geoconvention
Calgary • Canada • May 13-17 2019

The McMurray Conundrum: Brackish Water and Tidal Influence

Murray K. Gingras[1], Shahin E. Dashtgard[2], Andrew D. La Croix[3]

1. Ichnology Research Group, Department of Earth and Atmospheric Sciences, 1-26 Earth Science Building, University of Alberta, Edmonton, Alberta, Canada, T6G 2E3
2. Applied Research in Ichnology and Sedimentology (ARISE) Group, Department of Earth Sciences, Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6
3. Faculty of Science and Engineering, University of Waikato, Hamilton 3240, New Zealand

Summary

In recent years, researchers have been interpreting McMurray Formation valleys as the preserved product of a continental-scale drainage / river-dominated delta (*e.g.* Hubbard et al. 2011; Fustic et al. 2012; Blum and Jennings 2016; Durkin et al. 2017; Baniak and Kingsmith 2018). This “fluvial model” is based on the presence of meander belts in the McMurray A, B1 and B2 valleys. However, the model ignores the fact that the sedimentology and ichnology of the point bars in the McMurray valleys are unlike any fluvial point bars described from the modern or rock record, and it fails to explain the discrepancy between the volume of sediment delivered through a continental-scale drainage and the space available for sediment accumulation, the former of which would rapidly fill the McMurray Sub-Basin. An alternative view to the fluvial model is that of smaller-scale depositional systems with sediment delivery and deposition driven by a combination of tides and fluvial processes. Herein, we discuss the paleoecological and paleodepositional significance of bioturbated channel-associated sands of the McMurray Formation, Alberta, Canada, and make the case for stronger and more persistent tidal control on sedimentation. We also demonstrate why a major continental drainage interpretation is problematic based on stratigraphic correlation, lateral accretion rates and progradation rates.

Facies Analysis

The continental-scale drainage / river-dominated delta interpretation of the McMurray Fm is model-driven and ignores sediment characteristics that contradict the fluvial interpretation. In particular, bioturbation in the McMurray Formation is very common (*e.g.* Pemberton et al. 1982; Ranger and Pemberton 1992; Crerar and Arnott 2007; Musial et al. 2012; Gingras et al. 2016; Shchepetkina et al. 2017; La Croix et al., in press) (Figure 1) and includes: (1) thalweg-associated cross-stratified sands (Facies Association 1 (FA1) that contain mud-lined *Skolithos* and *Cylindrichnus*, and rare occurecnes of trace fossils common to marine systems; (2) bar-related inclined heterolithic stratification (FA2) that contains *Planolites-Teichichnus-Cylindrichnus* associations, *Cylindrichnus-Skolithos-Planolites* assemblages, and monospecific *Gyrolithes*-dominated facies; and, (3) bar-top / tidal-flat deposits (FA3) that are characterized by gently dipping to horizontal, bioturbated, heterolithic media containing *Planolites* and *Cylindrichnus*, with rare *Skolithos*, *Thalassinoides* and *Arenicolites*. As well, channel and point bar deposits are situated in variably bioturbated regional parasequences with abundant evidence of wave reworking and strikingly low amounts of soft-sediment deformation.

The trace-fossil assemblages in the three facies associations common to channel and point bar deposits show many features characteristic of brackish-water deposition: 1) low diversity suites; 2) dominance of marine-derived ichnogenera; 3) diminutive ichnogenera; 4) trace fossils representing the activities of trophic generalists; 5) bioturbation intensity locally reflecting high infaunal biomasses, and 6) evidence of opportunistic colonization strategies. Such trace-fossil assemblages are *only* observed in brackish-water ichnocoenoses in modern settings and in high-certainty rock record examples of brackish-water deposits from around the world and from the Mesozoic onwards (Buatois et al., 2005). Tidally driven sedimentation and brackish water are processes that are required to adequately explain the paleontological and physical sedimentological characteristics of McMurray Formation channel deposits.

Bioturbation ascribable to freshwater conditions is also present, albeit very rarely, in the McMurray Formation. This includes occurrences of irregularly shaped shafts and tunnels displaying variable diameters, as well as back-filled burrows (*Taenidium* and *Naktodemasis)* produced by terrestrial insects. These trace fossils are normally found in association with root traces and pedogenically altered sediments situated near the top of the lower McMurray. These "freshwater" assemblages confirm that at different times and in different environments, both freshwater and brackish water ichnocoenoses were developed in the McMurray Fm and can be discerned easily. Brackish-water thalweg, bar, and bar-top units (FAs 1 to 3) are consistently devoid of pedogenic alteration and root traces, and the trace assemblages in these deposits can only be explained by: (1) the presence of brackish water in the paleo-environment, and (2) the presence of tides to facilitate the landward transport of marine-derived larvae and the establishment of a bar-top tidal zone.

The brackish-water ichnological signature of McMurray channel deposits is supported by an abundance of tidally generated sedimentary structures (sigmoidal bedding, draped foresets, reactivation surfaces and bidirectionally oriented cross-stratification) as well as marine dinocysts recovered from these facies (Hubbard et al., 2011). Tidal lamination is present in both thalweg-associated deposits (Hayes et al. 2017) and in IHS (Timmer et al. 2016), yet these observations cannot be accounted for in the fluvial model. The sedimentological and ichnological arguments for a tidal, brackish-water channel cannot be ignored and they exclude the concept of a Mississippi-scale river as the depositional agent for the McMurray Formation (c.f., La Croix et al., in press). Based on the combination of sedimentological and ichnological characteristics of McMurray Fm channel deposits, the assertion that McMurray Formation channels can be broadly interpreted as "fluvial" is untenable.

Geomorphological and Stratigraphic Considerations

A fundamental problem with the fluvial model is the argument that the channels are genetically decoupled from the parasequences. The prevailing hypothesis is that deposition of regional parasequences was followed by relative sea level fall, and that channels were substantially translated seaward. This was subsequently followed by basin flooding and deposition of regional shales. The most obvious problem with this assertion is that the regional parasequences show no fossil evidence of backshore and upper delta plain forest development, which one would expect if the depositional system migrated substantially seaward. Additionally, if the provenance of regional parasequences were not the same as the channel belts, then why or how are deposits of a continental-scale drainage preserved during periods of sea level fall, but not during highstand? In contrast, if the parasequences <u>are</u> genetically related to the continental-scale fluvial channel belts then they should represent river-dominated delta deposits. This is not the case. Regional parasequences comprise small and thin deltas and shorefaces that are commonly bioturbated and wave reworked; these are not the typical facies associations predicted in models of large river-dominated deltas.

A fluvial interpretation is also not supported by calculated lateral accretion rates of McMurray channels in the southern Athabasca region (La Croix et al., in press). Channel bars dip between 2º and 15º and sand-mud couplet thicknesses in IHS that vary from 16–26 cm. These values return lateral migration rates of 1–7 m year^{-1} (0.1–1 % of channel width assuming a 750 m wide channel). In contrast, lateral accretion rates in the fluvial reach of the Mississippi range from of 25–125 m year^{-1}. The point bars preserved in the McMurray A, B1 and B2 valley indeed show clear evidence of lateral accretion and obvious point bar morphologies, but the rates of accretion in the McMurray are an order of magnitude lower than those of the fluvial to upper backwater reach of the Mississippi River. In fact, the rate of accretion of McMurray channels (1–7 m year^{-1}) lies somewhere between accretion rates recorded in tidal channels (0.1-1 m year^{-1}) and fluvial-dominated channels, attesting to the probable mixed fluvial-tidal origin of McMurray point bars.

Finally, approximations of the rate of progradation and sedimentation of a continental-scale drainage within a confined basin (the McMurray Sub-Basin) would be manifested in nearly 100% preservation of sedimentary structures at the expense of trace fossil preservation. If the McMurray channels are Mississippi scale and the channel is the sole sediment source, the potential sediment contribution would be 210 million tonnes of sediment delivered to the coastline annually. This equates to ~113,200,000 m^3 of sediment per year. The McMurray is a low accommodation system situated in a confined basin. The absolute age of the top of the lower McMurray is 121 Ma (Rinke-Hardekopf et al., in press) and McMurray deposition ceased due to transgression at ~113 Ma (Hein et al., 2013). The stratigraphic thickness between the top of the lower McMurray and the top of the McMurray Fm is typically less than 70 m and the regional parasequences are a maximum of 15 m thick (representing ~1.7 Ma). The valley would need to prograde at a rate of 38 m year^{-1} assuming a valley width of 200 km and evenly distributed sedimentation along the entire valley-confined shoreline. In other words, the entire system would prograde 38,000 km northward every million years. These numbers are, of course, over-the-top, but they do highlight the unlikelihood of a continental-scale drainage being responsible for McMurray deposition.

A More Realistic Interpretation

Our interpretation for McMurray channel belts is that they are not genetically decoupled from the parasequences, and that the architecture of the channel belts evolved slowly through time. We propose tha the channel belts represent lateral accretion of tide-influenced to tide-dominaed channels in a tide-dominated delta, where point bars were situated along the fluvial-tidal transition. As well, we hypothesize that the McMurray Valley stsems do not represent the preserved architecture of a single river system, but an amalgamation of multiple depositional systems whose architecture evolved as the shoreline prograded. A tidal channel, or fluvially affected tidal channel interpretation may present different problems, but more clearly explains the parasequence-channel relations, the sedimentological and ichnological characteristics of both regional parasequences and channel belts, the slow lateral accretion of McMurray point bars, and the nearly complete absence of vegetation in all upper McMurray parasequences. As well, a smaller depositional system would explain the obvious paucity of sediment that would occur at the mouth of a continental-scale drainage. In other words, a tide-dominated delta with a medium-sized river system (100,000 to 250,000 km^2 drainage area) better explains the range of characteristics of the McMurray Fm parasequences and channels.

References

Baniak, G.M. and Kingsmith, K.G., 2018. Sedimentological and stratigraphic characterization of Cretaceous upper McMurray deposits in the southern Athabasca oil sands, Alberta, Canada. AAPG Bulletin, 102(2), pp.309-332.

Blum, M. and Jennings, D., 2016. The McMurray conundrum: Conflicting interpretations of environment of deposition and paleogeography. In *AAPG 2016 Annual Convention and Exhibition, Calgary, Canada, article* (Vol. 51338).

Crerar, E.E. and Arnott, R.W.C., 2007. Facies distribution and stratigraphic architecture of the lower Cretaceous McMurray Formation, Lewis property, northeastern Alberta. *Bulletin of Canadian Petroleum Geology*, *55*(2), pp.99-124.

Durkin, P.R., Hubbard, S.M., Holbrook, J. and Boyd, R., 2017. Evolution of fluvial meander-belt deposits and implications for the completeness of the stratigraphic record. *Bulletin*, *130*(5-6), pp.721-739.

Fustic, M., Hubbard, S.M., Spencer, R., Smith, D.G., Leckie, D.A., Bennett, B. and Larter, S., 2012. Recognition of down-valley translation in tidally influenced meandering fluvial deposits, Athabasca Oil Sands (Cretaceous), Alberta, Canada. Marine and Petroleum Geology, 29(1), pp.219-232.

Gingras, M.K., MacEachern, J.A., Dashtgard, S.E., Ranger, M.J., Pemberton, S.G. and Hein, F., 2016. The significance of trace fossils in the McMurray Formation, Alberta, Canada. *Bulletin of Canadian Petroleum Geology*, *64*(2), pp.233-250.

Hayes, D.A., Timmer, E.R., Deutsch, J.L., Ranger, M.J. and Gingras, M.K., 2017. Analyzing dune foreset cyclicity in outcrop with photogrammetry. *Journal of Sedimentary Research*, *87*(1), pp.66-74.

Hein, F.J., Dolby, G. & Fairgrieve, B., 2013. A Regional Geologic Framework for the Athabasca Oil Sands, Northeastern Alberta, Canada. In: *Heavy-Oil and Oil-Sand Petroleum Systems in Alberta and Beyond* (Ed. by F. J. Hein, D. A. Leckie, S. Larter & J. R. Suter), **Studies in Geology No. 64**, 207-250. AAPG, Calgary.

Hubbard, S.M., Smith, D.G., Nielsen, H., Leckie, D.A., Fustic, M., Spencer, R.J. and Bloom, L., 2011. Seismic geomorphology and sedimentology of a tidally influenced river deposit, Lower Cretaceous Athabasca oil sands, Alberta, Canada. *AAPG Bulletin*, *95*(7), pp.1123-1145.

La Croix, A.D., Dashtgard, S.E., and MacEachern, J.A., in press. Using a modern analogue to interpret depositional position within ancient fluvial-tidal channels: an example from the McMurray Formation, Canada. Geoscience Frontiers, 37 p.

Musial, G., Reynaud, J.Y., Gingras, M.K., Féniès, H., Labourdette, R. and Parize, O., 2012. Subsurface and outcrop characterization of large tidally influenced point bars of the Cretaceous McMurray Formation (Alberta, Canada). *Sedimentary Geology*, *279*, pp.156-172.

Pemberton, S.G., 2001. Ichnology & sedimentology of shallow to marginal marine systems. Geol. Assoc. Can., Short Course, 15, p.343.

Pemberton, S.G., Flach, P.D. and Mossop, G.D., 1982. Trace fossils from the Athabasca oil sands, Alberta, Canada. *Science*, *217*(4562), pp.825-827.

Ranger, M.J. and Pemberton, S.G., 1992. The sedimentology and ichnology of estuarine point bars in the McMurray Formation of the Athabasca Oil Sands deposit, north-eastern Alberta, Canada.

Rinke-Hardekopf, L., Dashtgard, S.E. & Maceachern, J.A., in press. Earliest Cretaceous Transgression of North America Recorded in Thick Coals: Mcmurray Sub-Basin, Canada. *International Journal of Coal Geology*.

Shchepetkina, A., Speta, M., Gingras, M.K., Rivard, B. and Pemberton, S.G., 2017. Hyperspectral imaging as an aid for facies analysis in massive-appearing sediments: a case study from the middle McMurray Formation. *Bulletin of Canadian Petroleum Geology*, *65*(2), pp.262-278.

Timmer, E.R., Gingras, M.K., Morin, M.L., Ranger, M.J., Zonneveld, J.P. and Plint, G., 2016. Laminae-scale rhythmicity of inclined heterolithic stratification, lower Cretaceous McMurray Formation, NE Alberta, Canada. *Bulletin of Canadian Petroleum Geology*, *64*(2), pp.199-217.

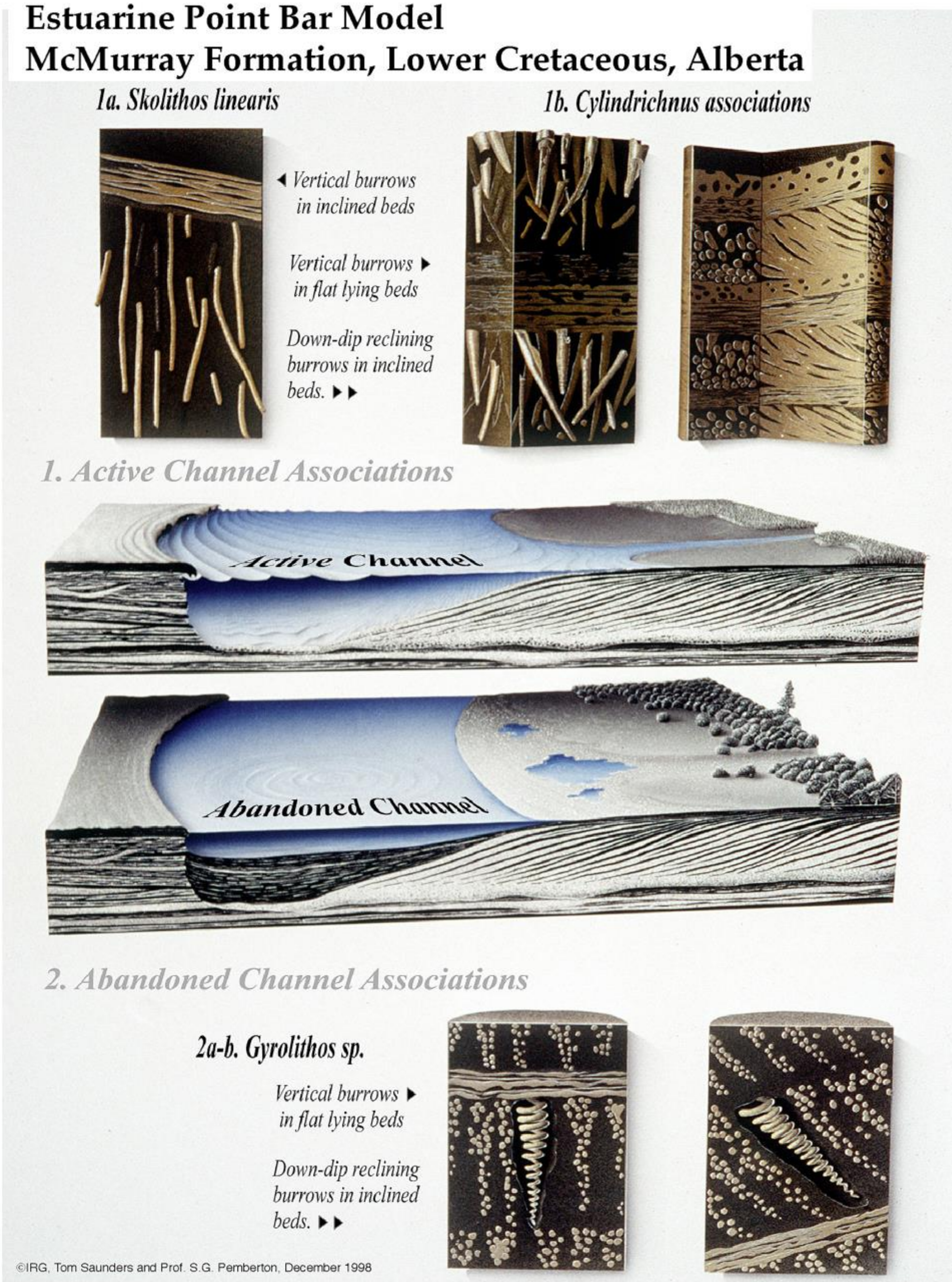

Figure 1. McMurray Formation ichnological associations from IHS. Shown are active point-bar assemblages that are dominated by the trace fossils *Skolithos* and *Cylindrichnus* (1a and 1b). Also depicted are the typical early-stage abandonment trace fossils Gyrolithes (2a and 2b). Both *Cylindrichnus* and *Gyrolithes* are not known from fresh-water settings. Artwork by Tom Saunders. From Pemberton et al. 2001.