Sequence Stratigraphic Architecture of the McMurray Formation

J. Edward Mathison*, M.Sc., P.Geol.
Fekete Associates Inc., 2000, 540 - 5 Avenue S.W., Calgary, AB T2P 0M2
mathison@fekete.com

ABSTRACT
The McMurray Formation is a complex clastic assemblage deposited under a strong tidal influence. Although the occurrence of estuarine incised valley fills within this assemblage implies the presence of internal unconformities, to date these have not been documented. Delineating unconformable breaks within a stratigraphic assemblage is the first step to establishing a sequence stratigraphic framework.

Reference to four unconformities is necessary to understand the sequence stratigraphic architecture of the McMurray Formation. Two unconformities bracket the formation and two unconformities occur internally. These subaerial unconformities are of high relief with broad interfluves separating deep paleovalleys. The four sequence boundaries define three stratigraphic sequences (Sequences 1-3 in descending order).

McMurray Formation straddling unconformities have long been recognized. The basal pre-Cretaceous unconformity between clastics of the McMurray and subjacent Upper Devonian carbonates and calcareous shales is unproblematic. The contact is readily discernable on wireline logs, particularly density and sonic, and will not be discussed further. The unconformable nature of the contact between the McMurray and overlying Wabiskaw has been documented by Wightman et. al (1995). The unconformity is evident regionally but precise placement on individual wireline logs and recognition in cores can be ambiguous.

The two intra-McMurray unconformities have not been documented in literature. The lowermost of these occurs near the top of the Middle McMurray of Carrigy (1959) (*Fig. 1*). The uppermost occurs within the Upper McMurray (Carrigy, 1959) at the contact between the Green and Blue units of Ranger and Pemberton (1997) (*Fig. 1*).

In addition to unconformities / sequence boundaries, two other surfaces are of importance in subdividing McMurray Formation sequences: maximum flooding surfaces and shoreface ravinement surfaces. Maximum flooding surfaces separate transgressive from regressive portions of sequences (i.e., T-R sequences, Embry, 1995). Two regional flooding surfaces occur within the Upper McMurray and are used to subdivide the unit (Pemberton and Ranger, 1997). Maximum flooding surfaces occur in each of these brackish water sedimentary assemblages. Brackish water flooding events mark the bases of the Red and Blue units of Pemberton and Ranger, (1997). These shallow marine sediments are gradationally overlain by mixed wave and fluvial dominated deltaic sediments

(Caplan and Ranger, 2001). Shoreface ravinement surfaces, at the base of marine flooding events separate shoreline/coastal plain sediments from overlying shallow marine sediments.

Carrigy, 1959	Ranger and Pemberton, 1997	This Study	
Upper McMurray	Red	Red	Sequence 1
	Green	Green	
	Blue	Blue	Sequence 2
Middle McMurray		MMc-TR	
		Middle McMurray	Sequence 3
Lower McMurray		Lower McMurray	

Fig. 1. Stratigraphic Nomenclature.

The sequence bounding unconformities will be illustrated with reference to selected cores as will shoreface ravinement surfaces.

Pre-Wabiskaw Unconformity

Well AA/10-26-80-7W4M

In well AA/10-26-80-7W4M the Wabiskaw/McMurray contact can be placed at either of two positions (*Fig. 2, Fig. 6*). The contact can be placed at the sharp contact between laminated sands of the Red and overlying thinly interbedded mudstones and wave rippled sandstones (note pen in *Fig. 2*). The interbedded sandstone mudstone assemblage grades rapidly up to mudstones with thin siltstones. The dark grey carbonaceous mudstones of this interval are waxy and fissile. This unit is non-bioturbated. Thinly interbedded glauconitic sandstones and light grey mudstones that are moderate to strongly bioturbated abruptly overlie the carbonaceous mudstone (arrow). Traditionally the base of the Wabiskaw would be placed at the first appearance of glauconitic sandstones.

Fig. 2.

Well AA/09-31-87-08W4M

A similar succession is evident in well AA/09-31-087-08W4 (*Fig. 3*, *Fig. 6*). Thinly interbedded dark grey, carbonaceous, fissile mudstones and massive to laminated sandstones abruptly overlie bioturbated sands and mudstones at the top of the Red unit (*Fig. 3*, lower arrow). The unit is non-bioturbated to weakly bioturbated. The interbedded sandstone and mudstones passes gradationally into moderately bioturbated medium grey silty mudstones with thin sandstone interbeds. The contact with overlying thinly interbedded medium grey mudstones and glauconitic sandstones is abrupt (upper arrow). Bioturbation has disrupted much of the bedding of the interbedded mudstones and glauconitic sandstones. The Wabiskaw/McMurray boundary, in the 9-31 well, can be placed at either the base of the carbonaceous mudstone/ wave rippled sandstone assemblage (lower arrow) or at the first appearance of glauconitic sandstones (upper arrow).

Fig. 3.

Well AA/07-10-88-8W4M

In well AA/07-10-88-08W4M, immediately northeast of the 9-31 well, the interbedded carbonaceous mudstone and sandstone facies is not present. Thinly interbedded glauconitic sandstone and medium grey mudstone rests directly upon moderately bioturbated sandstones and thin mudstones of the Red unit. The contact is a sharp irregular, evidently erosional, surface with a large burrow penetrating from above (*Fig. 4, Fig. 6*). The vertical burrow has a faint meniscate structure, perhaps belonging to either *Teichichnus* or *Diplocraterion* ichnogenera.

Fig. 4.

Well AA/09-15-85-09W4M

Placement of the Wabiskaw / McMurray in the AA/09-15-85-09W4M well is ambiguous (*Fig. 5, Fig. 6*). As in wells 10-26 and 9-31, there are two possible contacts. The lower is a highly distorted diffuse boundary between medium grey silty mudstones below and dark grey silty mudstones above (note black pen). Due to the contorted nature of the contact (presumably due to soft sediment deformation), precise placement of a contact cannot be made. The overlying sediments are weakly bioturbated medium to dark grey mudstones with siltstone laminae and rare thin sandstone beds. This upper surface (close up) is an irregular erosional contact with two small medium grained sandstone intraclasts sitting directly on the surface. There is a subtle colour change from dark grey to medium grey across the boundary. Interbedded glauconitic sandstones and mudstones above the boundary are strongly bioturbated with a robust ichnofaunal suite.

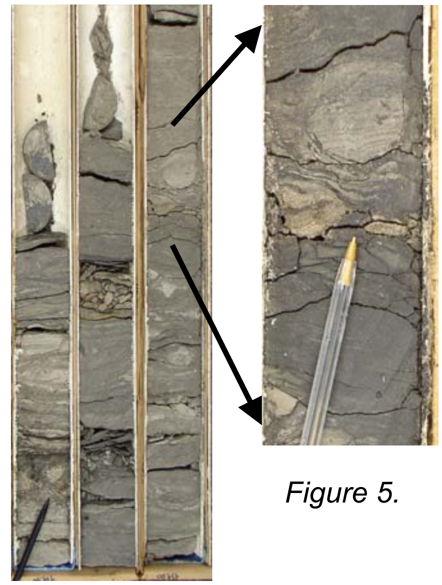

Figure 5.

Interpretation

On a well log cross-section of the described wells, the Red unit thins dramatically to the northwest, between well AA/10-26-80-7W4M and wells 9-31-87-08W4M and AA/07-10-88-08W4M (*Fig. 6*). Farther to the west in well AA/09-15-85-09W4, the Red shoreline is absent with Wabiskaw sediments sitting directly on brackish marine mudstones of the Red flooding event. Although progressive thinning can be interpreted as depositional, these relationships are best interpreted as a regional truncation below a subaerial unconformity surface (see Wightman et. al., 1995 and Ranger and Pemberton, 1997).

The upper surface of the two possible Wabiskaw/McMurray contacts, between glauconitic sandstone and underlying strata is a sharp, and in places, demonstrably erosional (e.g. well AA/07-10-88-08W4M). Locally intraclasts, derived from subjacent strata, armour the surface. The surface, in places, is penetrated by what is probably a firm ground boring assemblage (i.e. a *Glossifungites* ichnofauna). Interbedded glauconitic sandstones and mudstones bearing an abundant diverse, robust *Cruziana-Skolithos* ichnofauna (Ranger and Pemberton 1997) above the surface are fully marine sediment which is transitional to open marine shales above. Alternation between glauconitic sandstones, occasionally wave rippled, and mudstones indicate deposition within storm wave base, most probably on the lower shoreface (cf. Bechtel 1996 in Ranger and Gingras 2002). The occurrence of lower shoreface deposits above an erosional surface, at the base of marine transgression point to shoreface ravinement as the probable cause of the truncation surface (see Wightman et. al, 1995. surface T10.5).

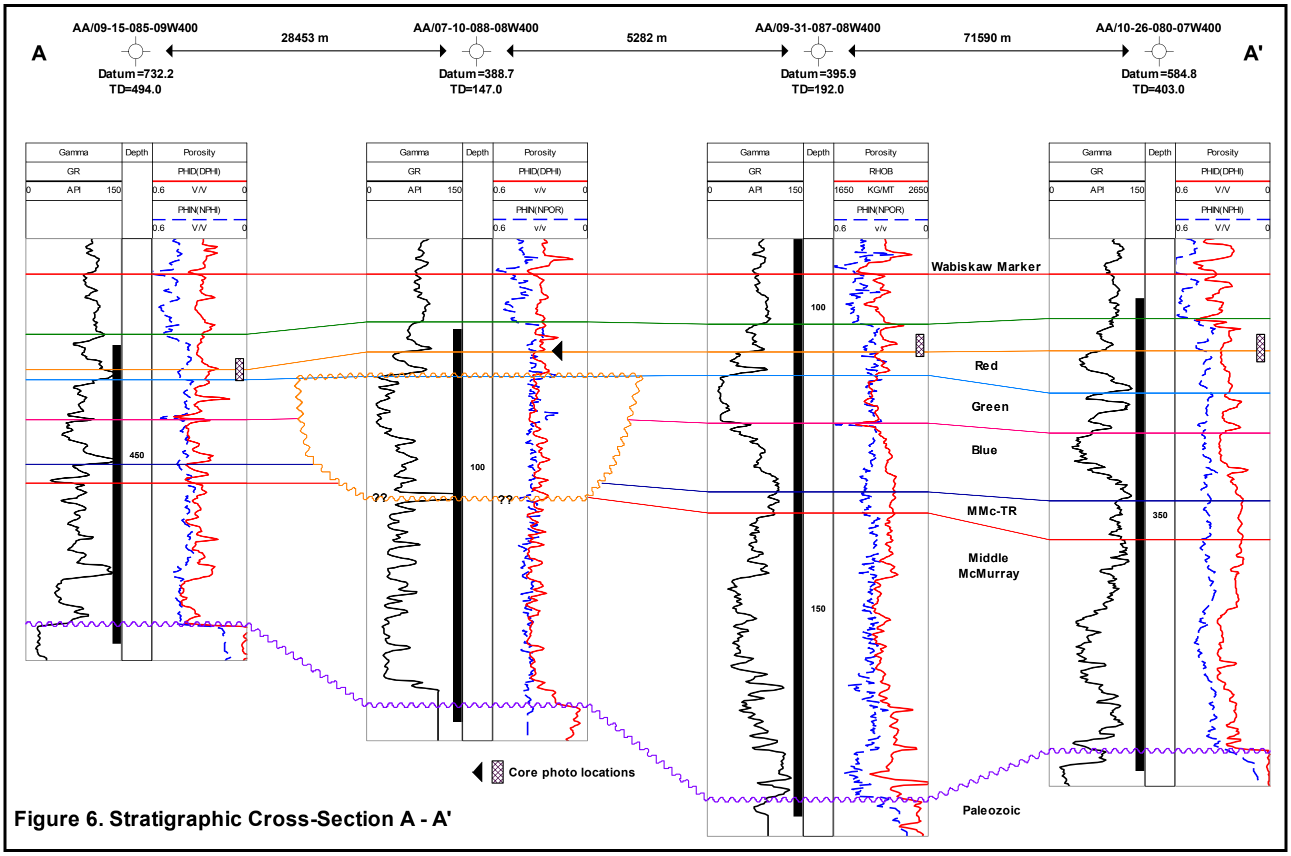

Figure 6. Stratigraphic Cross-Section A - A'

Strata below the shoreface ravinement surface and the top of the coarsening upward Red succession, in well 10-26, 9-31, and 9-15, are enigmatic. That this unit is genetically related to the overlying zone is indicated by the fact that it "tracks" the overlying glauconitic Wabiskaw. Although well 10-26 and 9-31 display different levels of erosion of subjacent sands the restricted carbonaceous mudstone is present in both wells. A very similar facies is present in the 9-15 well although the Red sand has been entirely removed. The absence of the carbonaceous mudstone facies in well 7-10 is probably due to non-deposition over paleo-high and/or post-depositional removal by shoreface ravinement.

Although the unit above the subareal exposure surface and below the ravinement surface is variable, dark grey carbonaceous mudstones intermixed with thin sands are common at its base. Wave rippled sands imply shallow (within wave base) sub-aqueous deposition. The virtual absence of bioturbation of the carbonaceous mudstones in this unit points to highly restricted, presumably very brackish conditions. Interbedding of dark grey non-bioturbated and weakly bioturbated medium grey mudstones towards the top of the zone suggests periodic incursions of more marine waters. The mix of highly brackish, sediments intermixed with more marine sediments suggests paralic conditions. The occurrence of these strata above a regional erosion/exposure surface and below a wave ravinement surface points to preservation of paralic sediments during a transgression. Backshore sediments may be preserved during a relatively rapid transgression although shoreface sediment are not (Davis and Clifton, 1987). Although a detailed facies interpretation of these sediments is not possible, the most probable depositional setting is back-barrier lagoons. A highly diverse sedimentary assemblage fills back barrier lagoons. Fluvial input on the landward side creates highly brackish conditions coupled with input of sands (bayhead deltas). On the seaward side sand is input into the lagoon through ebb tidal deltas and wash-over fans. Influx of marine waters into lagoons would occur during tidal cycles as well as periodically during storm events. Tidal processes within back barrier lagoons result in tidal flats frequently on both the landward and seaward sides of lagoons. Salt marshes occur often on landward sides. Large open water lagoons are subject to wave processes. The interbedded subaqueously deposited sands and carbonaceous mudstones were probably deposited on the subtidal portions of tidal flats (see Finkelstein and Ferland, 1987). Alternating carbonaceous mudstone and silty non-carbonaceous bioturbated mudstone probably represent open lagoon sediment deposited under fluctuating water salinities.

Upper McMurray Unconformity

Well 9-31-87-8W9M

The contact between the Green and Blue units in well 9-31 (*Fig. 7, Fig. 10*) is a sharp irregular evidently erosional contact between sands and rooted mudstones (arrow). Within the mudstone, below the contact, is a thin coal (beneath pen). At the base of the mudstone horizon is a small coal intraclast. The mudstone horizon sits upon bioturbated sands of the Blue unit. The contact is somewhat diffuse. Sands above the rooted mudstone are laminated to ripple cross-laminated with abundant small coal intraclasts.

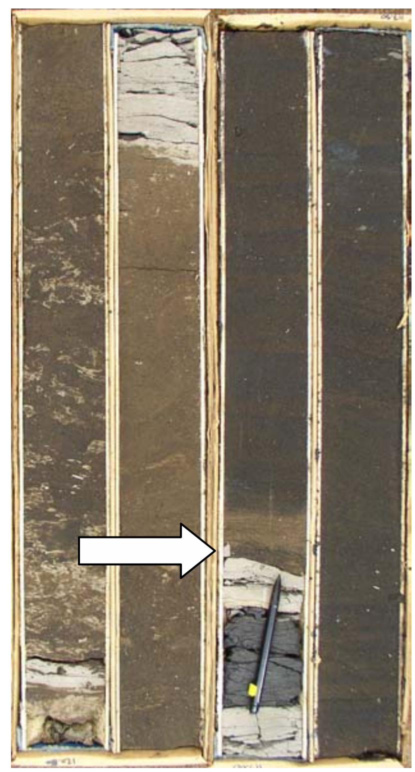

Fig. 7.

Fig. 8.

Well 14-22-80-11W4

The coarsening upward Blue depositional succession in well 14-22 is capped by a thin rooted mudstone (*Fig. 8, Fig. 10*). The top of this zone is fissured with carbonaceous mudstone from above filling the fissure. Within the overlying carbonaceous mudstone are intraclasts derived from below. Some of the silty mudstone intraclasts are rounded with highly contorted internal fabrics. The carbonaceous mudstone grades up to coal which is in turn sharply overlain by bioturbated silty mudstone that grade up to thinly interbedded sandstones and mudstones with a low diversity ichnofauna dominated by *Planolites* and *Skolithos*.

Well 1-18-82-13W4M

A thin rooted mudstone caps the Blue depositional succession in well 1-18 (*Fig. 9, Fig. 10*). The soil horizon overlies a bioturbated silty / sandy mudstone. The top of the rooted horizon is fissured with sand filling the fissures from above. The overlying sand is massive to weakly laminated. This sand is overlain by thinly interbedded sands and mudstones that are moderately bioturbated with a low diversity assemblage dominated by *Gyrolithes*.

Fig. 9.

Interpretation

In the cores described the Blue progradational shoreline assemblage is capped by soil horizons indicating subaerial exposure. Contact with overlying sediments in wells 9-31 and 14-22 is erosive. In well 9-31 the contact is sharp but irregular. In well 14-22, intraclasts derived from the soil horizon are incorporated into the overlying carbonaceous mudstone. The rounded nature of some of the intraclasts implies transport while the contorted internal structure suggests that the clasts were in a plastic state (perhaps mud balls). The most probable site for deposition of the carbonaceous mudstone grading to coal, in the 14-22 well is a salt marsh. The occurrence of this unit sandwiched between a rooted soil below and moderately bioturbated silty mudstones with a low diversity ichnofauna above suggests that the salt marsh was transitional to brackish open water deposition. The contact in well 14-22 therefore represents both a subaerial unconformity as well as a brackish water flooding surface. The sand overlying the fissured soil horizon in well 1-18 passes up-section to bioturbated silty/sandy mudstones indicating that the surface is also a subaerial exposure surface and brackish water flooding surface. This exposure/erosion surface can be correlated regionally using wireline logs (*Fig. 10*).

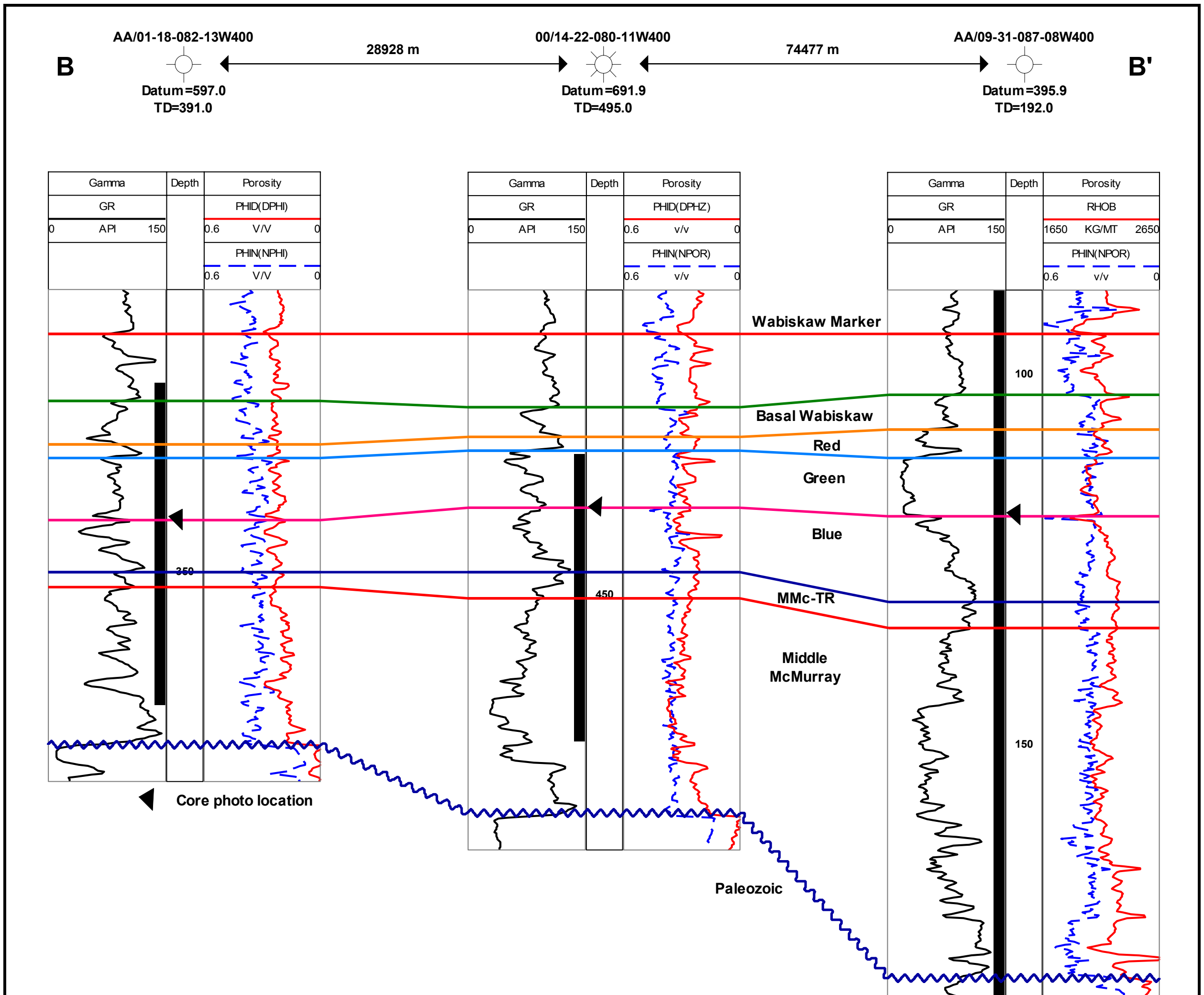

Figure 10. Stratigraphic Cross-Section B-B'

Middle McMurray Unconformity

Well 10-11-76-8W4

Fig. 11.

Approximately four meters below the base of the Blue flooding surface in well 10-11 is a sharp erosional contact between thinly interbedded moderately bioturbated sands and mudstones below and bioturbated silty mudstone above (*Fig. 11, Fig. 15*). The contact is highly irregular. A single small sandstone clast, reworked from below, occurs within the bioturbated mudstones above the surface(above the pen, *Fig. 11*). This mudstone forms the base of a thin coarsening upward depositional succession which culminates with *Cylindrichus* burrowed sands. This succession is in turn overlain by a thin coarsening upward succession similar to below but missing the lower silty mudstone portion and with a thicker sandy portion. The top of second depositional cycle fines upward, becoming interbedded bioturbated sandstone and mudstone. A thin carbonaceous mudstone, overlying a highly irregular (soft sediment deformation?) caps the unit. The carbonaceous mudstone is sharply overlain by medium grey silty shales of the Blue flooding surface (*Fig. 12, Fig. 15*). Simple burrows, possibly *Skolithos*, penetrate the surface and are filled with mudstone from above (*Fig. 12* above pen).

Fig. 12.

Well 9-15-85-9W4M

In well 9-15 an erosional contact occurs between a rooted mudstone below and a massive to weakly laminated sand above. The contact is sharp and irregular (above pen in *Fig. 13, Fig. 15*) A small intraclast derived from below occurs near the base of the overlying sand. Overlying the erosional surface are interbedded sandstones and mudstones which are organized into thin coarsening upwards depositional cycles, that fine up overall.

Fig. 13.

Well 1-18 83-13W4M

Two metres below the Blue flooding surface in the 1-18 well is a sharp highly irregular boundary between sideritized mudstone with thin interbeds of sand (below) and a highly bioturbated silty mudstone (above)(pen points to contact which rises sharply to the left, *Fig. 14, Fig. 15*). Small intrclast derived from below occur near the base of the bioturbated mudstone (above pen).The bioturbated mustone above the boundary grades upwards to sandstone with abundant fine carbonaceous debris.

Fig. 14.

Interpretation

A rooted mudstone near the top of the Middle McMurray in well 9-15 provides evidence of exposure at that level. The rooted mudstone is erosionally overlain by overlying sands. Erosional surfaces occur at a similar horizon in wells 11-10 and 1-18. The erosional surfaces in these wells are overlain by bioturbated mudstones which form the bases of single or multiple thin, coarsening upward depositional successions. A sand occurs immediately above the exposure surface in well 9-15, the sand is succeeded by a thin coarsening upward cycles. Although sediments between the erosion/exposure and overlying marine mudstones is thin it can be mapped reliably in subsurface (*Fig. 16*). The occurrence of this unit between an exposure surface and a flooding surface suggests paralic sedimentation. The small (depauperate) low diversity ichnofauna in well 1-18 implies restricted conditions. Mossop and Flach (1983), base on their interpretation of deep channels as fluvial they interpret the zone (their argillaceous sand facies) as overbank deposits in part equivalent to deep channels but also in part erosively overlying the channels. Flach, 1977, and Mossop and Flach (1983) record thin coals and rooted horizons and clay ironstone horizons concretion within this unit, all indicative of repeated exposure. In addition Flach (1977) records small channels within this assemblage. Ranger and Gingras (2002) interpret this interval as a tidal flat succession. The occurrence of repeated exposure coupled with evidence of highly stressed brackish deposition (stressed ichnofauna) is consistent with tidal flat sedimentation. The, in part, conformable, in part erosional relationship between the tidal flat sediments estuarine channel sediments can be explained by tidal flat progradation over channel sediments during filling of estuaries.(Allen, 1990). Repeated thin coarsening up depositional cycles reflects multiple episodes of tidal flat progradation. Fining upward caps to some cycles record intertidal (sand flat to mud flat) deposition. The overall fining upward pattern of stacked coarsening upward cycles is a back-stepping (retrogradational) stacking pattern formed in response to transgressions. The tidal flat sediments at the top of the Middle McMurray are truncated beneath brackish marine sediments of the Middle McMurray (Blue flooding event) (see Flach, 1977). In places this contact is penetrated by burrows assignable to a *Glossifungites* ichnofauna (e.g. well 11-10-76-6W4M).This tidal flat/shallow marine contact is a probably a wave ravinement surface.

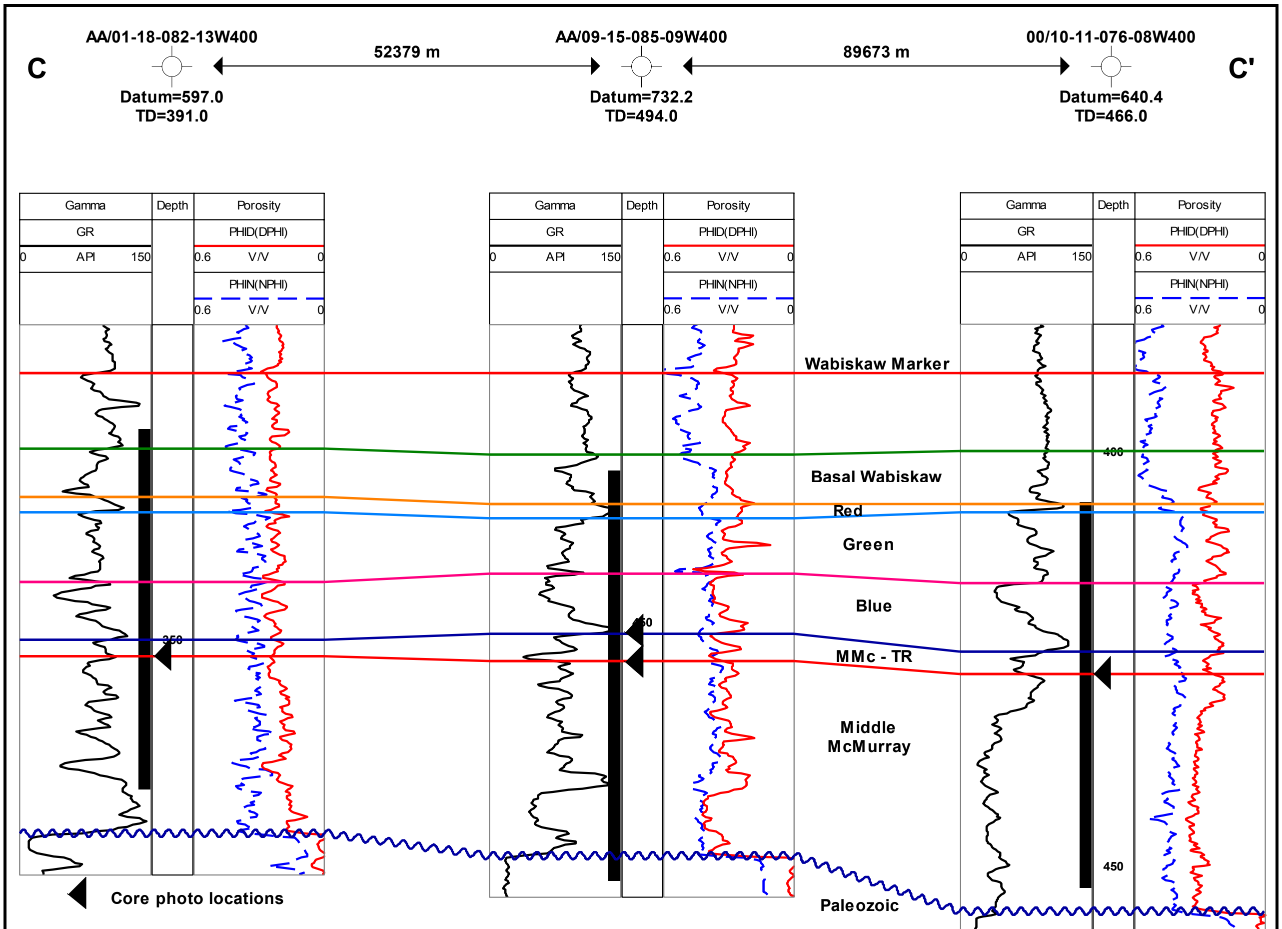

Figure 15. Stratigraphic Cross-Section C - C'

Sequence Stratigraphic Interpretation

Basal Wabiskaw

Paleovalleys cutting down from the Wabiskaw/McMurray unconformity have been recorded by Wightman et. al., (1995) and Ranger and Pemberton (1997). The unconformity is therefore a sequence boundary. The estuarine paleovalley fills, overlying paralic sediments and lower shoreface sediments (above the wave ravinement surface) are all part of the transgressive systems tract of the Wabiskaw transgression. The probable maximum flooding surface for the Wabiskaw Formation is the Wabiskaw marker. These sediments are the product of transgression by a wave dominated shoreline. The preservation of paralic succession points to transgression of a barred shoreline. Estuaries filled during the transgression are probably wave or mixed wave and tide dominated. Erosion by waves recycled barrier sand during transgression leaving behind a veneer of lower shoreface sand over top of a ravinement surface.

Sequence 1

Strata from the base of the pre-Wabiskaw unconformity to the Upper McMurray unconformity comprise Sequence 1. As outlined above, the Wabiskaw/ McMurray boundary is a sequence boundary. On regional cross-sections deeply incised valleys can be demonstrated to cut down from the Upper McMurray unconformity. (Blue/Green boundary). Valleys are evident due to truncation of the marine flooding event at the base of the Blue zone. Regionally correlatable units comprising the Green unit can frequently be shown to cross pale-valleys unchanged, although channelised sediments do occur at this level (e.g. well 07-10-88-8W4M). The Upper McMurray unconformity is interpreted as a sequence boundary which forms the base of Sequence 1.

The Upper McMurray sequence boundary is overlain by sediments with a low diversity, brackish water ichnofauna often occurring in close proximity to rooted exposure surfaces (wells 10-11-76-6W4M, 11-26-80-7W4M, and 14-22-80-11W4M). The occurrence of brackish flooding in conjunction with evidence of exposure, often repeated (e.g. well 14-22), suggests coastal plain strata. Wells 1-18-82-13W4M and 09-15-85-09W4M, in contrast, display no evidence of exposure. Regionally, to the northwest, the Green unit passes into shallow marine silty mudstones of the Upper McMurray. A thick north-northeast sand that occurs between wells demonstrating signs of exposure (i.e. to the southeast) and well with a marine aspect (i.e. to the northwest) is tentatively interpreted as a shoreline. Core from well 9-31-87-08W4, that is part of this trend, displays characteristics indicative of both fresh water input (i.e. abundant coal intraclasts) and marine shoreface deposition (*Bergaueria* traces). These sediments are tentatively interpreted as an flood tidal delta deposits (see Boersma, 1991, *Fig. 22*). The contact between the Green unit and brackish marine mudstones at the base of the overlying Red zone is sharp and in places erosional (e.g. well 9-31-87-08W4M). The surface is probably a wave ravinement surface separating coastal plain sediments below from shallow marine sediments above. The occurrence of brackish water sediments above the Upper McMurray unconformity signals that a rise in relative sea level created accommodation space. The absence of a flooding event at the base of the unit can be explained by sedimentation keeping pace with relative sea level rise. The Green unit is interpreted as a back-stepping unit deposited during the initial stages of the Red transgression. The diverse assemblage of sediments that comprise this unit were probably deposited as a mixed wave-fluvial-tidal delta. Channels within this assemblage would therefore be distributary channels, as opposed to estuarine valley fills. Accumulation of deltaic sediments above estuarine sediment filled paleo-valleys, prior to a marine flooding event (Red flooding) suggests a back-stepping succession deposited prior to maximum flooding. The final flooding event is marked by the ravinement surface at the base of the Red brackish marine mudstone. Strata between the Upper McMurray sequence boundary and Red maximum flooding surface comprise the transgressive systems tract of Sequence 1. The regressive systems tract of Sequence 1 consists of the progradational deltaic sediments of the Red unit, above the maximum flooding surface (*Fig. 16*).

Sequence 2

The top of Sequence 2 is the Upper McMurray sequence boundary. The base of the sequence is the Middle McMurray unconformity. Valleys deeply incised into underlying strata can be demonstrated to cut from this level where a recognizable regional stratigraphy occurs. Mossop and Flach (1983) argues that the occurrence of thick (up to 40 metres) single storied channel fill in the Middle McMurray Formation required pre-existing sediments that where incised into prior to deposition of the deep channel sediments. The Middle McMurray unconformity, which can be tied to incised valleys, is a sequence boundary. The thick estuarine valley fill successions are in part laterally equivalent to, and in part overlain by thin tidal flat sediments capping the Middle McMurray. The estuarine sediments filling paleo-valleys and tidal flat succession on the interfluves were deposited in response to a rise in relative sea-level following a Middle McMurray lowstand. A wave ravinement surface at the base of the Upper McMurray (Blue) flooding event truncates the top of these strata. Strata overlying the Middle McMurray sequence boundary to the maximum flooding event within the basal Upper McMurray marine mudstone comprise the transgressive systems tract of Sequence 2 (*Fig.16*). The regressive systems tract of Sequence 1 consists of all strata above the Maximum Flooding Surface and the Upper McMurray sequence boundary (i.e. Blue progradational deltaic sediments).

Sequence 3

The top of Sequence 3 is the Middle McMurray sequence boundary. The base of the sequence is the pre-Cretaceous surface. The pre-Cretaceous surface is deeply incised. Thick fluvial sediments, becoming estuarine toward their top, fill the valleys Carrigy, 1958, Ranger and Gingras (2002). Lower McMurray sediments are overlain by tidally influenced Middle McMurray strata. While Lower McMurray strata are confined to paleo-valleys Middle McMurray strata is widespread and covers interfluves present during Lower McMurray deposition. Middle McMurray strata, below the Middle McMurray sequence boundary, are stacked relatively thin tidally influenced channel sands (Mossop and Flach, 1983, Ranger and Gingras, 2002). In the western part of the McMurray sub-basin repeated thin coarsening upward cycles that can be traced over several townships form a regional background within channel deposits are imbedded (see wells 1-18-82-13W4M and 9-15-85-09W4M). The Lower McMurray represents transgressive filling of paleo-valleys Ranger and Pemberton, 1997). Although a marine flooding surface at the base of the Middle McMurray has not been recognized the strong tidal influence on Middle McMurray sedimentation suggest marine highstand deposition. The Lower McMurray represents the transgressive portion of a sequence while the Middle McMurray represents the regressive portion. Paleo-valleys incision and subaerial exposure of interfluves records a relative sea-level near the end of Middle McMurray deposition.

Summary

Three sequences defined by four sequence boundaries comprise the McMurray Formation. Each sequence can be divided into transgressive-regressive components (i.e. T-R sequences). Tidal influence in the lower most sequence (Sequence 3) is strongest while the upper sequences (Sequences 1 and 2) show a mixed wave-tidal-fluvial influence. Sediments above Sequence 1 (Wabiskaw Formation) are strongly wave dominated.

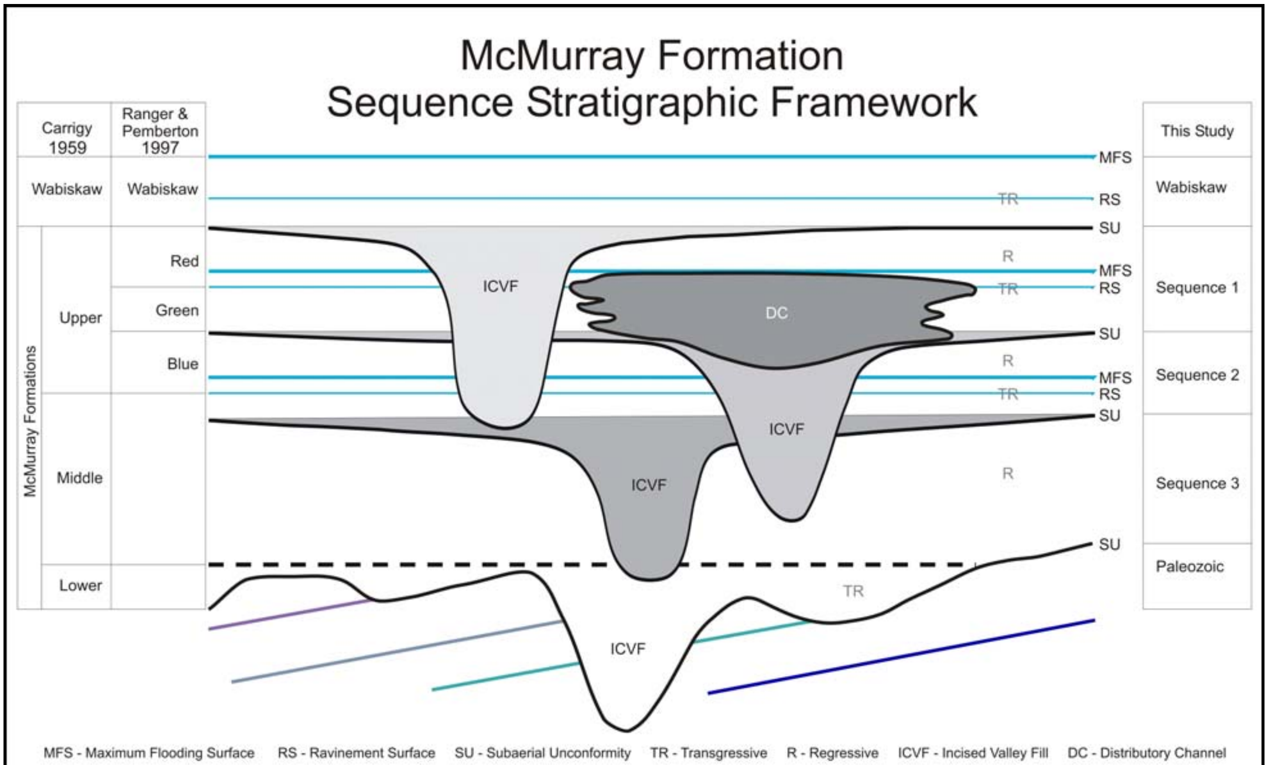

Figure 16

Acknowledgements

I gratefully acknowledge the support and assistance of Fekete Associates Inc. for this project, in particular Jim Lee. This work builds upon knowledge of my co-workers at Fekete. Thanks to Norbert Alwast, Brad Hughes, Lisa Dean, Rochelle Mack, Leah Robbins and Christine Sipos for their comments, criticisms, and support. Bill Brown of Snake Oil Inc. freely shared his considerable understanding of the McMurray Formation during several long talks.

Selected References

Allen, J.R.L., 1990, The Seven Estuary in southwestern Britian: its retreat under marine transgression. and fine sediment regime. Sedimentary Geology, v. 66, p. 13-28

Boersma, J.R., 1991, A large flood-tidal delta and its successive spill over apron: detailed proximal to distal facies relationships (Miocene Lignite Suite, Lower Rhine Embayment Germany) *In*: Clastic Tidal Sedimentology, (eds.) Smith, D.G., Reinson, G.E., Zaitlan, B.A, and Rahmani, R.A., Canadian Society of Petroleum Geologists, Memoir 16, p. 227-254

Caplan, M., and Ranger M.J., 2001, Description and interpretation of coarsening-upward cycles in the McMurray Formation, northeastern Alberta: Preliminary Results. *In*: Rocks the Foundation, Canadian Society of Petroleum Geologists*, extended abstract*

Carrigy, M.A., 1959, Geology of the McMurray Formation, Part 3, General geology of the McMurray area. Alberta Research Council, Memoir 1, 130p.

Davis, R.A., and Clifton, H.E., 1987, Sea-level change and the preservation potential of wave-dominated and tide-dominated coastal sequences*. In*: Nummendal, D., Pilkey,, O.H., and Howard, J.D., eds., Sea level fluctuations and coastal Evolution, Society of Petroleum Geologists, Special Publication 41, p. 167-178

Embry, A.F., 1995, Sequence boundaries and sequence hierarchies: problems and proposals, *In*: Steel, R.J. et. al. (eds.) Sequence Stratigraphy on the Northwestern European Margin, Norwegian Petroleum Society (NPF), Special Publication. p. 1-11.

Finkelstein, K., and Ferland, M.A., 1987, Back-barrier response to sea-level rise, eastern shore of Virginia. *. In*: Nummendal, D., Pilkey,, O.H., and Howard, J.D., eds., Sea level fluctuations and coastal Evolution, Society of Petroleum Geologists, p.145-155

Flach, P.D., 1977, A lithofacies analysis of the McMurray Formation, Lower Steepbank River, Alberta. M.Sc. thesis, University of Alberta. 139p.

Mossop G.D., and Flach, P.D., 1983, Deep channel sedimentation in the Lower Cretaceous McMurray Formation, Athabasca Oil Sands, Alberta. Sedimentology, v. 30, p. 439-509.

Ranger, M.J., and Pemberton, S.G., 1997, Elements of a Stratigraphic Framework for the McMurray Formation in South Athabasca. *In:* Pemberton, S.G., and James, D.P., (eds.) Petroleum Geology of the Cretaceous Mannville Group, Western Canada. CSPG Memoir 18, Canadian Society of Petroleum Geologists Calgary, p. 263-291.

Ranger, M.J., and Gingras, M.K., 2002, Geology of the Athabasca Oil Sands, Field Guide and Overview, Canadian Society of Petroleum Geologists, Calgary, 134 p.

Wightman, D. M., Attalla, M. N., Desmond, A.W., Strobl, R.S., Habtemicael, B, Cotterill, D.K., and Berezsniuk, T., 1995, Resource characterization of the McMurray/ Wabiskaw Deposit in the Athabasca Oil Sands Area: A synthesis, AOSTRA Technical Publication Series 10. 142 p.