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Not All IHS Was Created Equal-

A retrospective and prospective look at inclined heterolithic stratification of tidal-fluvial point bars of the middle McMurray Formation of Northeastern Alberta, Canada

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Abstract

Within academia and industry, there is a renaissance occurring, reforming our understanding of point bars and more specifically tidal-fluvial point bars of the fluvial-to-marine transition zone. Though early workers (Jackson 1975; 1976;1981; Bridges and Leeder, 1976; Allen et al.,1980, Reineck and Singh, 1980; Mossop and Flach, 1983; Miall, 1985; Thomas et al., 1987; Smith 1988; Wightman and Pemberton, 1997; Hein et al., 2000; Ranger and Gingras, 2001; etc.) of point bars and bars within the fluvial-marine transition provided fundamental insights which guide current thinking, in the past five years, marked advancements have reshaped our understanding of the processes (Willis and Tang, 2010; Dalrymple et al., 2011; Martinius and Van den Berg, 2011; Nittrouer et al., 2012; Ashworth and Lewin, 2012; Sisulak and Dashtgard, 2012; Blum et al., 2013); geomorphological elements (Smith et al.,2009; Hubbard et al., 2011; Musial et al., 2011; Fustic et al., 2012); architectural elements (Labreque et al., 2011; Jablonski 2012; Nardin et al., 2012;) and ultimately the deposits of tidal-fluvial point bars.

This renaissance in tidal-fluvial understanding has largely been spurred by great interest in the bituminous Lower Cretaceous (Aptian-Albian) McMurray Formation which is interpreted to be deposited within the fluvial-marine transition zone. Furthermore, a large proportion of the middle McMurray Formation was deposited within tidal-fluvial point bar environments, which can be dominantly composed of inclined heterolithic stratification (IHS; Thomas et al., 1987). *In Situ* bitumen extraction techniques (i.e., SAGD) appear to be extremely sensitive to reservoir heterogeneity associated with the distribution of this IHS, particularly the silt beds (Strobl et al., 1997; Nardin et al., 2012; Strobl, 2012). This prompted current and ongoing research into the developing a better understanding of 3-dimensional architecture, spatial distribution and depositional processed related to these IHS packages of tidal-fluvial point bars.

During two field campaigns within the Fort McMurray area, insight into seasonal IHS development was established. The Type Section, Abasand, Mackay Gauging Station, Steepbank River outcrops and the CNRL Bridge Section are all areas of current study for their diversity in form and diversity of IHS (Fig. 1). Fustic et al., (2012) synthesized previously established models (Smith, 1985; Wood, 1989, Wightman and Pemberton, 1997) to suggest that tidal-fluvial point bars have a general trend “around the bend” (i.e., sand -dominated to sandy IHS to muddy IHS both laterally and downstream; Fig 2A) and that the proportion of upper point bar versus lower point bar deposits increases in progressively younger point bar layers, resulting in a wedge shaped geometry of the lower

point bar deposits. However, analysis of these selected outcrops suggest that, though there is indeed a change in deposition around the bend, there is a variety of different depositional expressions (Fig. 2B-E), dependent on the relative proximity to the ocean, the shape of the bend, the migration history of the bend (i.e., reactivation, rotation, down-valley migration) the variation in channel hydrodynamics (i.e., seasonal discharge variation, susceptibly to chute and neck cut-off; tidal influence variation) and preservation potential. Most mudstone interbeds consist dominantly of silt-sized quartz and chert grains, hence, these are regarded as silt-beds in this paper.

Similar to Nardin et al., (2012) first results of a quantitative evaluation of silt-bed length within the IHS, to create a statistical database of horizontal and vertical silt bed parameters. The data-collection method differs from that used in Nardin et al., (2012) which used light detection and ranging scans (LIDAR). The Challenging Reservoirs team did not find LIDAR to be workable due to the low contrast and light absorbing nature of these bitumen-rich outcrops. Instead, the team used GigaPan™ technology to capture extremely high resolution, scaled photos of the outcrop and later post processed the photos to obtain silt-bed lengths, IHS “facies”, spatial orientation (gridded location vertically and horizontally) and apparent dip of the bedding surfaces (Fig. 3). This horizontal data was then compared to detailed, “bed-by-bed” vertical logging of the IHS exposures that were photographed. Integration of vertical and horizontal data was identified as a key necessity in order to make the dataset applicable for comparison with the subsurface.

Initial analysis of this quantitative data suggests that individual silt beds (1-10 cm thick; mm laminated to structureless; relatively low permeability compared to the sand beds) at selected outcrops (Type Section particularly) are less continuous (less than 10 m lateral extent) than originally thought before undergoing the study. This discontinuity of individual silt beds is interpreted to be related to erosion during the fluvial-flood stage. During these high velocity, high discharge events, the erratic nature of turbulence causes differential erosion of previously deposited sediments (i.e., silt beds). This process leads to the creation of amalgamated sand beds, and enhanced silt-bed discontinuity. Even though individual silt beds appear to be discontinuous in the outcrops sampled, it appears that there are “zones” within the IHS stratigraphy where silt beds are more abundant. These zones vary in thickness (50- 200 cm in thickness) and are laterally continuous across an entire outcrop bowl, and can often be traced for over 100 metres across numerous outcrop bowls. The abundance of the silt beds, and the resulting complex and tortuous permeability pathways (due to the individual mud beds within the zones being laterally discontinuous) likely indicate that these zones will be barriers to steam chamber development in SAGD over the life of a well-pair. These zones could be another depositional form of MSCs described by Labreque et al., (2011) in the subsurface, and Jablonski (2012) in Steepbank River Outcrops 3 and 4.

The ongoing research into tidal-fluvial point bars and the IHS of which they are composed of is a continuously evolving field. As research develops, it is becoming apparent that there is always another order of complexity that can be incorporated into our understanding. Hopefully this surge of tidal-fluvial research will continue into the coming years, which will not only benefit our geological/sedimentological knowledgebase, but also will directly impact recoveries of bitumen from IHS-dominated oil-sands reservoirs.

Acknowledgements

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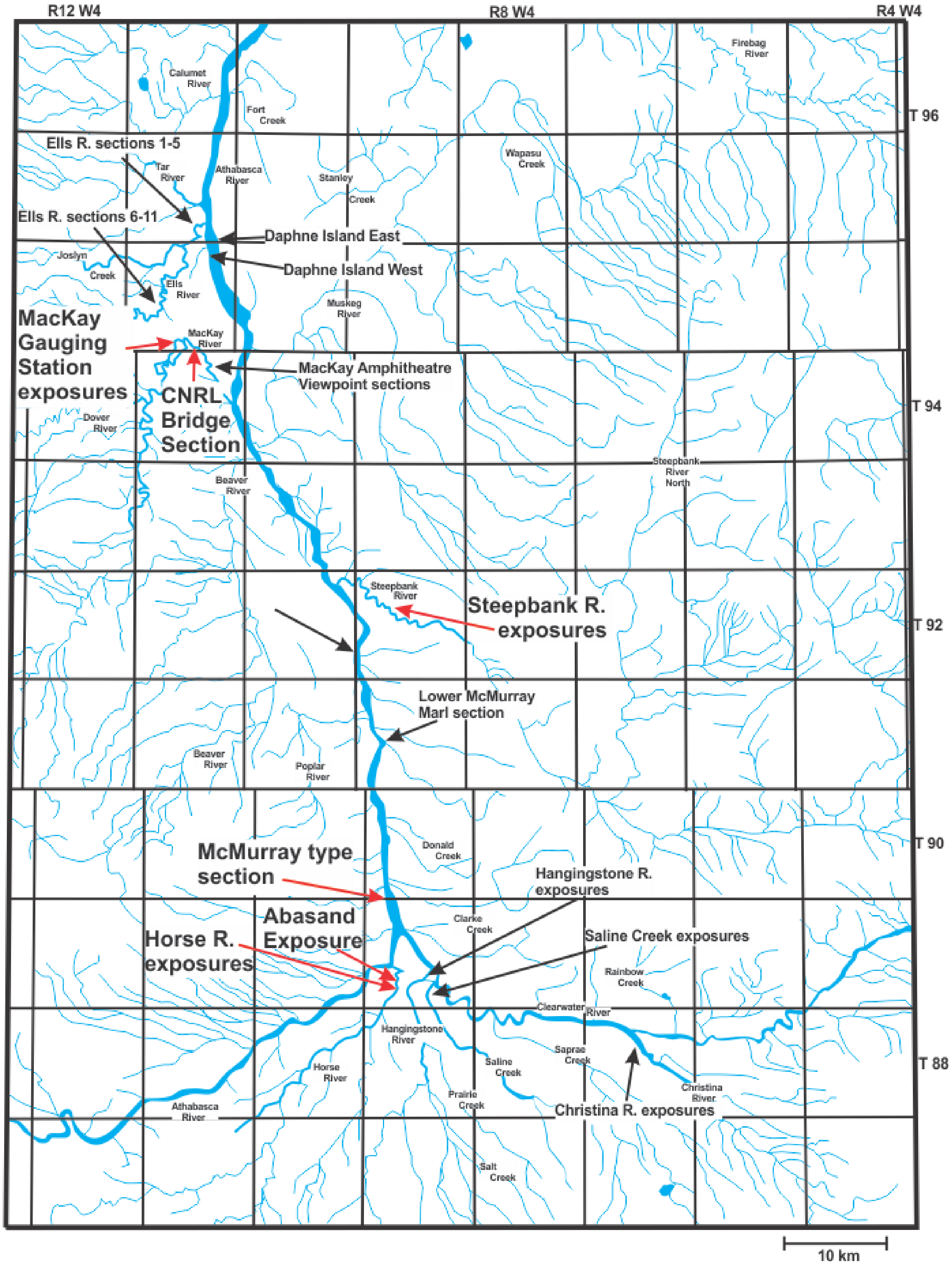

Figure 1. Regional map of the Fort McMurray Area, showing the major outcrop exposures. The current studies being undertaken by the Challenging Reservoirs team are focused on the outcrops highlighted by the red arrow. Collectively, these outcrops reveal a variety of IHS depositional expressions. Modified from Hein et al., (2001).

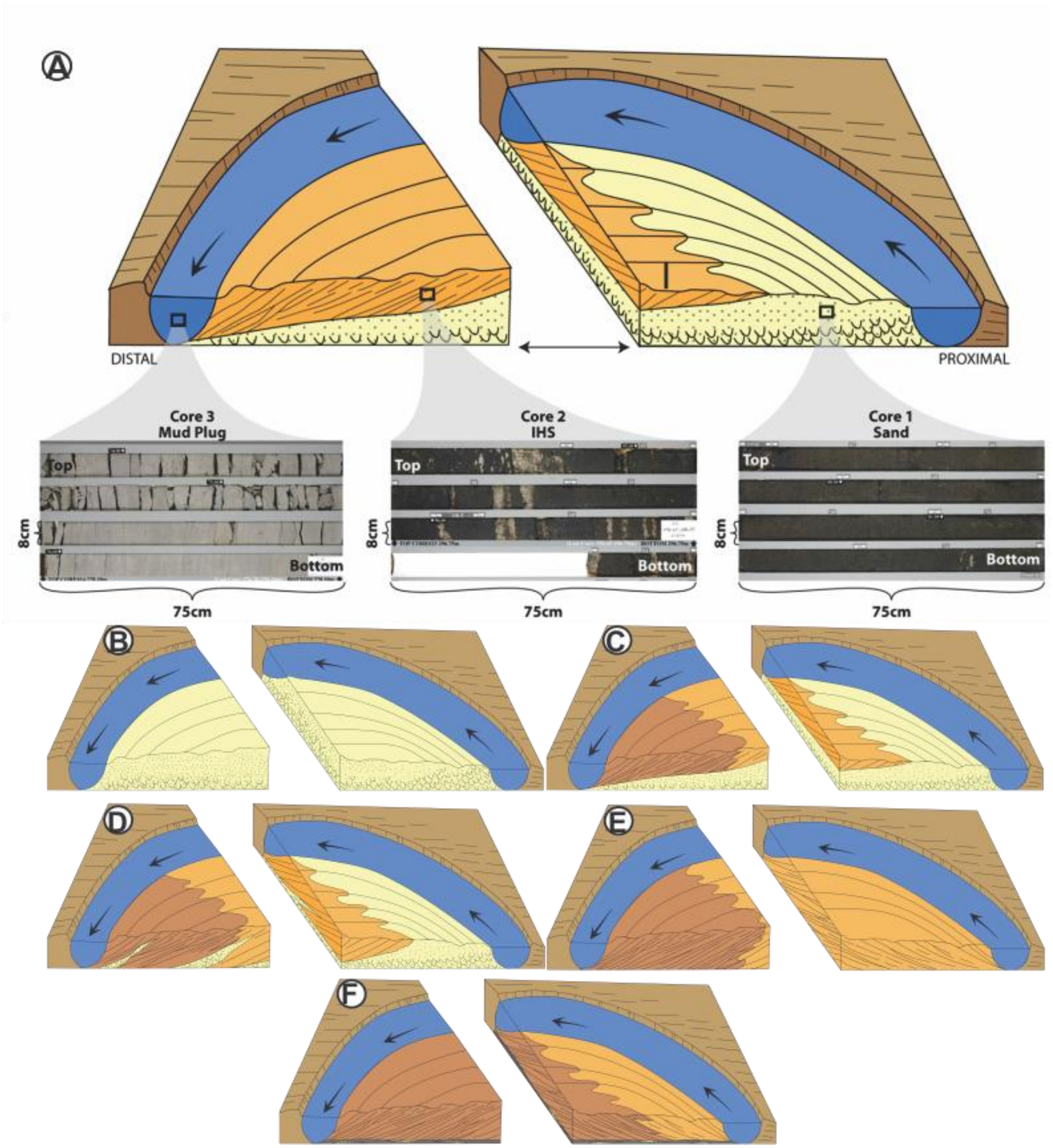

Figure 2. Theoretical Depositional Models for a variety of tidal-fluvial point bars based on analysis of McMurray Outcrops and developing theories related to the marine-fluvial transition zone. A is from Fustic et al. (2012) showing a transition of depositional facies “around a bend” with corresponding examples of each facies from core. B -F expands on this work, suggesting that there are multiple different facies arrangements, which are dictated by a number of factors which are discussed in the text. From B -F there is a transition from sand-dominance to mud dominance. Theoretically, as one moves more seaward towards the turbidity maximum, it might be expected to transition from A - E throughout the fluvial-to-marine transition zone. However, this may not be the case as the type of point bar that forms is dependent on a variety of first order controls. An archetypal tidal-fluvial point bar is represented by (C), although subsurface evaluation suggests that there are is a high frequency of point bars which contain IHS deposits to the base of the channel (D-F). Sand is represented by light yellow, sand-dominated IHS is represented by orange, mud-dominated IHS represented by maroon, fluid mud deposits represented by grey. (C) is modified from Fustic et al., (2012).

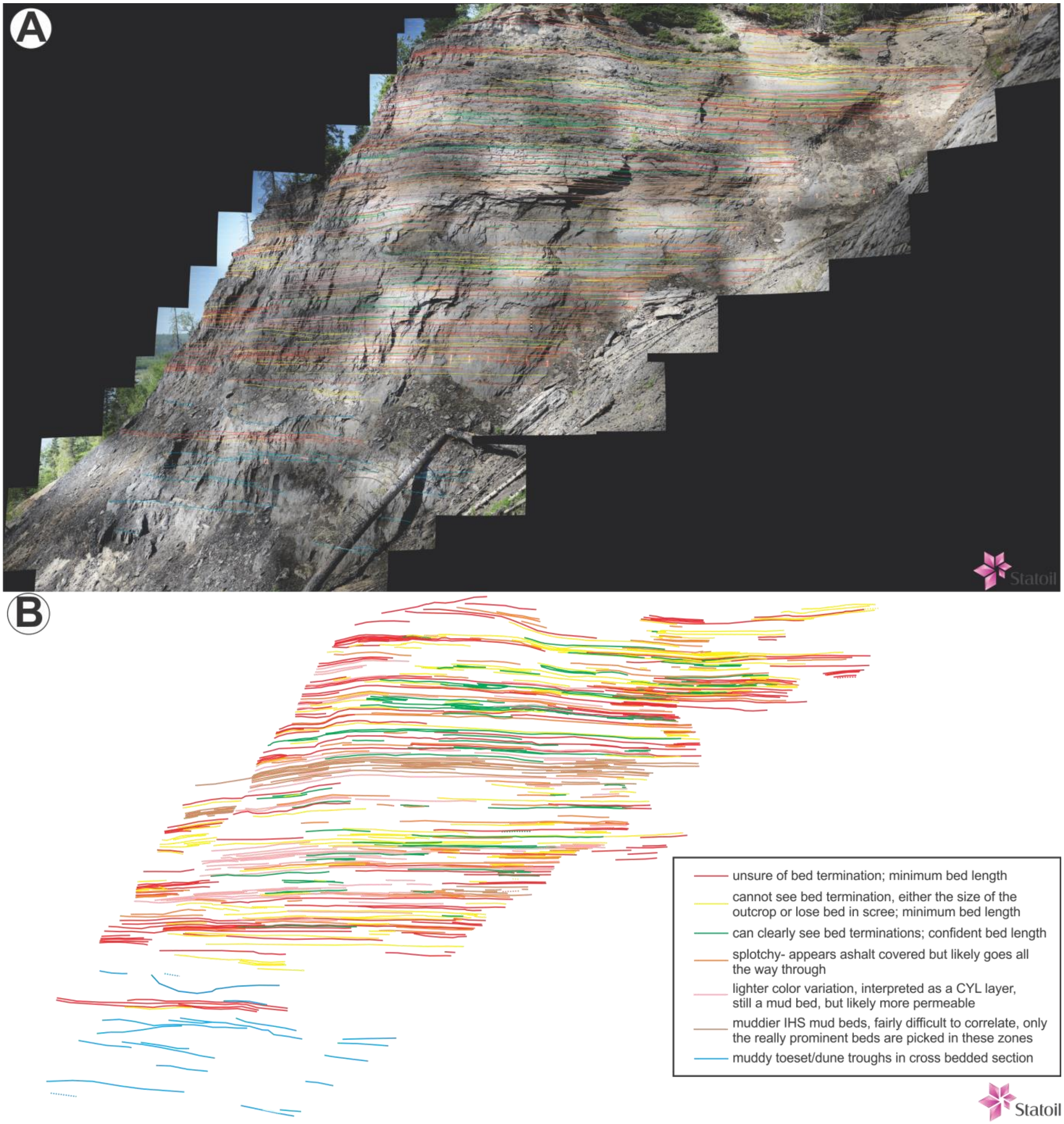

Figure 3. GigaPan™ Photomosaic and IHS bedding traces of a selected bowl from the McMurray Type Section. (A) The GigaPan ™ method of photomosaic creation allows for extremely high resolution stitching, allowing for the tracing of cm-scale thickness silt beds within outcrop bowls. By first scaling the outcrop (orange spray paint) it is possible to post-process the photo, and get quantitative results from the silt bed tracing, including apparent dip, and lateral bed length. (B) The schematic representation of each individual silt bed. The color of the bed is a classification code as displayed within the legend. Analysis of this schematic suggests that individual mud beds may not be very continuous (less than 10 m) however there do appear to be zones where mud beds are more abundant.

References

Allen, G.P., H.C. Salomon, P. Bassoullet, Y. du Penhoat, C. De Grandpre, 1980. Effects of tides on mixing and suspended sediment transport in macrotidal estuaries. Sedimentary Geology, v. 26, p. 69-90.

Ashworth, P.J., Lewin, J., 2012. How do big rivers come to be different? Earth Science Reviews v. 114, p. 84-107.

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

Bridges, P.H., Leeder, M.R., 1976. Sedimentary model for intertidal mudflat channels, with examples from the Solway Firth, Scotland. Sedimentology v.23, p. 533-553.

Dalrymple, R.W., Mackay, D.A., Ichaso, A.A., Choi, K.S., 2011. Processes, morphodynamics and facies of tide-dominated estuaries. In Davis, R.A., Jr., Dalrymple, R.W. (Eds.). Principles of Tidal Sedimentology. Springer, p. 79-107.

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

Hein, F.J., Cotteril, D.K., Berhane, H., 2000. An atlas of lithofacies of the McMurray Formation, Athabasca Oil Sand Deposit, northeastern Alberta: Surface and Subsurface. Alberta Energy and Utilities Board Earth Science Report 2000-07, 217 p.

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. American Association of Petroleum Geologists Bulletin, v. 95, p. 1123-1145.

Jackson II, R.G., 1975. Velocity–bedform-texture patterns of meander bends in the lower Wabash River of Illinois and Indiana. Geological Society of America Bulletin v .86, p. 1511-1522.

Jackson II, R.G., 1976. Depositional model of point bars in the Lower Wabash River. Journal of Sedimentary Petrology, v. 46, p. 579-594.

Jackson II, R.G., 1981. Sedimentology of muddy fine-grained channel deposits in meandering streams of the American Middle West. Journal of Sedimentary Petrology, v. 51, p. 1169-1192.

Labreque, P.A., Jensen, J.L., Hubbard, S.M., 2011b. Cyclicity in lower Cretaceous point bar deposits with implications for reservoir characterization, Athabasca Oil Sands, Alberta Canada. Sedimentology, v. 242, p. 18-33.

Martinius, A.W., Van den Berg, J.H., 2011. Atlas of Sedimentary Structures in Estuarine and Tidally-Influenced River Deposits of the Rhine-Meuse-Scheldt System. Houten, European Association of Geoscientists and Engineers Publication. 297 p.

Miall, A. D., 1985. Architectural-element analysis: A new method of facies analysis applied to fluvial deposits. Earth Science Reviews, v. 22, p. 261-308.

Mossop, G.D., Flach, P.D., 1983. Deep channel sedimentation in the Lower Cretaceous McMurray Formation, Athabasca Oil Sands, Alberta. Sedimentology, v. 30, p. 493-509.

Musial, G., Reynaud, J., Gingras, M.K., Fenies, H., 2011. Subsurface and outcrop characterization of large tidally influenced point bars of the Cetaceous McMurray Formation (Alberta, Canada). Sedimentary Geology, v. 17, 17 p.

Nardin, T. R., Feldman, H.R., Carter, B.J,, 2012. Stratigraphic architecture of a large-scale point-bar complex in the McMurray Formation: Light detection and ranging and subsurface data integration at Syncrude's Mildred Lake Mine, Alberta, Canada, in F. J. Hein, D. Leckie, S. Larter, and J. R. Suter, eds., Heavy oil and oil sand petroleum systems in Alberta and beyond: AAPG Studies in Geology 64, p. 273 – 311.

Nittrouer, J.A., Shaw, J., Lamb, M.P., Mohrig, D., 2012. Spatial and temporal trends for water-flow velocity and bed-material sediment transport in the lower Mississippi River. Geological Society of America Bulletin, v. 124, p. 400-414.

Ranger, M.J., Gingras, M.K., 2001. Geology of the Athabasca Oil Sands – Field Guide and Overview. Canadian Society of Petroleum Geologists, Calgary, 123 p.

Reineck, H.E., Singh, I.B., 1980. Depositional Sedimentary Environments: with Reference to Terrigeneous clastics (2nd) edition. New York, Springer – Verlag, 549 p.

Sisulak, C.F., and Dashtgard, S.E., 2012. Seasonal controls on the development and character of inclined heterolithic stratification in a tide-influenced, fluvially dominated channel: Fraser River, Canada. Journal of Sedimentary Research v. 82, pp. 244-257.

Smith, D.G., 1988. Modern point bar deposits analogous to the Athabasca Oil Sands, Alberta, Canada. In deBoer, P.L., van Gelder, A., and Nio, S.D., (Eds.) Tide-Influenced Sedimentary Environments and Facies. Dordrecht, Reidel Publishing Co., p. 417-432.

Smith, D.G., Hubbard, S.M., Leckie, D.A., Fustic, M., 2009. Counter point bar deposits: lithofacies and reservoir significance in the meandering modern Peace River and ancient McMurray Formation, Alberta, Canada. Sedimentology, v. 56, p. 1655 -1669.

Strobl, R., 2012. Integration of steam-assisted gravity drainage fundamentals with reservoir characterization of optimize production. In Hein, F.J., Leckie, D., Larter, S., Suter, J. (eds). Heavy Oil and oil-sand petroleum systems in Alberta and beyond, AAPG Studies in Geology 64. pp. 1-14.

Thomas, R.G., Smith, D.G., Wood, J.M.,Visser, J., Calverley-Range, E.A., Koster, E.H., 1987. Inclined heterolithic stratification -terminology, description, interpretation and significance. Sedimentary Geology, v. 53, p. 123-179.

Wightman, D.M., Pemberton, S.G., 1997. The lower Cretaceous (Aptian) McMurray Formation: an overview of the McMurray area, northeastern Alberta. In: Pemberton, G.S., James, D.P. (Eds.), Petroleum Geology of the Cretaceous Lower Manville Group: Western Canada. Can. Soc. Petroleum Geologists Mem, v. 18, p. 312-344.

Willis, B.J., Tang, H., 2010. Three-dimensional connectivity of point-bar deposits. Journal of Sedimentary Research, v. 80, p. 440-454.

Wood, J.M., 1989. Alluvial architecture of the upper Cretaceous Judith River formation, Dinosaur Provincial Park, Alberta, Canada. Bulletin of Canadian Petroleum Geology v. 37, p. 169-181.