# The McMurray Formation ‘A2 Valley’: Where is the shoreline?

*Paul R. Durkin[1], Stephen M. Hubbard[2], Sean C. Horner[2], Harrison K. Martin[2,3], Cynthia A. Hagstrom[2], Dylan Evanik[2]*

*[1]Department of Geological Sciences, University of Manitoba, [2]Department of Geoscience, University of Calgary, [3]Department of Earth and Atmospheric Sciences, Indiana University*

## Summary

Interpreting the position of a paleo-shoreline based on the characteristics of fluvial deposits is inherently challenging in the rock record. However, recent studies of modern fluvial systems that parameterize morphological changes in channels as they flow towards a shoreline can enable honed paleogeographic reconstructions. The depositional environment of the Lower Cretaceous McMurray Formation has been the subject of much debate and the presence of extensive channel-belt deposits provides an opportunity to test the applicability of channel-belt morpho-metric analysis for paleoenvironmental interpretations. An extensive dataset of borehole (well log, core, FMI) and 3D seismic data has constrained A2 Valley channel belts from Township 69 to 87 (180 km). Calculations of slope, backwater length, and estuarine convergence length are used to estimate position of the paleo-shoreline. We estimate a slope of $5.4 \times 10^{-5}$, a backwater limit of ~740 km, and a tidal convergence length of 50 - 60 km. Morpho-metric comparisons are made with analogous fluvial systems, including the Lower Mississippi and Sittang Rivers. We conclude that deposition of the analyzed segment of the A2 Valley took place in the upper backwater reach, with an equivalent shoreline at least 150 km north of Township 87 in northeastern Alberta. The application of morpho-metric parameters to estimate paleogeographic and paleoenvironmental conditions demonstrates a novel approach for interpreting the rock record, with implications for modern analogue selection and subsurface characterization of hydrocarbon-bearing strata.

## Introduction

The recent “McMurray Conundrum” debate has highlighted opposing views regarding the paleoenvironment of “middle” McMurray Formation point-bar deposits (Blum and Jennings, 2016; Gingras et al., 2016). Studies grounded in seismic geomorphology and process sedimentology suggest that the point bars are the deposits of a large-scale fluvial system with variable tidal influence (Hubbard et al., 2011; Durkin et al., 2017), whereas studies focused on trace fossil assemblages suggest deposition occurred much closer to the paleo-shoreline in an estuarine setting (Pemberton et al., 1982; Gingras et al., 2016). Evidently, identifying the position of the paleo-shoreline may provide insights that will help resolve the debate. Unfortunately, the time-equivalent shoreline deposits were removed during repeated Pleistocene glaciations (Fenton and Nielsen, 1994; Hayes et al., 1994). However, based on observations from modern systems, the paleo-shoreline position can be estimated using the morphological changes observed in a well-constrained McMurray ‘A2 Valley’ channel belt (Fig. 1; Hein et al., 2006).

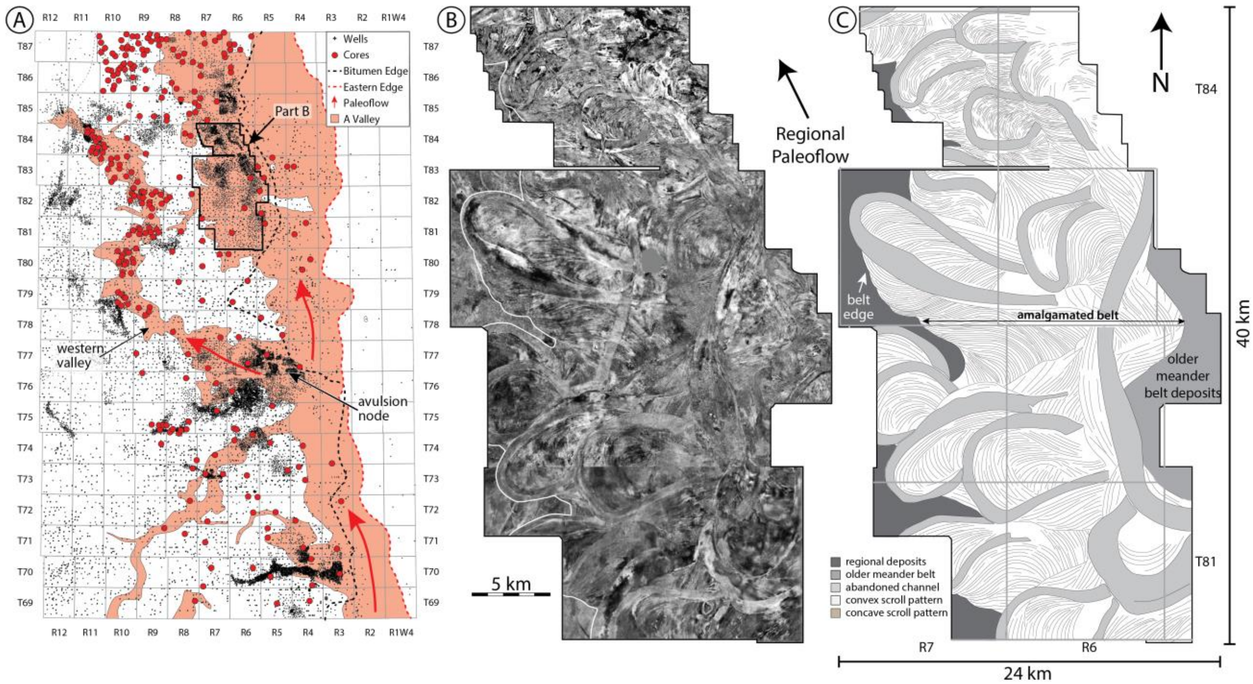


*Figure 1: Cretaceous McMurray Formation A2 Valley (Hein and Cotterill, 2006). A) Planform extent of the A2 Valley mapped from well logs, core, and 3D seismic data. The avulsion node denotes where a belt-scale avulsion occurred during the evolution of the A2 valley, resulting in the northward flowing western valley (Martin et al., in Review). B) 3D seismic time slice data from near the top of the McMurray Formation within the A2 Valley. C) Line-drawing trace depicting the seismic geomorphology of Part B, characterized by an amalgamated channel-belt deposit at least 40 km long and up to 20 km wide. This depositional architecture is representative of the deposits in the A2 Valley mapped in Part A.*

## Previous Work and Methods

A regional mapping effort over much of the Athabasca Oil Sands Region (AOSR) has demonstrated the extent of McMurray A2 Valley deposits (Fig. 1A; Hagstrom, 2018). Following the stratigraphic framework of Hein and others (2006), A2 Valley deposits are mapped as channel belts that incise regional parasequence sets (Units B2, B1, & A2), subtending from a flooding surface at the base of the A1 unit (if present) or the top of the McMurray Formation (Horner et al., 2018). Detailed mapping indicates the A2 Valley extends for more than 180 km from Township 69 to 87 (Fig. 1A); previous studies have shown an extension of this trend to at least Township 96 (i.e., 270 km total; Nardin et al., 2007).

Several studies have characterized point-bar deposits of the A2 Valley (Hubbard et al., 2011; Musial et al., 2012; Durkin et al., 2017; Martinius et al., 2017), and reported consistent facies and geomorphological parameters including sandstone- and IHS-dominated, large-scale (30-45 m thick, km's in length/width) point bars and counter point bars, as well as mudstone-dominated abandoned channel fills up to 750 m wide and 40 m deep (Fig. 1B, C). These deposits are all variably bioturbated with a low-diversity, diminutive suite of marine trace fossils. We utilize recently published scaling relationships to calculate slope (Holbrook and Wanas, 2014), backwater length ($L_b$) (Bhattacharya et al., 2016), and estuarine convergence length ($L_w$) (Davies and Woodroffe, 2010; Leuven et al., 2018) to inform estimates of the paleo-shoreline position. Key parameters include grain size ($d_{50}$), mean channel depth ($d_m$), mean channel width ($w_c$), abandoned channel width ($w_{ac}$), and channel-belt width ($w_{cb}$). Morpho-metrics are compared with those of modern depositional systems, including the Lower Mississippi River, U.S.A., and Sittang River, Myanmar.

## Results and Conclusions

Paleo-hydrologic parameters are quantified using data from core, well logs, and 3D seismic surveys. The slope of the A2 Valley channel-belt is estimated to have been $5.4 \times 10^{-5}$ with a paleo-backwater limit ($L_b$)

of ~740 km. In the study area, mean abandoned channel fill width is ~700 m, which shows no appreciable variation over 76.5 river kilometers. Mean channel-belt width-to-thickness ratio is ~400:1. The very low gradient and long paleo-backwater limit has implications for the position of the paleoshoreline. As rivers flow through the backwater zone, they undergo predictable changes in morphology from wide, amalgamated channel belts in the upper backwater zone, to narrow, avulsive channel belts in the lower backwater zone (Blum et al., 2013). Comparisons with the channel-belt width-to-thickness ratios from the Lower Mississippi and Sittang Rivers suggest that the deposits depicted in Figure 1B accumulated in the upper backwater zone, which could be >370 km from the paleo-shoreline ($0.5L_b$). A predictable morphological change that occurs as rivers flow through the backwater zone into estuaries is the exponential increase in channel width from the tidal limit to the river mouth (the “estuarine convergence zone”; Leuven at al., 2018). The consistency in mapped channel widths over 76.5 river kilometers (Figure 1B and C) suggests deposition occurred landward of the estuarine convergence zone.

Collectively, the amassed morphological evidence indicates that the channel-belt sediments from Township 81-84, R6-7 (Fig. 1B, C) were not deposited in proximity to the paleo-shoreline. We estimate the paleo-shoreline was positioned 100s of km to the north, and this conclusion has direct implications for the depositional environment and the applicability of modern analogues for reservoir distribution analyses.

**References**


Bhattacharya, J.P., Copeland, P., Lawton, T.F., and Holbrook, J., 2016. Estimation of source area, river paleo-discharge, paleoslope, and sediment budgets of linked deep-time depositional systems and implications for hydrocarbon potential: Earth-Science Reviews, v.153, p. 77-110.

Blum, M.D., Martin, J., Milliken, K., and Garvin, M., 2013. Paleovalley systems: Insights from Quaternary analogs and experiments: Earth-Science Reviews, v. 116, p. 128-169.

Blum, M., and Jennings, D. 2016a. The McMurray conundrum: conflicting interpretations of environment of deposition and paleogeography. Abstracts, 2016 Annual Convention, American Association of Petroleum Geologists, Calgary, Alberta. [Abstr.]

Davies, G., and Woodroffe, C.D., 2010, Tidal estuary width convergence: Theory and form in north Australian estuaries: Earth Surface Processes and Landforms, v. 35, p. 737–749.

Durkin, P.R., Boyd, R.L., Hubbard, S.M., Shultz, A.W., and Blum, M.D., 2017. Three-dimensional reconstruction of meander-belt evolution, Cretaceous McMurray Formation, Alberta Foreland Basin, Canada: Journal of Sedimentary Research, v. 87(10), p. 1075-1099.

Fenton, M.M. and Nielsen, E., 1994. Chapter 26, Quaternary Geology of the Western Plains: in Mossop, G.D. and Shetsen, I., eds., Geological Atlas of the Western Canada Sedimentary Basin: Canadian Society of Petroleum Geologists and Alberta Research Council.

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

Hagstrom, C.A., 2018. Stratigraphic architecture and lithofacies distribution in meander-belt deposits, South Saskatchewan River and Cretaceous McMurray Formation, Alberta. University of Calgary, Ph.D. Thesis.

Hayes, B.J.R., Christopher, J.E., Rosenthal, L., Los, G., McKercher, B., Minken, D., Tremblay, Y.M., and Fennel, J., 1994. Chapter 19: Cretaceous Mannville Group of the Western Canada Sedimentary Basin, in Mossop, G.D., and Shetsen, I., eds., Geological Atlas of the Western Canada Sedimentary Basin: Canadian Society of Petroleum Geologists and Alberta Research Council.

Hein, F.J. and Cotterill, D.K., 2006. The Athabasca Oil Sands – A regional geological perspective, Fort McMurray area, Alberta, Canada: Natural Resources Research, v. 15(2), p. 85-102.

Holbrook, J. and Wanas, H., 2014. A fulcrum approach to assessing source-to-sink mass balance using channel paleohydrologic parameters derivable from common fluvial data sets with an example from the Cretaceous of Egypt. Journal of Sedimentary Research, v. 84, p. 349-372.

Horner, S.C., Hubbard, S.M., Martin, H.K., Hagstrom, C.A., and Leckie, D.A., 2018. The impact of Aptian glacio-eustacy on the stratigraphic architecture of the Athabasca Oil Sands, Alberta, Canada. Sedimentology, Accepted Article, doi: 10.1111/sed.12545

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

Leuven, J.R.F.W., van Maanen, B., Lexmond, B.R., van der Hoek, B.V., Sprujit, M.J., Kleinhans, M.G., 2018. Dimensions of fluvial-tidal meanders: Are they disproportionally large? Geology, v. 46, p. 923-926.,

Martin, H.K., Hubbard, S.M., Hagstrom, C.A., Horner, S.C. and Durkin, P.R. Planform recognition and implications of a Cretaceous-aged continental-scale river avulsion node in the Western Interior Seaway. Submitted to Journal of Sedimentary Research (in Review).

Martinius, A.W., Fustic, M., Garner, D.L., Jablonski, B.V.J., Strobl, R.S., MacEachern, J.A., Dashtgard, S.E., 2017. Reservoir characterization and multiscale heterogeneity modeling of inclined heterolithic strata for bitumen-production forecasting, McMurray Formation, Corner, Alberta, Canada: Marine and Petroleum Geology, v. 82, p. 336-361.

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, v. 279, p. 156-172.

Nardin, T., J. Carter, B. Falls, J. Irish, R. Stancliffe, B. Varban, N. Wilson, L. Zabcic, and L. Pratt, 2007, Sequence stratigraphic and depositional facies framework of the Lower Cretaceous McMurray Formation, Kearl oil sands project, Alberta (abs.): AAPG Hedberg Conference, Banff, Alberta, Canada: AAPG Search and Discovery article 90075.

Pemberton, S., Flach, P., and Mossop, G. 1982. Trace-fossils from the Athabasca Oil Sands, Alberta, Canada. Science, 217: 825–827.