W400	210.50	*plano, gyro, thalass*	3	10 mm	2-3 mm	BI 1
1AA1D0808814W400	211.25	*plano, gyro, thalass*	3	20 mm	2 mm	BI 2-3
1AA1D0808814W400	212.00	*plano, teich, thalass, gyro*	4	20 mm	3 mm	BI 2-3

1AA100808814W400	213.50	*plano, teich, thalass, gyro*	4	10 mm	2 mm	BI 1
Well	1AA101108814W400					
1AA101108814W400	193.50	*thalass, chondrites, plano, skolithos, teich, astero*	7	13 mm	2-3 mm	BI 3-2
1AA101108814W400	195.00	*plano, thalass, skolithos, teich,*	6	10 mm	2 mm	BI 0-1, 3
1AA101108814W400	196.50	*plano, teich, skolithos*	5	7 mm	2 mm	BI 0-1
1AA101108814W400	198.00	*plano, cylind*	3	6 mm	2 mm	BI 0-1
1AA101108814W400	200.50	*plano, thalass, teich*	2	23 mm	3-4 mm	BI 1
1AA101108814W400	202.00	*plano, thalass, teich*	3	12 mm	3-4 mm	BI 1
1AA101108814W400	202.50	*plano, thalass, skolithos, teich*	3	22 mm	3-4 mm	BI 1
1AA101108814W400	203.00	*cylind, gyro-micro, plano, teich, thalass,*	4	10 mm	less than 2 to 2 mm	BI 3-4
1AA101108814W400	203.50	*cylind, gyro, plano, thalass*	6	20 mm	less than 2 to 2 mm	BI 4
1AA101108814W400	205.00	*teich, plano, cylind,*	4	8 mm	2 mm	BI 3-4
1AA101108814W400	206.25	*teich, plano, cylind, aren, thalass*	4	16 mm	2-3 mm	BI 2-3
1AA101108814W400	207.50	*plano, teich, cylind*	5	6 mm	2 mm	BI 2-3
1AA101108814W400	208.25	*plano, teich, thalassa*	3	13 mm	2 mm	BI 0-1
1AA101108814W400	209.00	*rhizo, teich, plano, chondrites, skolithos*	3	10 mm	2-3 mm	BI 2-3
1AA101108814W400	209.75	*teich, plano, chondrites, thalass, skolithos, astero,*	5	20 mm	2 mm	BI 2-3-4
1AA101108814W400	210.50	*chondrites, plano*	7	less than 2 mm	less than 2 mm	BI 0-1
1AA101108814W400	211.25	*plano, teich, thalassa*	2	11 mm	less than 2mm	BI 1, BI 3-4
1AA101108814W400	212.00	*plano, teich, gyro*	3	4 mm	2 mm	BI 2-3
1AA101108814W400	213.50	*plano, teich, gyro*	3	7 mm	2 mm	BI 2-3
Well	1AA102808814W400					
1AA102808814W400	188.75	–	-999	–	–	–
1AA102808814W400	189.50	–	-999	22 mm	6-7mm	BI 5-6, 0-1, 4-5
1AA102808814W400	192.50	*teich, diplo, thalassa, plano, astero, aren, skolithos*	6	30 mm	8 mm	BI 5-6
1AA102808814W400	194.00	*teich, thalass, plano, astero, diplo, aren*	7	20 mm	3-4 mm	BI 5-6
1AA102808814W400	194.75	*thalass, teich, plano, astero, skolithos, aren*	5	16 mm	4-5 mm	BI 5
1AA102808814W400	195.50	*gyro, cylind, plano, teich, thalas*	6	16 mm	2-3 mm	BI 4-5
1AA102808814W400	197.50	*cylind, gyro, plano, teich, thalass*	5	12 mm	2-3 mm	BI 3-4
1AA102808814W400	199.50	*cylind, gyro, plano,*	5	16 mm	3 mm	BI 4, BI 2

1AA102608814W400	201.50	*cylind, gyro, plano, teich, thalass*	4	16 mm	2 mm	BI 0-1, BI 4
1AA102608814W400	203.00	*gyro, cylind, plano, lingulichnus*	5	8 mm	less than 2 mm	BI 0-1, BI 3, BI 4
1AA102608814W400	203.75	*gyro, teich, cylind, plano, chohndrites?*	4	6 mm	less than 2mm	BI 5-4
1AA102608814W400	204.50	*teich, plano, zoo, thalass, gyro, rosselia*	5	11 mm	2 mm	BI 0-1, BI 3-5
1AA102608814W400	205.25	*gyro, skolithos, plano, teich, chondrites,*	6	nine mm	less less than 2	BI 1
1AA102608814W400	206.00	*zoo, teich, plano, chondrites, cylind*	6	10 mm	less than 2 mm	BI 2-3, BI 4-5
1AA102608814W400	206.75	*teich, plano, zoo, thalass, aren, cylind*	5	8 mm	less than 2 mm	BI 6-4
1AA102608814W400	207.50	*plano, teich, thalass, zoo, aren*	6	24 mm	2 mm	BI 2-3
1AA102608814W400	208.25	*plano, teich, cylind, rhizo, paleo, gyro, zoophycos?, thalass*	5	18 mm	2 mm	BI 3
1AA102608814W400	209.00	*plano, teich, cylind, rhizo, astero?*	8	10 mm	less less than 2	BI 2-3
1AA102608814W400	210.50	*plano, teich, cylind, rhizo*	5	10 mm	less less than 2	BI 2-3
1AA102608814W400	211.00	*plano, teich*	4	less than 2 mm	less less than 2 mm	BI 000-1
Well	**1AA072908814W400**					
1AA072908814W400	175.40	*chondrites*	1	<2	<2	BI 0-1
1AA072908814W400	176.80	*plano, chondrites*	2	<2	<2	BI 0-1
1AA072908814W400	177.90	*Th, As, Te, Pl, Ch Sk*	6	30	3	BI 3-4
1AA072908814W400	178.65	*Pl, Te, Dp, Pa, Sk, Ra, Ch, Sh, Zoo*	9	13	3	BI 3-4
1AA072908814W400	179.40	*Se, th, As, Sk, Ar, Te, Pl ?Oph*	8	15	3	BI 2-3
1AA072908814W400	179.90	*Pl, Te, Ar, Th, Sk*	5	15	2	BI 3
1AA072908814W400	180.40	*Pl, Te, Ar, Th, As, ?Ch Sk Sh* F,	8	18	2	BI 3
1AA072908814W400	181.15	*Th, Pl, Ch, Te Ar, Zoo*	6	18	3	BI 3
1AA072908814W400	181.90	*Th, Pl, Sh, Ar, As,*	6	11	2	BI 3
1AA072908814W400	182.40	*Th, Pl, Ch, Ar,*	3	12	3	BI 3
1AA072908814W400	182.90	*Se, Te, Pl, Th, As*	6	14	4	BI 3-4
1AA072908814W400	183.40	*Cy, Gy, Mgy, Te, Ar,*	6	13	<2	BI 5-6
1AA072908814W400	184.40	*Gy, Te, Sk, Th, Cy, Pl*	6	28	<2	BI 4-5
1AA072908814W400	185.40	*Cy, Mgy, Gy, Te, Sk, Ar Pl Th*	8	20	2	BI 4-5
1AA072908814W400	186.15	*Gy, Mgy, Pl, Te, Ar, Cy Th*	7	15	2	BI 1-2, BI 4
1AA072908814W400	186.90	*Gy, Pl, Cy,*	3	4	2	BI 1-2
1AA072908814W400	187.65	*Gy, Mgy, Cy, Th, Ar,*	5	24	3	BI 4
1AA072908814W400	188.40	*Mgy, Te, Ar, Gy, Cy*	6	20	<2	BI 4-5
1AA072908814W400	189.15	*Mgy, Gy, Te, Sk, Cy*	5	16	<2	BI 4-5

1AA072808814W400	189.90	Cy, Mgy, Gy, Pl, Sk, Te, Th Ar ?Pa	9	15	<2	BI 5
1AA072808814W400	191.30	Cy, Mgy, Gy, Pl, Sk, Te, Th Ar ?Pa	9	20	<2	BI 5
1AA072808814W400	192.05	Cy, Mgy, Gy, Pl, Sk, Te, Th Ar ?Pa	9	15	2-3 mm	BI 5
1AA072808814W400	192.80	Cy, Mgy, Gy, Sk, Th,	6	10	2	BI 3-4
1AA072808814W400	193.55	Cy, Mgy, Sk, Pl, Th	5	10	<2	BI 2-3
1AA072808814W400	194.30	Cy, Mgy, Pl, Te, Th,	6	11	<2	BI 1-2
1AA072808814W400	195.05	Cy, Mgy, Pl	3	5	<2	BI 0, 1 local
1AA072808814W400	195.80	Cy, Mgy, Pl	3	4.5	<2	BI 0, 1 local
1AA072808814W400	197.20	Cy, Pl	2	<2	<2	BI 0-1
1AA072808814W400	198.70	0	0	0	0	0
Well	1AB110609013W400					
1AB110609013W400	187.10	Pl, Ch, Te	3	4	less than	BI 1-2
1AB110609013W400	187.85	Pl, Th, Ch, As, Te,	5	20	<2	BI4
1AB110609013W400	188.60	As, Ch, Sh, Sk, Th,	6	11	2	BI 3
1AB110609013W400	189.35	Rs, Sh, As, Pl, Sk,	5	5	3	BI 3
1AB110609013W400	190.10	Rs, Pl, Sk, Sh,	4	6	3	BI 2
1AB110609013W400	191.60	Sh, Sk, Pl, As	1	6	3	BI 0-1
1AB110609013W400	193.10	Sh, Sk	2	<2	<2	BI 0-1
1AB110609013W400	194.60	Sh, Pl	2	<<2	<2	BI 0-1
1AB110609013W400	196.10	Th, Pl, Sh	3	15	<2	BI 0-1
1AB110609013W400	197.60	Sh, Pl, Th	3	9	<2	BI 0-1
1AB110609013W400	199.10	Pl, Sk, Th, Sh	2	<2	<2	BI 0-1
1AB110609013W400	200.50	Pl, Sk, Th, Sh	4	15	5	BI 1
1AB110609013W400	202.00	Pl, Th	2	11	2	BI 1
1AB110609013W400	203.40	Pl, Sh, Sk, Th	4	14	<2	BI 0-1
1AB110609013W400	204.15	Sk, Pl	2	3	<2	BI 0-1
1AB110609013W400	204.90	Pl, Sh	2	<2	<2	BI 0-1
1AB110609013W400	205.65	Pl, Th, Sh	3	11	<2	BI 1
1AB110609013W400	206.40	Pl, Te, Sh, Th	4	20	2	BI 1-2
1AB110609013W400	207.90	As, Pl, Th, Te	4	11	2	BI 2
1AB110609013W400	208.65	As, Pl, Th, Rz, Zoo/Sc, Sh	3	10	3	BI 2
1AB110609013W400	209.40	Te, Sc, Pl, As, Th, Ch, Sk, Sh	8	28	3	BI 4 to 2
1AB110609013W400	210.15	As, Th, Pl, Te, Ch, Sh	6	18	4	BI 4
1AB110609013W400	210.90	As, Pl, Te, Sk, Th, Sc, Ch, ?Gy	8	28	5	BI 4
1AB110609013W400	211.65	As, Pl, Th, Rz, Zoo/Sc, Sh	6	18	4	BI 4-5
1AB110609013W400	212.40	As, Sc, Th, Sk, Pl, Rz, Sh,	7	28	6	BI 4-5
1AB110609013W400	213.15	Th, Sh, Te, Sc, Pl, Sk, Rz	7	17	4	BI 5
1AB110609013W400	213.90	As, Pe, Sh, Th, Pl,	6	27	4	BI 4
1AB110609013W400	214.65	Th Pl, Sk, As, Sh, Sc/Zoo	6	18	6	BI 4-5

1AB110609013W400	215.40	*Sk, Th, Pl, Sh, As,*	5	20	4	BI 4
1AB110609013W400	216.15	*As, Sk, Pl, Ch, Th, Te, Sh, Para, Sc*	9	10	3	BI 5
1AB110609013W400	216.90	*Pa, As, Pl, Pa, Sh, Th, Sc*	7	21	3	BI 4
1AB110609013W400	218.40	*As, Sk, Pl, Para, Sh,*	6	11	4	BI 4
Well	1AA100709013W400					
1AA100709013W400	187.75	*As, Ch, Th, Pl, Sk, Dp, Te*	7	20	3	BI 4
1AA100709013W400	188.50	*As, Rs,Sk*	3	2	2	BI 1
1AA100709013W400	190.00	*Rs, As, Pl, Sk Rs*	5	2	2	BI 1
1AA100709013W400	190.90	*Rs, Pl, Sh,*	3	8	2	BI 2
1AA100709013W400	191.80	*Ch, Pl, Th, Rs, Te, Sh*	6	15	3	BI 2
1AA100709013W400	192.55	*As, Rs, sh, Sk, Ch, Pl, Zoo,*	7	20	3	BI 3
1AA100709013W400	193.30	*Ch, As, Pl, Th, Zoo, Sk, Sh,*	7	15	3	BI 3
1AA100709013W400	194.05	*Ch, Ar, As, th, Pl, Sh, Rs,*	7	22	3	BI 4-3
1AA100709013W400	194.80	*Ch, As, Pl, Th, Zoo, Te,Ar*	7	23	3	BI 4-3
1AA100709013W400	195.55	*As, Th, Zoo, Ch, Sk,*	6	23	4	BI 4
1AA100709013W400	196.30	*As, Rs, Th, Pl, Ch, Zoo, Sh, Sc, Rz,*	9	42	8	BI 4
1AA100709013W400	197.05	*As, Rs, Zoo, Rz, Th, Te, Pl, Ch,*	8	50	6	BI4
1AA100709013W400	197.80	*As, Rs, Ch, Te, Th, Pl, Sc, Sh, Ar, Zoo,*	10	20	4	BI 4
1AA100709013W400	198.55	*Rs, Ch, Pl, Th, As, Rz, Sk, Sc, Sh*	9	32	3	BI 4
1AA100709013W400	199.30	*As, Th, Pl, Rs, Ch, Zoo, Sc*	7	20	4	BI 5-4
1AA100709013W400	200.05	*Th, As, Zoo, Ch, Sc, Pl, Te,*	7	23	5	BI 5
1AA100709013W400	200.80	*As, Th, Pl, Ch, Sc, Te, Sk, Rz, Zoo*	9	30	6	BI 5
1AA100709013W400	201.55	*As, Th, Ch, Zoo, Pl, Sc, Sk, Dp*	8	27	6	BI 5
1AA100709013W400	202.30	*As, Sc, Th, Pl, Ch, Sh, Rz,*	7	30	7	BI 5
1AA100709013W400	203.05	*As, Ch, Th, Pl, Te, Sc*	6	20	4	BI 5
1AA100709013W400	203.80	*As, sc, Pl, Th, Ch, Te,*	6	18	5	BI 4-5
1AA100709013W400	204.55	*As, Th, Pl, Te, Ch, Rz, Sc*	5	28	6	BI 4-5
1AA100709013W400	205.30	*As, Th, Pl, Ch, Sc,*	6	30	6	BI 4
1AA100709013W400	206.05	*Te, Th, Ar, As, Pl, ?Ch, Zoo*	7	20	5	BI 4
1AA100709013W400	206.80	*As, Th, sk, Pl, Sh, ch, Te, Zoo*	8	32	4	BI 3-4
1AA100709013W400	207.40	*Th, Pl, Ch, Te, Zoo,*	6	20	3	BI 3-4
1AA100709013W400	208.00	*Th, Pl, Rz, Ch, As,*	6	21	3	BI 3-4

Well	1AA100809013W4 00					
1AA100809013W400	194.25	*Ch, Phy*	2	<2	<2	BI 0-1
1AA100809013W400	195.00	*Ch, Zoo, Phy, Pl*	4	2	<2	BI 0-1
1AA100809013W400	196.50	*Th, Pl, Ch, SK,*	4	11	<2	BI 2
1AA100809013W400	197.00	*Pl, Sk, Ch, Th, Te,*	6	12	2	BI 3-4
1AA100809013W400	197.50	*Pl, Th, Rs*	2	3	2	BI 2-3
1AA100809013W400	198.50	*Pl, Sk, Sh, Rs*	4	3	2	BI 2-3
1AA100809013W400	199.50	*Pl, Sk, Sh, Te, Rs,*	5	8	2	BI 2-3
1AA100809013W400	200.20	*Rs, As, Pl, Sh*	4	3	2	BI 3
1AA100809013W400	200.90	*As*	1	3	2	BI 3
1AA100809013W400	201.60	*Sh, Rs, Pl, Sk,Th*	5	4	2	BI 3
1AA100809013W400	202.30	*As, Rs, Sh, Ch, Pl, Te, Sk,*	7	7.5	3	BI 4-5
1AA100809013W400	203.10	*Ch, As, Rs, Pl, Te, Sk, Th, SH,*	8	10	4	BI 6
1AA100809013W400	203.90	*Ch, Th, Rs, As, Zoo, Pl, Te, Sk, Sh,*	9	11	4	BI 6
1AA100809013W400	204.60	*Ch, Zoo, Pl, Th, Te, Sk, As, Sh, Rs*	9	20	5	BI 6
1AA100809013W400	205.30	*Pl, Zoo, Th, Ch, Te, Rs, Sk, Sh, As*	9	18	5	BI 6
1AA100809013W400	205.50	*Pl, Ch, Th*	3	14	2	BI 5-6
1AA100809013W400	206.25	*Zoo, Ch, Pl, Th, Rs, Ar, Sh,*	7	18	3	BI 6
1AA100809013W400	207.00	*Zoo, Pl, Ch, Th, Rs, Ps, Sh, As*	8	13	3	BI 6
1AA100809013W400	207.75	*Th, Ch, Zoo, Pl, Sk,*	5	14	3	BI 5
1AA100809013W400	208.50	*Th, Ch, Zoo, Pl, As, Ps, Rs*	7	21	3	BI 5-6
1AA100809013W400	209.25	*Zoo, Ch, As, Rs, Pl, Th, Sc,*	7	19	3	BI 6
1AA100809013W400	210.00	*Ch, Zoo, Th, Pl, As, Te , Sk*	7	22	3	BI 6
1AA100809013W400	210.75	*Zoo, Ch, Pl, Th, Sh, Rs, Te. As*	8	17	2	BI 5-6
1AA100809013W400	211.50	*Pl, Zoo, Ch, Th, Sh ,*	6	19	2	BI 6
1AA100809013W400	212.25	*Zoo, Ch, Pl, Ps, As, Te, Sk, Th, Rs,*	8	11	4	BI 6
1AA100809013W400	213.00	*Ch, Zoo, Pl, Ps, As, Sk, Th,*	7	7	4	BI 5-6
1AA100809013W400	213.80	*Rs,Pl, Ch, Sk, As, Te, Th,*	8	10	2	BI 4-5
1AA100809013W400	214.60	*Pl, Ch, Sk, As, Ps, Te, Th, Rs*	6	10	2	BI 4-5
1AA100809013W400	215.20	*Pl, Th, Ps, ch, Sc,*	5	18	3	BI 3-4
1AA100809013W400	215.80	*Pl, Th, Ch, As, Ps, Zoo, Rs*	7	19	3	BI 3-4
1AA100809013W400	216.60	*Pl, As, Ar, Sk, Rh, Te, Rs, Zoo, th, Ch*	9	18	3	BI 4
1AA100809013W400	217.40	*Pl, Th, As, Dp, Sh, sk*	6	12	3	BI 4
1AA100809013W400	217.95	*Pl, Th, Sk, Sh*	4	14	3	BI 4

1AA100809013W400	218.50	*Pl, Th, As, Sh*	4	17	3	BI 4
Well	1AA160109014W400					
1AA160109014W400	184.50	*Sh, sk, Ch, Te, Pl,*	5	6	-	-
1AA160109014W400	185.25	*Te, Pl, Ch, Sk*	4	10	-	-
1AA160109014W400	186.00	*0*	0	0	0	0
1AA160109014W400	187.00	*0*	0	0	0	0
1AA160109014W400	188.50	*Sk, Pl, Pa, Th, Ch, As Te*	7	23	2	bi 2-3
1AA160109014W400	190.35	*0*	0	0	0	0
1AA160109014W400	192.20	*zoo*	1	2	2	BI 0-1
1AA160109014W400	193.70	*0*	0	0	0	0
1AA160109014W400	195.20	*Zoo*	1	2	2	BI 0-1
1AA160109014W400	196.70	*0*	0	0	0	0
1AA160109014W400	198.20	*0*	0	0	0	0
1AA160109014W400	199.80	*PL*	1	<2	<2	BI 0-1
1AA160109014W400	201.10	*Pl*	1	<2	<2	BI 0-1
1AA160109014W400	201.80	*Pl*	1	<2	<2	BI 0-1
1AA160109014W400	204.20	*Pl*	1	<2	<2	BI 0-1
1AA160109014W400	205.00	*Pl*	1	<2	<2	BI 0-1
1AA160109014W400	205.80	*As, Te, Th, Pl, Rz, Sc, Dp, Zoo, Ar, ch*	10	25	7	BI 5
1AA160109014W400	206.50	*As, Th, Rz, Ch, Pl, Te, AR, Sc zoo*	9	13	2	BI 5
1AA160109014W400	207.20	*Ar, As, Th, Rz, Sk, Sc, Te*	7	24	4	BI 5
1AA160109014W400	208.60	*Rz, Th, Sk, Pl, As, Te, ?Ch, sc, Dp*	9	23	7	BI 4-5
1AA160109014W400	210.10	*Th, Pl, Rz, As, Sc,*	6	20	7	BI 4-5
1AA160109014W400	210.85	*Th, Pl, As, Rz, Sc, Sh*	6	40	5	BI 4-5
1AA160109014W400	211.60	*Th, Pl, As, Rz, Te*	5	35	4	BI 4-5
1AA160109014W400	212.35	*Pl, Sk, Ar, Te, Rz, Th*	6	13	5	BI 4-5
1AA160109014W400	213.10	*Pl, Pa, Th, Te, Rz*	5	35	6	BI 4-5
1AA160109014W400	213.85	*Te, Dp, Th, Sc, Pl, Sh*	6	28	6	BI 4
1AA160109014W400	214.60	*Te, Pl, As, Th, Sh, Pa*	6	12	3	BI 4
1AA160109014W400	215.40	*Pl, Th, As*	3	10	3	BI 4
1AA160109014W400	216.20	*Pl, Sk, Th, Pa, As*	5	31	3	BI 4
1AA160109014W400	217.80	*Pa, Pl, Sk, Sh, Th*	5	13	3	BI 4
1AA160109014W400	218.00	*Pa/Th, Sk, Pl*	3	50	6	BI 4
Well	1AA100809014W400					
1AA100809014W400	177.75	-	5	14 mm	2-3 mm	BI 5
1AA100809014W400	178.50	-	6	19 mm	4 mm	BI 4
1AA100809014W400	179.00	*plano, thalasa, astero*	6	11.5 mm	4 mm	BI 3
1AA100809014W400	179.50	*plano, astero, thalasa, skolithos*	3	14 mm	3-4 mm	BI 2-3
1AA100809014W400	180.00	*plano, thalasa*	4	13 mm	2 mm	BI 1-2
1AA100809014W400	180.75	*Plano, thalasa,*	2	13 mm	2 mm	BI 1
1AA100809014W400	181.50	*plano, paleo*	3	6 mm	3 mm	BI 1
1AA100809014W400	182.50	*plano, paleo, thalasa, astero*	2	12 mm	3 mm	BI 1

1AA100809014W400	183.50	*plano, astero*	4	10 mm	2 mm	BI 4-5
1AA100809014W400	184.25	*astero, plano, thalass, aren, skolithos*	2	10 mm	2 mm	BI 5
1AA100809014W400	185.00	*astero, plano, thalass, paleo, skolithos*	5	18 mm	2-3 mm	BI 4-5
1AA100809014W400	185.75	*astero, plano, thalass, paleo, skolithos*	5	18 mm	2-3 mm	BI 4-5
1AA100809014W400	186.50	*As, Pl, Th, Ch*	5	20 mm	2-3 mm	BI 4-5
1AA100809014W400	187.25	*As, Pl, Th*	4	14 mm	3 mm	BI 3-4
1AA100809014W400	188.00	*Pl*	3	9 mm	2 mm	BI 0-1
1AA100809014W400	188.75	*Pl, Th, Ch*	1	14 mm	2 mm	BI 2
1AA100809014W400	189.50	*Pl, Th, Sk, Cy*	2	12 mm	2 mm	BI 2-3
1AA100809014W400	195.50	*Pl, Sk*	4	4 mm	less than 2 mm	BI 1
1AA100809014W400	197.00	*Sk, Pl, Th*	2	10 mm	2 mm	BI 1
1AA100809014W400	201.50	*Sk, Pl*	3	2 mm	less than 2 mm	BI 1
1AA100809014W400	203.00	*Sk, Pl*	2	6 mm	less than 2 mm	BI 1-2
Well	**1AA161109014W400**					
1AA161109014W400	173.50	*Te, Ch*	2	7	<2	BI 0-1
1AA161109014W400	176.50	*Sk, Th, Ch, Pl, As,*	5	24	2	BI 3-4
1AA161109014W400	178.00	*As, Pl, Sk, Ro,*	2	3	<2	BI 2
1AA161109014W400	179.50	*Para, Pl, Sk*	3	7	<2	BI 1
1AA161109014W400	181.00	*Sh*	1	<2	<2	BI 0-1
1AA161109014W400	182.50	*0*	0	0	0	0
1AA161109014W400	184.00	*0*	0	0	0	0
1AA161109014W400	185.10	*Sh*	1	<2	<2	BI 0-1
1AA161109014W400	186.60	*0*	0	0	0	0
1AA161109014W400	187.70	*Sh*	1	<2	<2	BI 0-1
1AA161109014W400	189.10	*Th*	1	20	-	BI 0-1
1AA161109014W400	190.50	*Pl, Th*	2	10	2	BI 1
1AA161109014W400	191.80	*Te, Pl, Sk*	3	27	<2	BI 0-1
1AA161109014W400	192.40	*Pl, Th, Te, As, Sk, Dp*	6	28	3	BI 6
1AA161109014W400	193.00	*Pl, Sk, Cy*	3	3	<2	BI 2-3
1AA161109014W400	193.65	*Pl, Sk, Cy, Mgy*	4	3	<2	BI 3
1AA161109014W400	194.30	*Pl, Sk, Cy,*	3	6	<2	BI 3
1AA161109014W400	195.55	*Sk, Pl, Th, Non-M*	4	5.5	<2	BI 2-3
1AA161109014W400	196.80	*Pl, Non-m*	2	4	<2	BI 2-3
1AA161109014W400	198.05	*Pl, Sk, Ar?, Te, Non-marine*	4	10	<2	BI 3
1AA161109014W400	198.30	*Sk, Te, Non-m*	3	10	<2	BI 3
1AA161109014W400	198.80	*Pl, Sk, Non-m*	3	4	<2	BI 1-2
1AA161109014W400	199.90	*Pl, Th, non-m*	3	10	<2	BI 1-2
1AA161109014W400	201.00	*0*	0	0	0	0
Well	**1AA081209014W400**					
1AA081209014W400	181.10	*Ch, Rz, Sk, Sh, Th, Pl, As, Zoo*	8	30	5	BI 4
1AA081209014W400	182.80	*As, Sh, Th, Ch Sk, Te*	6	30	2	BI 3
1AA081209014W400	184.30	*Sh, Pa, Sk,*	3	10	2	BI 2

1AA081209014W400	187.20	*Sh, Th*	2	20	<2	BI 2
1AA081209014W400	188.70	*Sh*	1	<2	<2	BI 0-1
1AA081209014W400	190.20	*Sh, Pl*	2	<2	<2	BI 0-1
1AA081209014W400	191.70	*Sh*	1	<2	<2	BI 0-1
1AA081209014W400	193.20	*Sh, sk*	2	<2	<2	BI 0-1
1AA081209014W400	193.95	*Pl, Sh*	2	2	<2	BI 0-1
1AA081209014W400	194.70	*Th, Sh, Sk*	3	17	<2	BI 1
1AA081209014W400	195.45	*Pl, Th*	2	31	2	BI 1
1AA081209014W400	196.20	*Pl, Sh*	2	2	<2	BI 0-1
1AA081209014W400	197.60	*Pl, Sh*	2	6	<2	BI 1
1AA081209014W400	199.10	*Pl, TH, Sh*	3	13	2	BI 1
1AA081209014W400	199.85	*Pl, Sh*	2	<2	<2	BI 0-1
1AA081209014W400	200.60	*Pl, Sh, Oph, Th*	4	10	2	BI 1
1AA081209014W400	201.20	*Pl, Sh, Oph*	3	5	<2	BI 0-1
1AA081209014W400	201.80	*Sh*	1	<2	<2	BI 0-1
1AA081209014W400	202.70	*Pl, Sk, Sh*	3	3	<2	BI 1
1AA081209014W400	203.60	*Pl, Th, Sh*	3	13	<2	BI 1
1AA081209014W400	204.35	*Pl, Sh*	1	6	<2	BI 0-1
1AA081209014W400	205.10	*Sk, Sh, Rs,*	3	6	<2	BI 1
1AA081209014W400	205.85	*Pl, Sk, Th,*	3	10	<2	BI 0-1
1AA081209014W400	206.60	*Sk, Sh*	2	<2	<2	BI 0-1
1AA081209014W400	207.30	*Pl, Non-m*	2	3	<2	BI 1
1AA081209014W400	208.00	*0*	0	0	0	0
Well	**1AA141209014W400**					
1AA141209014W400	174.50	*Te, Phy*	2	4	<2	BI 1
1AA141209014W400	176.00	*Pl, Ch, Sk*	3	5	<2	BI 2
1AA141209014W400	176.65	*Ch, Th, Pl, Sk, As, Sh*	6	12	2	BI 3
1AA141209014W400	177.30	*Sk, Sh, Th*	3	7	<2	BI 1
1AA141209014W400	178.05	*Sk, Sh*	2	2	<2	BI 1
1AA141209014W400	178.80	*Sk, Sh*	2	3	<2	BI 1
1AA141209014W400	179.55	*Sh, Para, Sk*	3	3	<2	BI 1
1AA141209014W400	180.30	*Pl, Sk*	2	3	<2	BI 1
1AA141209014W400	181.60	*Sh, Sk*	2	<2	<2	BI 0-1
1AA141209014W400	182.60	*Sh, Sk*	2	<2	<2	BI 0-1
1AA141209014W400	184.10	*sh*	1	<2	<2	BI 0-1
1AA141209014W400	185.60	*0*	0	0	0	0
1AA141209014W400	187.80	*Sk*	1	<2	<2	BI 0-1
1AA141209014W400	188.70	*Pl, Sh*	2	<2	<2	BI 0-1
1AA141209014W400	190.10	*Sc*	1	12	<2	BI 0-1
1AA141209014W400	191.70	*Pl, Sh*	2	<2	<2	BI 0-1
1AA141209014W400	193.00	*Pl, Sk, Sh, TH, Sc*	5	10	<2	BI 1
1AA141209014W400	194.30	*Pl*	1	<2	<2	BI 0-1
1AA141209014W400	195.80	*Pl, Th*	2	14	<2	BI 0-1
1AA141209014W400	197.30	*Sh, Sk*	2	<2	<2	BI 0-1
1AA141209014W400	198.80	*Pl*	1	3	<2	BI 0-1
1AA141209014W400	199.55	*Sk*	1	<2	<2	BI 0-1
1AA141209014W400	200.30	*Sh, Pl*	2	<2	<2	BI 0-1
1AA141209014W400	201.05	*Sh, Pl*	2	3	<2	BI 0-1
1AA141209014W400	201.80	*Sh, Th, Ar*	3	10	<2	BI 0-1
1AA141209014W400	202.15	*Sh*	1	<2	<2	BI 0-1
1AA141209014W400	202.50	*Pl, Sk, Non-m*	3	3	<2	BI 1

Well	1AA041309014W400					
1AA041309014W400	170.70	*Ch*	1	<2	<2	BI 0-1
1AA041309014W400	172.20	*Ch, Pl, Te, Ae*	4	3	<2	BI 0-1, BI 2
1AA041309014W400	173.70	*Sk, Re, Ch, Zoo, Dp, Pl, Th*	7	13	2	BI 3
1AA041309014W400	175.20	*Pl, Sk, Sh, Te*	4	5	2	BI 0-2
1AA041309014W400	178.20	*Sk, Sh*	2	<2	<2	BI 0-1
1AA041309014W400	179.20	*Sh*	1	<2	<2	BI 0-1
1AA041309014W400	181.20	*Sh*	1	<2	<2	BI 0-1
1AA041309014W400	182.70	*Pl*	6	<2	<2	BI 0-1
1AA041309014W400	184.20	*Pl*	1	2	<2	BI 0-1
1AA041309014W400	185.60	*Sh*	1	<2	<2	BI 0-1
1AA041309014W400	187.00	*Sh, Pl, As, Te*	2	2	<2	BI 0-1
1AA041309014W400	188.60	*Pl, Th, Sh*	3	13	<2	BI 0-1
1AA041309014W400	191.10	*Sh*	1	<2	<2	BI 0-1
1AA041309014W400	191.70	*SH*	1	<2	<2	BI 0-1
1AA041309014W400	193.10	*Sh, Pl, Oph*	3	7	<2	BI 0-1
1AA041309014W400	193.90	*Pl, Sh*	2	<2	<2	BI 0-1
1AA041309014W400	194.70	*Sk, Pl, Sh*	3	4	<2	BI 0-1
1AA041309014W400	195.35	*Oph, Sk, Sh, Pl*	4	8	<2	BI 0-1
1AA041309014W400	196.00	*Sh, Pl*	2	2	<2	BI 0-1
1AA041309014W400	196.75	*Sh*	1	4	<2	BI 0-1
1AA041309014W400	197.50	*Te, Pl, non-m, Sh*	4	7	<2	BI 1
Well	**1AA121309014W400**					
1AA121309014W400	170.25	*Th, Ch, Sh, Pl,*	4	10	<2	BI 2
1AA121309014W400	171.00	*Sk, Pl, Sh, Te, As, Th, Ch,*	4	20	4	BI 1, 3
1AA121309014W400	171.90	*Sh, Sk, Pl,*	3	2	<2	BI 1
1AA121309014W400	172.80	*Sh, Re, Pl, Sk, Ar*	5	4	<2	BI 2
1AA121309014W400	173.55	*Re, Sh, Sk, Pl*	4	4	<2	BI 2
1AA121309014W400	174.30	*Sh, Sk, Ch, Re*	4	6	<2	BI 2
1AA121309014W400	175.05	*Sh, Re, Pl, Th,*	4	11	<2	BI 3
1AA121309014W400	175.80	*Sh, Sk, Ch,*	3	2	<2	BI 2
1AA121309014W400	176.55	*Ra, Pl, Th, Sh, Ch, Sk, Ar,*	7	18	4	BI 3
1AA121309014W400	177.30	*Pl, Th, Sk, Ch, As, Sh*	6	20	4	BI 3
1AA121309014W400	178.05	*Pl, Th, Re, As, Sh, Ch*	6	12	3	BI 3
1AA121309014W400	178.80	*Pl, Th, Sk, Re, Sh*	5	22	3	BI 3
1AA121309014W400	179.50	*Pl, Te, As, Th, Ra*	2	14	3	BI 3
1AA121309014W400	180.20	*Pl, Sk, Ra, Sh*	3	6	3	BI 3
1AA121309014W400	181.00	*Pl, Th, Te, Sh*	4	17	2	BI 2
1AA121309014W400	181.80	*Sk, Pl, Th, Sh*	4	13	2	Bi 1
1AA121309014W400	182.55	*Sh, Oph, Sk, ?pa*	4	7	<2	BI 0-1
1AA121309014W400	183.30	*Sh, Pl*	2	4	<2	BI 0-1
1AA121309014W400	184.05	*Sk, Sh, Re*	3	5	<2	BI 0-1
1AA121309014W400	184.80	*Pl, Sh*	2	4	<2	BI 0-1
1AA121309014W400	185.55	*Sh, Pl, Th*	3	18	<2	BI 0-1
1AA121309014W400	186.30	*Sh, Pl*	2	2	<2	BI 0-1
1AA121309014W400	187.05	*Sk, Sh*	2	2	<2	BI 0-1

1AA121309014W400	187.80	*Pl, Th, Sh*	3	9	<2	BI 0-1
1AA121309014W400	188.55	*Pl, Th, Sh*	3	8	3	BI 1
1AA121309014W400	189.30	*Rs, Sh, Th, Pl*	4	20	2	BI 1
1AA121309014W400	190.05	*Sh, Pl*	2	3	<2	BI 1
1AA121309014W400	190.80	*Sh, Pl*	2	2	<2	BI 1
1AA121309014W400	191.55	*Sh, Pl, Sk*	3	3	<2	BI 0-1
1AA121309014W400	192.30	*Sh, Pl*	2	3	< 2	BI 0-1
1AA121309014W400	192.90	*Pl, Sh*	2	4	<2	BI 1
1AA121309014W400	193.50	*Pl, Th, Sh, Sk*	4	8	2	BI 1
1AA121309014W400	194.25	*Th, Pl, Sh*	3	10	<2	BI 1
1AA121309014W400	195.00	*Sh*	1	<2	<2	BI 0-1
Well	1AA141409014W400					
1AA141409014W400	167.00	*Ch, Te*	2	<2	<2	BI 0-1
1AA141409014W400	168.50	*Ch, Pl, Th*	3	9	<2	BI 2-1
1AA141409014W400	170.00	*Sh, Ch, Sk, As, Th, Pl, Te*	7	23	3	BI 3-4
1AA141409014W400	171.50	*Sk, Pl, Sh,As, Ch, RS*	6	4	<2	BI 3-4
1AA141409014W400	173.00	*Sh, Sk, Pl, As*	5	8	<2	BI 2
1AA141409014W400	174.50	*Sh, Sk, Pl, Th, Rs, As*	6	10	2	BI 1
1AA141409014W400	176.00	*As, Sh, Sk*	3	2	<2	BI 0-1
1AA141409014W400	177.50	*Sh, As*	2	<2	<2	BI 0-1
1AA141409014W400	178.20	*Sh, Sc*	2	3	<2	BI 0-1
1AA141409014W400	179.80	*Pl, Sh, Sc*	3	9	<2	BI 0-1
1AA141409014W400	180.50	*Sk, Sh,*	2	<2	<2	BI 0-1
1AA141409014W400	182.00	*Pl, Th*	2	9	2	BI 0-1
1AA141409014W400	183.50	*Sk, Pl,*	2	2	<2	BI 0-1
1AA141409014W400	185.00	*Sh, Rs, Sk*	3	2	<2	BI 1
1AA141409014W400	186.50	*Sh, Sk*	2	<2	<2	BI 0-1
1AA141409014W400	188.00	*Rs, Sh, Sk*	3	2	<2	BI 1
1AA141409014W400	189.50	*Sh, Pl*	2	<2	<2	BI 0-1
1AA141409014W400	191.00	*Sk, Sh, Pl*	3	<2	<2	BI 0-1
1AA141409014W400	192.50	*Th, Te, Sh, Pl, As, Sk*	6	17	2	BI 1
1AA141409014W400	193.50	*Th, Te, Pl, Sh, Sk*	5	12	<2	BI 1
Well	1AA151409014W400					
1AA151409014W400	167.50	*Ch*	1	<2	<2	BI 0-1
1AA151409014W400	167.75	*Sk, Ch*	2	<2	<2	BI 1
1AA151409014W400	168.00	*Pl, Th, Te, Ch, SH*	5	20	<2	BI 3
1AA151409014W400	169.50	*Sk, Pl, Ch, Th, As*	5	17	2	BI 3
1AA151409014W400	171.00	*Pl, Th, Sk Sh, Ar, Te, Pa*	7	18	2	BI 2
1AA151409014W400	172.50	*Pl, Th, Sk, Sk*	4	8	2	BI 2
1AA151409014W400	174.00	*As, Rs, Pl, Sh,*	4	6.5	3	BI 3
1AA151409014W400	175.50	*Pl, Sh, Rs*	3	2	<2	BI 2
1AA151409014W400	177.00	*Pl, Sh*	2	6.5	<2	BI 0-1
1AA151409014W400	178.50	*Sh*	1	<2	<2	BI 0-1
1AA151409014W400	180.00	*As Sh*	2	2	<2	BI 1
1AA151409014W400	183.50	*Sh, Sk, Oph, As*	4	9	2	BI 2
1AA151409014W400	184.00	*Sh, Rs, Rz,*	3	6	2	BI 2
1AA151409014W400	184.70	*Th, Sh*	2	14	<2	BI 0-1
1AA151409014W400	185.40	*Sh, Th, Pl*	3	8	<2	BI 0-1

1AA151409014W400	186.00	*Sk, Sh, Pl*	3	5	<2	BI 0-1
1AA151409014W400	187.40	*Pl, Th, Sh, Te*	4	25	2	BI 1
1AA151409014W400	188.15	*Pl, Th*	2	22	2	BI 1
1AA151409014W400	188.90	*Sk, Sh*	2	2	<2	BI 0-1
1AA151409014W400	190.40	*Oph, Sh*	2	33x10	<2	BI 0-1
1AA151409014W400	191.90	*Sk, Oph, Sh*	3	4x12	<2	BI 0-1
1AA151409014W400	192.80	*Oph, Sh*	2	10	<2	BI 0-1
1AA151409014W400	193.70	*Pl, Sk, Th, Sh*	4	8	<2	BI 0-1
1AA151409014W400	195.10	*Sh*	1	<2	<2	BI 0-1
Well	**1AA161409014W400**					
1AA161409014W400	166.80	*Pl, Ch*	2	4	<2	BI 1
1AA161409014W400	167.55	*Ch, Te, Pl, Th, Sk*	5	23	2	BI 3-2
1AA161409014W400	168.30	*Sk, Pl, Th, Sh*	3	38	3	BI 4
1AA161409014W400	169.05	*Sk, Sh, Pl, Para, Rs,*	5	10	<2	BI 4
1AA161409014W400	169.80	*Sh, Sk, Pl, Para,*	4	10	2	BI 1-2
1AA161409014W400	170.55	*Sk, Sh*	2	3	<2	BI 1
1AA161409014W400	171.30	*Sk, Rs, Pl, Sh*	4	4	<2	BI 3
1AA161409014W400	172.05	*Sh, Sk, Rs,*	3	5	2	BI 3
1AA161409014W400	172.80	*Sk, Sh, As,*	3	4	<2	BI 2
1AA161409014W400	173.55	*Pl, As, Sh, Sk, Rs*	5	4	2	BI 3
1AA161409014W400	174.30	*Pl, Rs, Sk, Sh, Th, Pa*	6	11	2	BI 3
1AA161409014W400	175.15	*Rs, Th, Sh, Pl, Sk*	5	9	<2	BI 2
1AA161409014W400	176.00	*Pl, Te, Sh, Th*	4	18	2	BI 2
1AA161409014W400	177.40	*Sk, Te, Th, Sh, Ch*	5	18	<2	BI 2
1AA161409014W400	178.90	*Sk, Sh, Rs, Th, Pl*	5	9	<2	BI 2
1AA161409014W400	180.40	*Sk, Sh, Pl*	3	3	<2	BI 1
1AA161409014W400	181.90	*Sh*	1	2	<2	BI 1
1AA161409014W400	182.60	*Sh, Sk, Th*	3	10	<2	BI 1
1AA161409014W400	183.30	*Sh, As*	2	<2	<2	Bi 1
1AA161409014W400	184.80	*As, Sh*	2	<2	<2	BI 1
1AA161409014W400	185.55	*Sh, Te*	2	5	<2	BI 1
1AA161409014W400	186.30	*Sh, Te, Pl, Sk*	4	8	<2	BI 1
1AA161409014W400	187.90	*Sh, SK, Pl, Rs, Th*	5	10	<2	BI 1
1AA161409014W400	188.70	*Sk, Sh, Pl*	3	3	<2	BI 1
1AA161409014W400	189.50	*Sk, Sh, Te, Pl, Th*	4	10	2	BI 1
1AA161409014W400	190.25	*Sk, Th, Sh*	3	12	<2	BI 0-1
1AA161409014W400	191.00	*Sh, Pl, Th*	3	12	2	BI 0-1
1AA161409014W400	191.75	*Sh, Pl, Sk*	3	5	<2	BI 0-1
1AA161409014W400	192.50	*Sh, Pl, Sk*	3	6	<2	BI 0-1
Well	**1AA102209014W400**					
1AA102209014W400	166.75	*Ch*	1	<2	<2	BI 0-1
1AA102209014W400	167.50	*Pl, Ch, Te, Th*	2	17	<2	BI 3-2
1AA102209014W400	168.20	*Sk, Ch, As, Pl, TH,*	5	40	2	BI 4
1AA102209014W400	168.90	*Pl, Sk, As, Te, Sh, Rz*	6	6	2	BI 2-3
1AA102209014W400	170.40	*As, Pl, Sk, Sh, Para, Th, Te*	7	20	3	BI 3
1AA102209014W400	171.90	*Rs, Sc, As, Pl, Sh, Ski*	6	9	2	BI 2-3
1AA102209014W400	174.20	*Pl, Sk, Th, As, Sh*	5	11	2	BI 1-2
1AA102209014W400	175.70	*Th, Sh, Pl, Sk, As*	5	6	<2	BI 1
1AA102209014W400	177.00	*Sh, As, Sk, Rs,*	4	2	<2	BI 1

1AA102209014W400	178.50	*Ro, Th, As, Pl*	4	10	2	BI 1
1AA102209014W400	179.50	*Pl, Ar*	2	5	<2	BI 0-1
1AA102209014W400	181.00	*Sh, Sk*	1	3	<2	BI 0-1
1AA102209014W400	182.50	*Sh, Pl, Sk*	2	3	<2	BI 0-1
1AA102209014W400	184.00	*Sk, Sh*	2	<2	<2	BI 1
1AA102209014W400	184.90	*Th*	1	17	2	BI 1
1AA102209014W400	186.30	*Sh, Sk, Ro*	3	3	<2	BI 1
1AA102209014W400	187.40	*Sh, Ro, Pl, Th*	2	10	3	BI 1
1AA102209014W400	189.80	*Sh, Th*	2	18	3	BI 1
1AA102209014W400	190.30	*Pl, Th*	2	30	3	BI 1
1AA102209014W400	191.05	*Sh, Pl, Sk*	3	4	2	BI 1
1AA102209014W400	191.80	*Pl, Gy, Cy, Te, Sk*	5	17	3	BI 3
1AA102209014W400	192.80	*Te, Gy, Mgy, Pl, Th, Sk, Cy*	7	11	<2	BI 2-3
1AA102209014W400	193.10	*Te, Gy, Pl*	3	5.5	2	BI 2
1AA102209014W400	193.20	*Pl*	1	3	<2	BI 0-1
Well	**1AA162209014W400**					
1AA162209014W400	167.20	*Ch, Pl, Th*	3	10	<2	BI 1
1AA162209014W400	167.95	*Ch, Sh, Sk, Pl, Th,*	6	24	2	BI 4
1AA162209014W400	168.70	*Sk, Sh,*	2	2	<2	BI 1
1AA162209014W400	169.45	*Ch, Sh, Pa, Sk, Para,*	6	20	<2	BI 2
1AA162209014W400	170.20	*Sh, Sk, As,*	3	9	<2	BI 2
1AA162209014W400	170.95	*Pa, Sh, Pl, Th*	4	18	2	BI 2
1AA162209014W400	171.70	*Sh, Ro, Pl,*	3	5	<2	BI 1-2
1AA162209014W400	172.45	*Sh, Pl, Sk*	3	2	<2	BI 0-1
1AA162209014W400	173.20	*Pl, Sh*	2	2	<2	BI 0-1
1AA162209014W400	173.95	*Th, Pl, Sk, Sh*	4	10	<2	BI 1
1AA162209014W400	174.70	*Sh, Ro, Pl, SK, As, Th*	6	14	2	BI 2
1AA162209014W400	175.45	*Te, Pl, ?Ch, Th, Sh,*	6	22	3	BI 3
1AA162209014W400	176.20	*Th, Pl, Ch, Sh, As*	5	60	3	BI 3
1AA162209014W400	176.95	*Th, Pl, Ro, ?Gy, Sh,*	6	30	7	BI 3
1AA162209014W400	177.70	*Sh, Th, Pl, Ar, As,*	5	34	4	BI 3
1AA162209014W400	178.45	*Th, Pl, Sh, Sk, As*	5	22	4	BI 3
1AA162209014W400	179.20	*Th, Sh, Pl, Sk*	4	20	3	BI 3
1AA162209014W400	179.95	*Pl, Th, As, Ro,*	4	32	3	BI 3
1AA162209014W400	180.70	*Pl, Th, Sh, As,*	4	28	3	BI 3
1AA162209014W400	181.45	*Pl, Sh, Sk, Th*	4	11	<2	BI 1
1AA162209014W400	182.20	*Sk, Pl*	2	6	2	BI 1
1AA162209014W400	183.00	*Th, Pl, Sh*	3	30	2	BI 1
1AA162209014W400	183.80	*Sh, Sk, Pl*	3	<2	<2	BI 1
1AA162209014W400	184.50	*Sh, Sk, Pl*	3	2	<2	BI 1-2
1AA162209014W400	185.20	*Sh, Sk*	2	<2	<2	BI 1
1AA162209014W400	186.00	*Sh, Pl*	2	2	<2	BI 1
1AA162209014W400	186.80	*Sh*	1	2	<2	BI 1
1AA162209014W400	187.50	*Pl, Sh*	2	2	<2	BI 1
1AA162209014W400	188.20	*Sh, Ro, Pl*	3	3	<2	BI 1
1AA162209014W400	189.00	*Sh, Th, Sk*	3	9	<2	BI 1
1AA162209014W400	189.80	*Ro, Sh*	2	4	<2	BI 1
1AA162209014W400	190.30	*Sh, Pl, Th*	3	9	<2	BI 1
1AA162209014W400	190.80	*Sh, Pl, Th*	3	20	<2	BI 1
1AA162209014W400	191.40	*Sh, Sk, Pl, Th*	4	18	<2	BI 1

1AA162309014W400	192.00	Sk, Pl, Th	3	13	<2	Bl 1
Well	1AA032309014W400					
1AA032309014W400	167.05	Ch, Pl, Th	3	13	2	4
1AA032309014W400	167.80	Pl, Th, Ch, Pa, Sk, Lg, Te, Sh	8	12	4	5
1AA032309014W400	168.55	Pl, Th, Sk, Pa, Sc, Dp, Ch	7	10	4	5
1AA032309014W400	169.30	Pa, Sk, Ra, Pl, Th, Sh	6	11	3	5
1AA032309014W400	170.05	Rs, pe, pl, sk, th, sh,	7	12	3	5
1AA032309014W400	170.43	Sk, Pl	2	2	less than 2 mm	1
1AA032309014W400	170.80	"	-999	"	"	0
1AA032309014W400	171.23	0	0	0	0	0
1AA032309014W400	171.65	Pl, Rs, Th	2	12	less than 2 mm	2 or 3
1AA032309014W400	173.15	Pl, Sk, Rs	2	12	less than 2 mm	2 or 3
1AA032309014W400	174.10	Rs, Pl, Pa	3	10	less than 2 mm	2 or 3
1AA032309014W400	175.05	Pl, Oph, Pa	2	3.5	less than 2 mm	2
1AA032309014W400	176.55	Pl, Sh, Rs	3	2	less than 2 mm	2
1AA032309014W400	177.30	Sk, Pl, Pa, Sh	4	4	3	2
1AA032309014W400	178.05	Pa, Sk	2	8	3	2
1AA032309014W400	178.30	Pa, Sk	2	3	2	2
1AA032309014W400	178.55	Pa, Sk	2	4	2	2
1AA032309014W400	178.80	Pl, Pa	2	4	2	2
1AA032309014W400	179.05	Pl, Pa	2	7	2	2
1AA032309014W400	179.30	Oph	1	8	2	2
1AA032309014W400	179.55	Pl, Th	2	11	2	2
1AA032309014W400	181.05	Oph, Pl, Th	3	10	3	2
1AA032309014W400	185.70	Pl, Th, SK	3	18	3	2
1AA032309014W400	187.10	Pl, Sk	2	14	3	2
1AA032309014W400	188.70	Rs, pl, Sk	2	8	2	2
1AA032309014W400	191.80	Oph	1	17	10	2
1AA032309014W400	193.00	Pl, Pe, Th, Oph, Sh	5	14	4	3
Well	1AA042309014W400					
1AA042309014W400	168.75	Pl, Sk, Sh, Te, Ch, Th	6	6	2	Bl 3-4
1AA042309014W400	169.50	Ch, Sk, Sh, As, Th, Pl	6	11	2	Bl 3
1AA042309014W400	171.00	Pl, Sk, Sh, Ar, Te,Ch, Para, Rs	7	13	2	Bl 3
1AA042309014W400	172.10	Sh, Sk, Para, Pl,	4	28	2	Bl 2
1AA042309014W400	173.80	Sh, Sk, Pl, Th, Rs	5	5	"	Bl 2
1AA042309014W400	174.45	Pl, Te, Sk, Pa, Sh	5	9	2	Bl 1-2
1AA042309014W400	175.10	Pl	1	3	<2	Bl 0-1
1AA042309014W400	175.95	Sk, Sh, Pl	3	4	<2	Bl 0-1
1AA042309014W400	176.80	Sk, Sh, Pl	3	5	<2	Bl 0-1
1AA042309014W400	178.10	Sh, Sk	2	<2	<2	Bl 0-1
1AA042309014W400	179.80	Sh, Sk, Pl	3	3	<2	Bl 0-1

1AA042309014W400	181.10	*Sh, Sk*	2	<2	<2	Bl 0-1
1AA042309014W400	182.80	*Sh, Sk, Pl*	3	<2	<2	Bl 0-1
1AA042309014W400	183.45	*Sh, Ra*	2	2	<2	Bl 0-1
1AA042309014W400	184.10	*Sh, Pl, Sk*	3	<2	<2	Bl 0-1
1AA042309014W400	185.80	*Th, Sh, As,*	3	18	2	Bl 1
1AA042309014W400	187.10	*Pl, Th, Ra, Te,*	4	10	2	Bl 1
1AA042309014W400	187.90	*Pl*	1	3	<2	Bl 1
1AA042309014W400	188.70	*Pl, Sh*	2	2	<2	Bl 1
1AA042309014W400	189.40	*Pl, Th, Zeo, Sk*	4	9	2	Bl 1
1AA042309014W400	190.10	*Pl, Sk, Sh*	3	5	<2	Bl 1
1AA042309014W400	191.70	*Pl, Sh, Sk*	3	4	<2	Bl 1
1AA042309014W400	192.40	*Sh, Pl, Pa*	3	9	<2	Bl 1
1AA042309014W400	193.10	*Pl, Sh, Te,*	3	10	2	Bl 1
Well	**1AA072309014W400**					
1AA072309014W400	166.55	*Ch, Te, Pl*	3	<2	-	-
1AA072309014W400	167.30	*Ch, Pn*	2	<2	-	-
1AA072309014W400	168.10	*Pl, Te*	2	8	10	-
1AA072309014W400	168.90	*Pl, Th, Sk, Ch, te, Pn*	5	25	14	-
1AA072309014W400	169.40	*Pl, Th, Sk, Ch, Te*	5	10	2	Bl 0-1
1AA072309014W400	170.20	*Pl, Sk, Rs, Tr, Sh*	2	12	3	Bl 3-4
1AA072309014W400	171.00	-	-999	-	-	-
1AA072309014W400	172.40	*0*	0	0	0	-
1AA072309014W400	173.15	*Pl, Sk*	2	6	2	Bl 0
1AA072309014W400	173.90	*Pl, Oph*	2	13	3	-
1AA072309014W400	174.90	*Pl, Rs*	2	2	2	-
1AA072309014W400	175.65	*Pl, Sk, Pa, Rs*	4	2	3	-
1AA072309014W400	176.40	*Pl, Th, As*	1	2	3	-
1AA072309014W400	177.15	*Rs, Pl, Oph, Sk, Tr*	5	7	4	-
1AA072309014W400	177.90	*Ra, Pa, Pl, Sk, Sc*	5	7	3	Bl 3
1AA072309014W400	178.55	*Pl, Th, Sk, As*	4	10	3	-
1AA072309014W400	179.20	*Pl, Tr, Sk, Pa*	4	13	4	-
1AA072309014W400	180.70	*Pl, Sk, Sc, Ch?*	4	7	2	-
1AA072309014W400	181.45	*Pl, Sk, Pa*	3	10	3	-
1AA072309014W400	182.20	*Pl, Sk, Sc, Th*	4	12	5	-
1AA072309014W400	183.70	*Pl, Sk*	2	10	2	Bl 3
1AA072309014W400	185.20	*Pl, Sk, Rs*	3	7	4	-
1AA072309014W400	185.95	*Sk, Pl*	2	3	2	-
1AA072309014W400	186.70	*Sk*	1	1.5	2	-
1AA072309014W400	187.45	*Sk, Rs*	2	5	3	-
1AA072309014W400	188.20	*Sk, Pl*	2	5	3	-
1AA072309014W400	188.95	*Sk, Pl*	2	3	3	-
1AA072309014W400	189.70	*Sk, Pl, Pa, Tr*	4	9	3	-
1AA072309014W400	190.45	*Sk, Pl*	2	5	3	-
1AA072309014W400	191.20	*Sk, Pl, Pa, Op*	4	9	3	-
1AA072309014W400	191.95	*Sk, Pl*	2	5	2	-
1AA072309014W400	192.70	*Sk, Pl*	2	9	2	-
1AA072309014W400	193.00	*Sk, Pl, Rs*	3	7	2	Bl 2-3
Well	**1AA052609014W400**					
1AA052609014W400	167.40	-	-999	-	-	-
1AA052609014W400	168.15	*Ch, Pl, Zeo*	3	3	<2	Bl 1

1AA052609014W400	168.90	*Ch, Zoo, As, Th, Dpl, Pl, Te, Sk*	8	14	2	BI 4-5
1AA052609014W400	169.65	*Sh, Sk*	2	2	<2	BI 1
1AA052609014W400	170.40	*Sh, As, Th, Pl, Sk,*	6	38	2	Bi 3
1AA052609014W400	171.15	*Sh, Rs, Pa, Sk*	4	7	<2	BI 2
1AA052609014W400	171.90	*Sh, As*	2	5	<2	BI 1
1AA052609014W400	172.65	*Sh, Pl, Th*	3	9	2	BI 1
1AA052609014W400	173.40	*Pl, Sh*	2	2	<2	BI 1
1AA052609014W400	174.15	*Pl, Te, As, Rs, Sh*	5	4	2	BI 2
1AA052609014W400	174.90	*Pl, Te, Sk, Sh, Th*	4	13	<2	BI 2
1AA052609014W400	175.65	*Rs, Sh, Th, Pl, Sk*	5	11	2	BI 3
1AA052609014W400	176.40	*Pl, Th, Zoo, Sh,*	4	12	2	BI 3
1AA052609014W400	177.15	*Pl, Sh, Th, Te, Ch,*	5	22	2	Bi 3
1AA052609014W400	177.90	*Th, Sh, Pl, Rs, Te, Ch*	6	18	3	BI 3
1AA052609014W400	178.65	*Pl, Ch, Th, Sh, Zoo*	5	38	3	BI 3
1AA052609014W400	179.40	*Ar, Sh, Pl, lit, Ch,*	5	12	2	BI 3
1AA052609014W400	180.15	*Th, Pl, Ch, Zoe, Sk, As, Sc, Te, Sh*	9	20	4	BI 4
1AA052609014W400	180.90	*Th, Pl, Sc, Ch, Sk, Sh*	6	25	3	Bi 4
1AA052609014W400	181.65	*Rs, Zoo, Pl, Th, Sh,*	6	24	4	BI 4
1AA052609014W400	182.40	*Pl, Te, Th, Ch, Sh, Sk, As*	7	40	6	Bi 4
1AA052609014W400	183.15	*Th, As, Zoo, Sh, Pl, Ch, Rs,*	7	17	3	BI 4
1AA052609014W400	183.90	*Zoo, Pl, Th, Ch, Sk, Sh, Op, Se*	8	18	3	BI 4
1AA052609014W400	184.65	*Te, Sh, Th, Pl, Sk, As, Ch*	7	44	6	BI 4
1AA052609014W400	185.40	*Th, Pl, Sh, Zoo, Rz, Ar, As, Te, Sc, Ch*	9	48	5	BI 4
1AA052609014W400	186.15	*Pl, Th, Zoo, Sh,*	4	14	3	BI 3
1AA052609014W400	186.90	*Sk, Th, Pl, Te, Rz, Zoo, Sh*	7	20	4	BI 3
1AA052609014W400	187.65	*Zoo, Pl, Th, Ar*	4	30	3	BI 3
1AA052609014W400	188.40	*As, zoo, Th, Pl, ?Ch*	5	23	2	BI 2
1AA052609014W400	189.15	*Sh, Th, Pl, As*	4	25	2	BI 2
1AA052609014W400	189.90	*Th, Pl, Sk, Sh, Te, As*	6	10	<2	BI 2
1AA052609014W400	191.50	*Pl, Sh, Th*	3	9	<2	BI 2
Well	**1AA022709014W400**					
1AA022709014W400	166.75	*planolites*	1	<2	<2	1
1AA022709014W400	167.50	*Pl, Ch, Th, Te,*	4	3	3	5
1AA022709014W400	168.25	*Pl, Th, Ch, Pa, As, Sh*	6	11	3	4
1AA022709014W400	169.00	*Pl, Sk, Sh, Rs*	4	6	3	4
1AA022709014W400	169.75	*Pl, Rs, Sk, Sh,*	4	3	3	3
1AA022709014W400	170.50	*Pa, Sk, Pl, Rs, Th*	3	10	2	3
1AA022709014W400	171.25	*Pl, Pa, Th*	2	10	2	2
1AA022709014W400	172.00	*Pl, Pa, Sk, Rs, As, Th*	4	11	2	3
1AA022709014W400	173.50	*Pl,Th, As, Rs, Sc*	4	10	2	2
1AA022709014W400	174.25	*Pl,Th, As, Rs, Sc*	4	15	2	3
1AA022709014W400	175.00	*Sk, Pl, Rs, Sc*	4	5	2	2
1AA022709014W400	175.75	*Pl, Sc, Th, Rs,Sh*	5	14	3	2

1AA022709014W400	176.50	Pl, Ra, Sk, Th,	4	17	4	2
1AA022709014W400	177.25	Pl, Sk, Sh, Zoo, Th,	5	20	3	3
1AA022709014W400	178.00	Pl, Th, Ra, Te	4	9	2	3
1AA022709014W400	178.75	Pl, Pa, Sk, Th, Sc	5	13	3	3
1AA022709014W400	179.50	Pl, Th, Te, Ra	4	18	3	2
1AA022709014W400	180.25	Pl, Th, Sk, Zoo	4	20	3	3
1AA022709014W400	181.00	Pl, Th, As, Te, Ch?	5	22	3	3
1AA022709014W400	181.75	Pl, Pa, Ra	3	4	2	1
1AA022709014W400	182.50	Pl, Th, Sh	3	13	<2	1
1AA022709014W400	183.25	Pl, Sh	2	2	<2	1
1AA022709014W400	184.00	Pl, Sk, Oph, Th, Sh	5	10	2	1
1AA022709014W400	184.75	Pl, Sk, Th, Sh, Gy	5	12	2	1
1AA022709014W400	185.50	Pl, Sk, Sh, As	4	4	2	1
1AA022709014W400	186.25	Te, Sh, SkAs, Th, Pl	6	8	2	1
1AA022709014W400	187.00	Sk, Sh,	2	<2	<2	1
1AA022709014W400	188.50	Th, Pl, Te, Sh	4	10	2	1
1AA022709014W400	189.25	Pl, Th	2	11	2	1
1AA022709014W400	190.00	Pl, Sk, Pa, Th	4	10	2	1
1AA022709014W400	191.40	Pl, Sh, Th,	3	17	2	1
1AA022709014W400	191.85	Pl, Sh, Oph, Ra	4	9	2	1
1AA022709014W400	192.30	Pl, Sk, Sh	3	3	<2	1
Well	1AA042709014W400					
1AA042709014W400	167.75	Ch, Sk, Th, Pl, Sh,	4	10	3	BI-4
1AA042709014W400	168.50	Ch, Sk, Pl, Th, Te	5	12	4	BI 4-5
1AA042709014W400	169.15	Pl, Th, Ch, Zoo, Sc,	5	30	4	BI 5
1AA042709014W400	169.80	As, Sh, Pl, Sc, Sk	4	9	<2	BI 5
1AA042709014W400	170.40	Ra, Ch, Sh, As, Para, Sk	6	7	3	BI 3-4
1AA042709014W400	171.00	Sh, Ch, Pl, Th, Sk, Ra	6	30	3	BI-4
1AA042709014W400	171.75	Ra, Ch, Th, Pl, Sh, Pa, As,	7	20	3	BI 3-4
1AA042709014W400	172.50	Ar, Pl, Th, As	4	22	3	BI 3
1AA042709014W400	173.25	Th, Pl, Sk, Sh	4	10	<2	BI 0-1
1AA042709014W400	174.00	Sk	1	4	<2	BI 0-1
1AA042709014W400	174.75	Sk	1	<2	<2	BI 0-1
1AA042709014W400	175.50	Pl	1	<2	<2	BI 0-1
1AA042709014W400	176.00	Pl, Sh, Ra	3	4	<2	BI 1
1AA042709014W400	176.85	Ra, Pl, Th, Sk, Sh	4	10	3	BI 2
1AA042709014W400	177.70	Sh, Pl	2	4	<2	BI 2
1AA042709014W400	178.25	Pl	1	5	<2	BI 1
1AA042709014W400	178.80	Pl, Th, As, Pa	4	9	<2	BI 1
1AA042709014W400	179.50	Th, Pl, Sk As,	4	18	3	BI 2
1AA042709014W400	180.20	Sh, Pl, Th, Ra,	4	14	3	BI 2
1AA042709014W400	180.95	Pl	1	3	3	BI 0-1
1AA042709014W400	181.70	Pl, Pa	2	3	<2	BI 0-1
1AA042709014W400	183.20	Sh, Pl, Sk, Ra	4	3	<2	BI 1
1AA042709014W400	183.85	Pl, Th, Sk, Sh	4	28	<2	BI 1
1AA042709014W400	184.50	Sh, Pl, Th	3	30	3	BI 1
1AA042709014W400	186.00	Sh, Pl, As, Th,	4	13	3	BI 1-2
1AA042709014W400	187.40	Pl, Sk, Sh	3	3	<2	BI-1
1AA042709014W400	188.90	Sh, Pl, Th	1	37	<2	BI 0-1

1AA042709014W400	189.65	*Pl*	1	<2	<2	BI 0-1
1AA042709014W400	190.40	*Pl, Sh, Th*	3	22	2	BI 1
1AA042709014W400	191.15	*Pl, Te*	2	5	<2	BI 0-1
1AA042709014W400	191.90	*Pl, Sk*	2	5	<2	BI 1
Well	**1AA102709014W400**					
1AA102709014W400	166.80	*Ch*	1	<2	<2	1
1AA102709014W400	167.80	*Ch*	1	<2	<2	1
1AA102709014W400	168.50	*Ch, As, Sk, Th, Zoo,*	6	20	<2	4
1AA102709014W400	169.20	*Ch, Sk, Sh, As, Th,*	5	30	<2	5
1AA102709014W400	170.00	*Pl, Sh, Sk, Te, Th, Ch, Rs*	7	13	2	4
1AA102709014W400	170.80	*Sk, Pl, Ar, Sh*	4	3	<2	3
1AA102709014W400	171.50	*Pl, As, Th, Rs,*	5	10	3	3
1AA102709014W400	172.20	*Pl, Sk, Rs, Th, Pe, As*	6	10	3	3
1AA102709014W400	173.80	*Rs, As, Sk, Pl, Sh, Ch*	6	10	3	3
1AA102709014W400	175.20	*Th, Pl, Sh*	3	11	3	3
1AA102709014W400	176.00	*Pl, Th, Te,*	3	14	2	3
1AA102709014W400	176.80	*Sk, Pl, Escape, Th,*	4	17	2	3
1AA102709014W400	178.20	*Pl, As, Th,*	3	5	2	2
1AA102709014W400	179.80	*Pl, Th, Rs, As, Zoo, Ch, Sh, Te*	7	20	2	3
1AA102709014W400	180.50	*Pl, Pe, Sk, Th,*	4	20	3	3
1AA102709014W400	181.20	*Pl, Th, Rs, Sh*	4	10	3	3
1AA102709014W400	182.00	*Pl, Th, Ar, Sh,*	4	10	3	3
1AA102709014W400	182.80	*Pl, Rs, As, Zoo, Th,*	6	10	4	3
1AA102709014W400	183.50	*Pl, Te, Pa, Th, Sk,*	6	10	4	3
1AA102709014W400	184.20	*Th, Pl, As*	3	20	3	3
1AA102709014W400	185.00	*Te, Pl, Th, Sh, Sc*	5	10	3	3
1AA102709014W400	185.80	*Te, Pl, Th, Sh, Ar,*	5	15	3	3
1AA102709014W400	186.50	*Th, Pl, Sk,*	3	24	3	3
1AA102709014W400	187.20	*Te, Pl, Sc, Th,*	4	22	4	2
1AA102709014W400	187.73	*Pl, Th, Sh, Rs*	4	10	4	2
1AA102709014W400	188.27	*Th, Pl,*	2	13	3	2
1AA102709014W400	188.80	*Pl, Sh, Th*	3	10	<2	2
1AA102709014W400	190.20	*Pl, Sh, Oph?*	3	5	<2	2
1AA102709014W400	190.90	*Sk, Rs, Sh, Pl*	4	5	3	2
1AA102709014W400	191.60	*Sk, Pl, Th, Sc,*	4	11.5	4	2
Well	**1AA122709014W400**					
1AA122709014W400	170.50	*Chondrites*	1	2	<2	1
1AA122709014W400	171.00	*Ch, Sk, Th*	3	7	<2	4
1AA122709014W400	171.75	*Sk, Pl, Th, Te, Ch, Sc Sh, As*	8	18	3	4
1AA122709014W400	172.50	*Te, Th, Pl, As, Sk, Sc, Ch,*	7	25	3	4
1AA122709014W400	173.20	*Te, pl, th, As, Zoo, Sh*	6	20	3	4
1AA122709014W400	173.90	*Te, Pl, Sk, Sh, Th,*	5	18	3	3
1AA122709014W400	174.65	*Pl, As, Oph/Pa*	-999	8	4	3
1AA122709014W400	175.40	*Sk, Rs, As, Ar, Th, Pl, Pa*	7	28	6	3
1AA122709014W400	176.80	*Sk, Oph*	2	3	2	0-1

1AA122709014W400	178.20	*Sk, Pl, Rs, Th,*	4	10	3	3
1AA122709014W400	179.80	*Rs, Pl, Sk, Th, Sc*	5	10	3	3
1AA122709014W400	181.20	*Pl, Th, Te*	3	35	6	3
1AA122709014W400	182.80	*Pl, Sk, Th, Te, Sc, Rs*	6	40	5	3
1AA122709014W400	183.50	*Pl, Th, Sc*	3	11	4	3
1AA122709014W400	184.20	*Pl, Pa, Sh, Rs, Th*	5	14	3	3
1AA122709014W400	185.00	*Pl, Th, Zoo, Rs, Te*	5	15	4	3
1AA122709014W400	185.80	*Pl, Th, Te, Zoo, Lg?*	4	10	3	3
1AA122709014W400	186.50	*Pl, Th, Rs, Te, Sh*	5	40	4	3
1AA122709014W400	187.20	*As, Rs, TH, Pl*	4	15	3	2
1AA122709014W400	188.00	*Pl, Th, Sh*	3	15	3	2
1AA122709014W400	188.80	*Th, Pl, As,*	3	20	3	2
1AA122709014W400	189.23	*Pl, Th*	2	20	3	2
1AA122709014W400	189.67	*Pl, Th, Te,*	3	11	4	2
1AA122709014W400	190.10	*Pl, Th*	2	40	4	2
1AA122709014W400	193.20	*Th, Sh, Rs, Pl*	4	15	3	1
1AA122709014W400	193.95	*Pl, Th*	2	10	2	1
1AA122709014W400	194.70	*Pl, Sh, As*	3	5	2	1
Well	1AA162809014W400					
1AA162809014W400	168.30	*Pl, Ch*	2	<2	<2	BI 0-1
1AA162809014W400	169.05	*Pl, Ch*	2	<2	<2	BI 1
1AA162809014W400	169.80	*Zoo, Sk, Ch, TH, Pl,*	5	40	2	BI 4-3
1AA162809014W400	170.55	*Sk, As, Th, Zoo, Sh,*	6	20	<2	BI 4
1AA162809014W400	171.30	*Pl, Ch, As, Te, Sk, TH, Sh, Zoo*	8	32	2	BI 4
1AA162809014W400	172.10	*Te, Sk, Pl, Ch, Sh, Ar Th, As*	8	41	4	BI 5
1AA162809014W400	172.90	*Sh, As, Sk, Pl , Th,*	6	14	<2	BI 3
1AA162809014W400	174.40	*Th, Sh, Ch, Rs, Pl*	5	24	2	BI 3
1AA162809014W400	174.90	*Sh, Sk*	2	2	<2	BI 0-1
1AA162809014W400	175.40	*Rs, Pl, Th, Sk*	4	18	2	BI 2-3
1AA162809014W400	175.90	*Te, Pl, Th, Sk*	4	9	2	BI 1
1AA162809014W400	177.40	*Sh, Pl*	1	<2	<2	BI 0-1
1AA162809014W400	178.20	*Th, Sk, Pl, Sk*	4	11	2	BI 2-3
1AA162809014W400	179.00	*Pl, Th, Ar, Sh, Sk*	5	12	2	BI 2-3
1AA162809014W400	179.70	*Th, Pl, As, Sh,*	4	37	3	BI 3
1AA162809014W400	180.40	*Pl, Th, Sh*	3	21	<2	BI 2
1AA162809014W400	181.15	*As, Pl, Th, Sk*	4	11	2	BI 2
1AA162809014W400	181.90	*Th, Pl, Te*	3	13	3	BI 2-3
1AA162809014W400	182.60	*As, Sh, Sk, Pl, Te, Th, ?Ch*	7	23	4	BI 3
1AA162809014W400	183.30	*Sk, Pl, Th, Rz, Rs, As, Te, Sh*	8	21	3	BI 3
1AA162809014W400	184.10	*Pl, Th, As,*	3	13	3	BI 2
1AA162809014W400	184.90	*Pl, As, Th,*	3	38	6	BI 2
1AA162809014W400	185.60	*Pl, Th, Sh, As*	4	30	4	BI 2-3
1AA162809014W400	186.30	*Th, Sh, Pl*	3	10	3	BI 1-2
1AA162809014W400	187.15	*Pl, Th, Sh*	3	22	3	BI 2
1AA162809014W400	188.00	*Pl, Th, Zoo, Sh, Rs*	5	10	4	BI 2
1AA162809014W400	189.50	*Pl, Th, Zoo, Sh*	4	22	3	BI 2
1AA162809014W400	191.00	*Pl, Th, Rs, Sk*	4	10	2	BI 1

1AA162809014W400	191.75	*Pl, Sh, Zoo, Rs, As*	5	10	2	BI 1
1AA162809014W400	192.50	*Th, Pl*	3	14	<2	BI 1
1AA162809014W400	193.15	*Sh, Pl*	2	3	<2	BI 1
1AA162809014W400	193.80	*0*	0	0	0	0
Well	**1AA060309114W400**					
1AA060309114W400	167.60	*thalass*	1	25 mm	–	BI 0-1
1AA060309114W400	168.35	*Ch, Pl, Th, Te*	4	12	2	BI 43
1AA060309114W400	169.10	*Ch,As, Pl, Th, Sk, Te, Zoo Sh*	8	30	4	BI4
1AA060309114W400	169.85	*Th, Rs, Sk,Pl, As, Ch*	6	12	2	BI 4
1AA060309114W400	170.60	*Pl, zoo,Sk, Rs , As, Th, Ar*	7	30	4	BI 4
1AA060309114W400	171.35	*Th, Pl, Sk, Ch, Rz, Sc*	6	53	7	BI 5
1AA060309114W400	172.10	*Sh, Te, Ch, Th, Pl, Rz, As, Sk*	7	22	3	BI 4-5
1AA060309114W400	173.60	*Sh, Sk, As Rs, Pl*	5	7	2	BI 2-3
1AA060309114W400	175.10	*As, Sk, Sh, Pl, Rs,*	6	20	2	BI 2-3
1AA060309114W400	176.90	*Sh, Pl, As, Sk*	4	11	2	BI 2-3
1AA060309114W400	178.30	*Sh, Pl, As, Sk*	4	4	<2	BI 2
1AA060309114W400	179.90	*Oph, Sh, Pl, Sk, Th*	5	28	<2	BI 1
1AA060309114W400	181.30	*Rs, Pl, Th, Sh*	4	9	<2	BI 1
1AA060309114W400	182.90	*Sk, Pl, Sh*	3	8	2	BI 1-2
1AA060309114W400	184.30	*Th, Pl, Ch, Te, Sk, Sc, As*	7	60	20	BI 3-4
1AA060309114W400	184.95	*Rs, As, Pl, Th, Ch,*	6	40	4	BI 4
1AA060309114W400	185.60	*Rs, Ch, Pl, As, Sc,*	6	40	4	BI 4
1AA060309114W400	186.35	*Sk, Rs, Te, Sc, As, Ch, Pl, Ar, Th*	9	34	3	BI 4
1AA060309114W400	187.10	*Ch, Sh, Rs, Pl, Te, Zoo, Sk, Th*	8	20	2	BI 3-4
1AA060309114W400	188.60	*Pl, Rs, As, Th, Sk, Te, Ch, SH, Zoo, Rz* **plano, rosa, astero, paleo, thalass, sk?,**	10	20	3	BI 4
1AA060309114W400	190.10	*As, Sh, Th, Pl, Te,Ar*	6	13	3	BI 3-4
1AA060309114W400	190.40	*Th, Te, Pl, ?ch*	4	15	4	BI 3
1AA060309114W400	191.15	*Te, Pl, Th, Sh, Zoo, As, Ar,*	7	24	4	BI 3-4
1AA060309114W400	191.90	*Th, Te, Pl, As, Sh*	5	20	4	BI 3
1AA060309114W400	192.85	non-m	1	3	<2	BI 2
1AA060309114W400	193.80	non-m	1	4	<2	BI 0-1
Well	**1AA060509114W400**					
1AA060509114W400	157.55	–	3	20 mm	2 mm	BI 2-0
1AA060509114W400	158.30	–	2	23 mm	2 mm	BI 3
1AA060509114W400	159.05	*Pl, Sk, Ar, As, Ch, Th*	6	25	4	BI 3-4
1AA060509114W400	159.80	*Sk, Pl, Te, Sh, As,*	6	14	3	BI 3
1AA060509114W400	161.20	*Pl, Sh, As, Sk, Ch, Th*	6	10	3	BI 2-3
1AA060509114W400	161.95	*Pl, Th, Ch, As*	4	22	4	BI 2-3
1AA060509114W400	162.70	*Th, Te, Pl, Sk, ch, Rz, Zoo,*	7	28	4	BI 4-5

1AA060509114W400	163.45	*Th, Zoo, Ch, As, Pl,*	5	28	2	BI 4-3
1AA060509114W400	164.20	*Te, Sc, Th, Pl, Ch,*	6	14	2	BI 4-3
1AA060509114W400	164.95	*Ch, As, Te, Th, Pl, Sc, Sk*	7	23	2	BI 4-5
1AA060509114W400	165.70	*As, Ch, Pl, Th, Sk,*	6	20	2	BI 4-5
1AA060509114W400	166.60	*Pl, As, Ch, Te, Th, Rz, Zoo*	7	18	2	BI 3-4
1AA060509114W400	167.50	*As, Pl, Te, Ch,*	4	4	2	BI 2
1AA060509114W400	168.25	*Pl, Th, Te, As, Zoo,*	6	18	<2	BI 2-3
1AA060509114W400	169.00	*Th, As, Pl, Sc, Te, Sk, Ar, Sh, Ro, Zoo*	10	28	5	BI 5-6
1AA060509114W400	169.75	*Th, Pl, As, Gy, Te, Sk, Ar, Zoo, Ch*	9	38	18	BI 5-6
1AA060509114W400	170.50	*Th, As, Rz, Ch, Pl, Sk, Te, Ar,*	7	70	20	BI 4
1AA060509114W400	171.20	*Ro, Te, Ch, Pl, Th, Sh, Sk*	7	60	10	BI 4
1AA060509114W400	171.90	*As, Ro, Th, Pl, Te, Sh, Sk, Pa,*	8	32	10	BI 4
1AA060509114W400	172.00	*As, Pl, Ch, Te, Sh*	5	7	4	BI 4
1AA060509114W400	172.75	*Th, As, Pl, Te, Pa, Ch, Rz, Rz, Sh, ?Sc*	10	60	6	BI 4
1AA060509114W400	173.50	*Th, As, Pl, Te, Ro, Ch, Sk*	7	28	8	BI 4
1AA060509114W400	174.25	*Pl, Te, Rz*	3	10	2	BI 0-1
1AA060509114W400	175.00	*Pl, Ro, As*	3	2	2	BI 0-1
1AA060509114W400	175.75	*Ro, Pl*	2	2	2	BI 0-1
1AA060509114W400	176.50	*Ro, Pl*	2	2	2	BI 0-1
1AA060509114W400	178.00	*Pl, Ro, Pa*	3	4	2	BI 0-1
1AA060509114W400	178.20	*As, Pl*	2	2	2	BI 1
1AA060509114W400	178.90	*As, Pl, Th, Sh*	4	13	2	BI 1
1AA060509114W400	179.60	*Zoo, As, Sh, Pl, Th, Pl,*	6	15	2	BI 4, BI 2-3
1AA060509114W400	180.35	*Gy, Mgy, Cy, Pl*	4	3	<2	BI 2
1AA060509114W400	181.10	*Mgy, gy, Pl, Cy, Sk, Te, ?Ch*	7	5	<2	4, 1
1AA060509114W400	181.80	*Mgy, Gy, Pl, Te, Th, Sh, Sk,*	7	11	<2	BI 4, 1 local
1AA060509114W400	182.50	*Gy, Mgy, Te, Pl, Th, Cy Pa, Sk*	8	18	<2	BI 3-4, 1 local
1AA060509114W400	183.25	*Gy, Mgy, Te, Pl, Th, Cy Pa, Sk*	5	25	2	BI 4-5
1AA060509114W400	184.00	*Gy, Mgy, Th, Pl, Sk, Te, Cy, Ar*	8	20	<2	BI 3-4
1AA060509114W400	184.75	*Mgy, Cy, Pl, Sk, Te*	5	12	2	BI 3-4
1AA060509114W400	185.50	*Te, Cy, Mgy, Pl, Sk,*	6	7	2	BI 3-4
1AA060509114W400	186.25	*Pl, Sk, Te, Th, Cy, Mgy, Ar*	7	15	<2	BI 3
1AA060509114W400	187.00	*Te, Sk, Cy, Pl,?CH*	5	7	2	BI 3-4
1AA060509114W400	187.75	*Te, Sk, Pl, Mgy, Ar,*	6	7	2	BI 4
1AA060509114W400	188.50	*Cy, Pl, Te, Sk, Th, Mgy, ?Ch*	7	13	2	BI 4-5

1AA060509114W400	189.00	*Th, Cy, Mgy, Pl, Te,*	6	8	<2	Bl 2
Well	**1AA120809114W400**					
1AA120809114W400	160.25	""	-999	15	5	Bl 5-6
1AA120809114W400	161.00	""	-999	20	4	Bl 5
1AA120809114W400	161.75	*Pl, As, Th*	3	9	3	Bl 1-0
1AA120809114W400	162.50	*Pl, Th, As, Sk*	4	18	2	Bl 3
1AA120809114W400	163.25	*Pl, Th, Op, As, Pa*	5	25	<2	Bl 3
1AA120809114W400	164.00	*Pl, Th*	2	3	<2	Bl 2
1AA120809114W400	164.75	*Pl, Ar, As*	3	8	<2	Bl 2-3
1AA120809114W400	165.50	*Pl, Th, Te, Ar*	4	15	3	Bl 2-3
1AA120809114W400	167.00	*Te, Pl, Th, As, Sk, Op*	6	25	4	Bl 3-4, Bl 4
1AA120809114W400	168.50	*As, Ra, Th, Pl, Sk Te*	6	40	3	Bl 4, Bl 2
1AA120809114W400	169.25	*As, Ra, Th, Pl, Sk*	5	25	5	Bl 4
1AA120809114W400	170.00	*As, Ra, Th, Pl, Sk*	5	22	5	Bl 4
1AA120809114W400	170.75	*As, Ra, Te, Th, Sk,*	6	23	4	Bl 4
1AA120809114W400	171.50	*As, Ra, Pl, Th*	4	12	4	Bl 3-4
1AA120809114W400	172.25	*As, Op, Th, Te, Sk, Pl*	6	45	10	Bl 4
1AA120809114W400	173.00	*As, Ra, Te, Th, Sk, Pl*	6	50	5	Bl 3-4
1AA120809114W400	173.75	*Th, Pl, Te, Op, Sk, As*	6	22	6	Bl 3-4
1AA120809114W400	174.50	*Th, Pl, Te, Sk, Mon*	5	40	6	Bl 3-4
1AA120809114W400	175.25	*Pl, Te*	2	12	2	Bl 00-1
1AA120809114W400	176.00	*Pl, Th, Te, As*	4	30	3	Bl 1
1AA120809114W400	177.50	*Sk, Pl*	2	4	<2	Bl 00-1
1AA120809114W400	178.25	*Pl, Sk, As*	2	5	<2	Bl 00-1
1AA120809114W400	179.00	*Pl, Sk*	2	8	2	Bl 0-1
1AA120809114W400	179.75	*Pl, Th, Sk*	3	12	2	Bl 0-1
1AA120809114W400	180.50	*Pl, Th, Sk*	3	15	2	Bl 1
1AA120809114W400	181.25	*Pl, Th*	2	40	10	Bl 2
1AA120809114W400	182.00	*Pl, Th, SK Ra*	4	20	3	Bl 2
1AA120809114W400	182.75	*Pl, Te, Th, Sk, Rz*	5	15	3	Bl 2
1AA120809114W400	183.50	*Pl, Te, Th, Sk*	5	15	3	Bl 2
1AA120809114W400	184.25	*Th, Pl, Te, As, Ar*	5	21	4	Bl 2
1AA120809114W400	185.00	*Th, Pl, Te, As, Sk*	5	32	4	Bl 2
1AA120809114W400	185.75	*Th, Pl, Te, Ar, Pa, Sc, As*	6	22	5	Bl 2
1AA120809114W400	186.50	*Th, Pl, Te, As Pa, Sc*	5	20	5	Bl 2
1AA120809114W400	187.25	*Th, Pl, Te Sk, As, Pa*	6	12	3	Bl 2
1AA120809114W400	188.00	*Th, Pl, ie, Sk Sk, As*	6	20	4	Bl 2
1AA120809114W400	188.75	*Sk, Th, Pl, Gy,*	4	22	3	Bl 1
1AA120809114W400	189.50	*Pl, Te, Th, Sk, Cy*	5	15	2	Bl 0-1
1AA120809114W400	191.00	*Pl, Mgy, Cy,*	3	5	<2	Bl 0, 1 local
Well	**1AA152609114W400**					
1AA152609114W400	156.50	*Te, Pl, Th*	3	15 mm	4-5 mm	Bl 3
1AA152609114W400	157.25	*Te, Pl, Th*	3	28 mm	5 mm	Bl 3
1AA152609114W400	158.00	*Zo, Pl, Te, Th*	4	15 mm	3-4 mm	Bl 6
1AA152609114W400	158.75	*Zo, Pl, Te, Th*	4	22 mm	3 mm	Bl 5
1AA152609114W400	159.50	*Zo, Pl, Te, Th*	4	12 mm	2-3 mm	Bl 5
1AA152609114W400	160.25	*Zo, Pl, Te, Th*	4	10 mm	2-3 mm	Bl 5

1AA152609114W400	161.00	*Zo, Pl, Te, Th, Ar, Sk, As*	7	12 mm	2-3 mm	BI 5
1AA152609114W400	161.75	*Zo, Pl, Te, Th, Ar, Sk, As*	6	14 mm	2-3 mm	BI 4-5
1AA152609114W400	162.50	*Gy, Mgy, Pl, Te, Th*	5	10 mm	less than 2 to 2 mm	BI 4
1AA152609114W400	163.15	*Gy, Mgy, Pl, Te, Th*	5	10 mm	less than 2 to 2 mm	BI 4
1AA152609114W400	163.80	*Pl, Te,Cy, Gy, Ch, Th*	6	15 mm	2 mm	BI 3-4
1AA152609114W400	164.50	*Pl, Te, Cy, Gy, Ch, Th*	6	10 mm	2 mm	BI 4-3
1AA152609114W400	165.20	*Pl, Cy, Te, Ch*	4	4 mm	less than 2 mm	BI 3-4
1AA152609114W400	166.00	*Pl, Cy, Te, Ch, Sk*	5	8 mm	less than 2 mm	BI 3-4
1AA152609114W400	166.80	*Pl, Te, Cy, Gy*	4	6 mm	2-3 mm	BI 3
1AA152609114W400	167.65	*Pl, Te, Cy, Pe*	4	8 mm	2-3 mm	BI 3
1AA152609114W400	168.50	*Pl, Th, Te*	3	5 mm	less than 2 mm	BI 2-3
1AA152609114W400	170.00	*Pl, Th, Te, Sk*	4	4 mm	less than 2 mm	BI 0-2
1AA152609114W400	171.50	*Cy*	1	2 mm	less than 2 mm	BI 00-1
1AA152609114W400	173.00	*Pl, Sk, Th, Te, Cy, Gy*	5	14 mm	2-3 mm	BI 0-1