Regional stratigraphy and U-Pb detrital zircon geochronology of the Lower Cretaceous Mannville Group, Alberta: insights into sediment transfer in an uplifted foreland basin

Benjamin G. Daniels
Department of Earth and Environmental Sciences, Mount Royal University

Stephen M. Hubbard
Department of Geoscience, University of Calgary

William A. Matthews
Department of Geoscience, University of Calgary

Sean C. Horner
Hudbay Minerals Inc.

Garrett M. Quinn
Department of Geoscience, University of Calgary

Summary

Sediment routing in foreland basins is largely controlled by tectonically driven subsidence and sediment supply (Price, 1973; DeCelles and Giles, 1996). As a result, sediment-routing systems in actively subsiding foreland basins frequently display predictable drainage patterns where orogen-parallel channel systems in the basin axis are fed by tributaries that emanate from the orogen (Heller et al., 1988). However, during periods of relative tectonic quiescence, foreland basins undergo tectonic rebound (Heller et al., 1988), and the evolution of sediment-routing systems during periods of rebound can be challenging to predict (e.g., Gómez et al., 2005). Documenting sediment routing patterns during periods of rebound can be particularly important for helping to elucidate controls on foreland basin evolution that are frequently masked by the effects of tectonism and sediment supply (e.g., sea-level change), as well as for helping to assess how depositional patterns are influenced by topography within a basin foredeep (Horton, 2018).

The Alberta Foreland Basin consists of an up-to-4 km thick wedge of clastic sediment that records paleoenvironmental changes from 200-50 Ma. The initial development of the basin is related to tectonic convergence on the western margin of North America, which instigated the growth of the North American Cordillera during the Jurassic (Smith, 1994). Jurassic strata in the basin record this initial phase of orogenic growth, with stacked deposits of basin-axial channel systems present in the basin foredeep (Raines et al., 2013). However, after the Jurassic, Western Canada experienced a phase of relative tectonic quiescence, which resulted in rebound in the basin and the development of the sub-Cretaceous unconformity (Hayes et al., 1994; Pană and van der Pluijm, 2015). The differential erosion of subcropping units associated with the unconformity surface, combined with dissolution of evaporitic units deeper in the subsurface, contributed to the

formation of a partitioned basin during this time. Deposits of the Barremian-Aptian Lower Mannville Group were deposited on the unconformity surface, and are thought to record paleodrainage evolution in this partitioned basin. Uplift and tectonism in the North American Cordillera resumed in the Albian, and deposits of the Albian Upper Mannville Group are thought to record paleodrainage evolution in response to these processes.

We investigate paleodrainage evolution in the Alberta Basin during deposition of the Mannville Group. For this work, we evaluate stratigraphic information derived from outcrops and thousands of wellbores, as well as U-Pb detrital zircon dates derived from a large database of Mannville Group samples ($N_{samples}$ = 111; n_{dates} = 19,898), which includes new detrital zircon results from the Mannville Group in Alberta ($N_{samples}$ = 17; n_{dates} = 3,540; Figures 1 and 2). The objectives of this study are to: (1) decipher the evolution of basin drainage patterns during Mannville Group deposition; and (2) investigate the effects of basin partitioning within the Alberta Foreland Basin during the Early Cretaceous.

Theory / Method / Workflow

Stratigraphic data for this study was derived from Mannville Group deposits that are exposed in outcrop, as well as from subsurface data sets. Detailed outcrop data was primarily acquired via measurement of stratigraphic sections. Stratigraphic data from the subsurface was primarily obtained from wireline logs analyzed in geoSCOUT and AccuMap software; however, these data were augmented with descriptions from drill cores wherever possible. Newly acquired U-Pb detrital zircon dates were derived from sandstones sampled from various intervals within the Mannville Group. Published U-Pb dates from the Mannville Group were integrated with these data to enable comprehensive geochronologic characterization of the interval.

Results, Observations, Conclusions

Regional stratigraphic mapping of the Lower Mannville Group confirms that stratigraphic units formed in three distinct paleovalleys across the basin, which are bounded by inherited paleotopographic highs composed of pre-Cretaceous units (Hayes et al., 1994). U-Pb detrital zircon dates from Lower Mannville Group units are largely pre-Cretaceous in age, which reflect recycling of pre-Cretaceous units. Populations of Lower Mannville Group U-Pb detrital zircon dates can be placed into three groups that are apparently related to each distinct paleovalley. Importantly, the amount of detritus derived from fold-thrust belt units in the Cordillera decreases considerably across the basin from west to east, which suggests that partitioning significantly impacted sediment delivery across the basin. Regional stratigraphic mapping of the Upper Mannville Group shows that stratigraphic units were deposited on top of the aforementioned paleotopographic highs, indicating that relief from pre-Cretaceous units was largely healed by the Albian. U-Pb detrital zircon dates from this interval contain notable proportions of Albian grains, which suggest that sediment-routing systems captured large volumes of Cordilleran sediment.

Novel/Additive Information

This study represents a new synthesis of stratigraphic information, sediment provenance data, and geochronologic information for Mannville Group units across Alberta. The results of this study offer insight into changes in basin configuration in Early Cretaceous Alberta, and emphasize the link between inherited paleotopographic features and the development of sediment-routing systems over millions of years. Moreover, the results of this study also provide new temporal constraints on various Mannville Group units, and offer new insight into the timing of depositional evolution in Early Cretaceous Alberta. All of these data can be used to assist with natural resource exploration efforts associated with time-equivalent units in the Alberta subsurface.

Acknowledgements

Funding for this project was derived from a Mount Royal University faculty start-up grant awarded to Daniels, as well as from an NSERC Discovery Grant awarded to Hubbard (RG-PIN/341715-2013). Discussions with Yakov Aluph, Marilyn Becerra de Rosales, Anirudh Bhargava, Marie-Pier Boivin, Paul Durkin, Rebecca Englert, Nicolas Garroni, Thomas Hadlari, Cynthia Hagstrom, Brad Hayes, Danica Heath, Dale Leckie, Lauren Madronich, Harrison Martin, Lynsey McKinnon, Per Pedersen, Peter Putnam, and Dane Synnott enhanced many of the interpretations presented in this study, and we are grateful for their input. We wish to thank geoLOGIC Systems Limited for providing access to geoSCOUT software at the University of Calgary, as well as S&P Global Incorporated for providing access to AccuMap software at Mount Royal University.

References

DeCelles, P.G., and Giles, K.A., 1996. Foreland basin systems. Basin Research, v. 8, p. 105-123.

Gómez, E., Jordan, T.E., Allmendinger, R.W., and Cardozo, N., 2005. Development of the Colombian foreland-basin system as a consequence of diachronous exhumation of the northern Andes. Geological Society of America Bulletin, v. 117, p. 1272-1292.

Hayes, B.J.R., Christopher, J.E., Rosenthal, L., Los, G., McKercher, B., Minken, D., Tremblay, Y.M., and Fennell, J., 1994. Cretaceous Mannville Group of the Western Canada Sedimentary Basin. In: Geological Atlas of the Western Canada Sedimentary Basin. G.D. Mossop and I. Shetsen (comp.). Canadian Society of Petroleum Geologists and Alberta Research Council, Edmonton, Alberta, p. 317-334.

Heller, P.L., Angevine, C.L., Winslow, N.S., and Paola, C., 1988. Two-phase stratigraphic model of foreland-basin sequences. Geology, v. 16, p. 501-504.

Horton, B.K., 2018. Sedimentary record of Andean mountain building. Earth-Science Reviews, v. 178, p. 279-309.

Pană, D.I, and van der Pluijm, B.A., 2015. Orogenic pulses in the Alberta Rocky Mountains: radiometric dating of major faults and comparison with the regional tectono-stratigraphic record. Geological Society of America Bulletin, v. 127, p. 480-502.

Price, R.A., 1973. Large-scale gravitational flow of supracrustal rocks, southern Canadian Rockies. In: Gravity and Tectonics. K.A. De Jong and R. Scholten (eds.). Wiley and Sons, New York, p. 491-502.

Raines, M.K., Hubbard, S.M., Kukulski, R.B., Leier, A.L., and Gehrels, G.E., 2013. Sediment dispersal in an evolving foreland: detrital zircon geochronology from Upper Jurassic and lowermost Cretaceous strata, Alberta Basin, Canada. Geological Society of America Bulletin, v. 125, p. 741-755.

Smith, D.G., 1994. Paleogeographic evolution of the Western Canada Foreland Basin. In: Geological Atlas of the Western Canada Sedimentary Basin. G.D. Mossop and I. Shetsen (comp.). Canadian Society of Petroleum Geologists and Alberta Research Council, Edmonton, Alberta, p. 277-296.

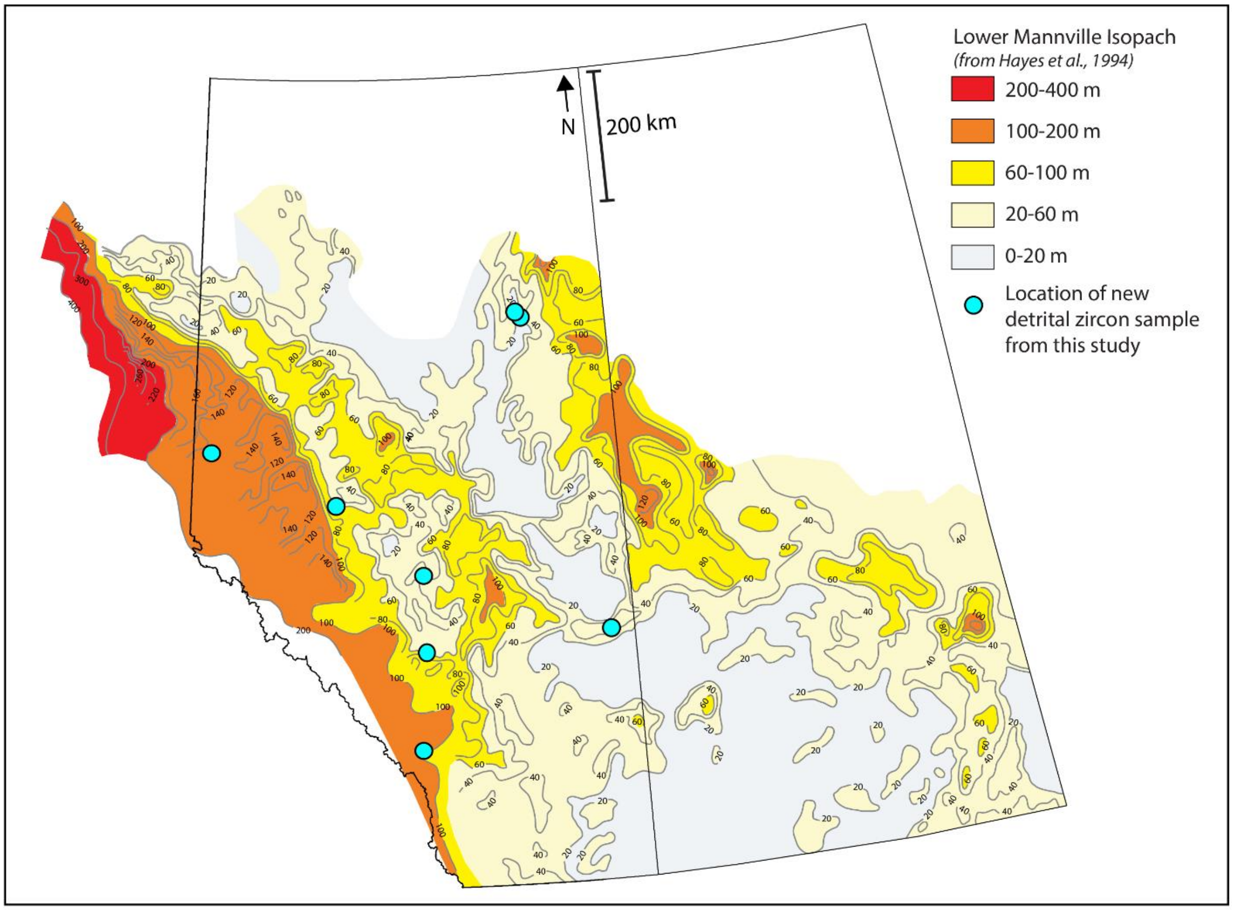

Figure 1. Overview of new detrital zircon samples associated with deposits of the Lower Mannville Group that are featured in this study. Outlines of the provinces of Alberta and Saskatchewan are provided for geographic context. Background colours and associated contours correspond to measurements of total Lower Mannville Group isopach thickness derived from subsurface data sets (e.g., cores, well logs) and outcrop data (see Hayes et al., 1994 for additional information). Contours modified from Hayes et al. (1994).

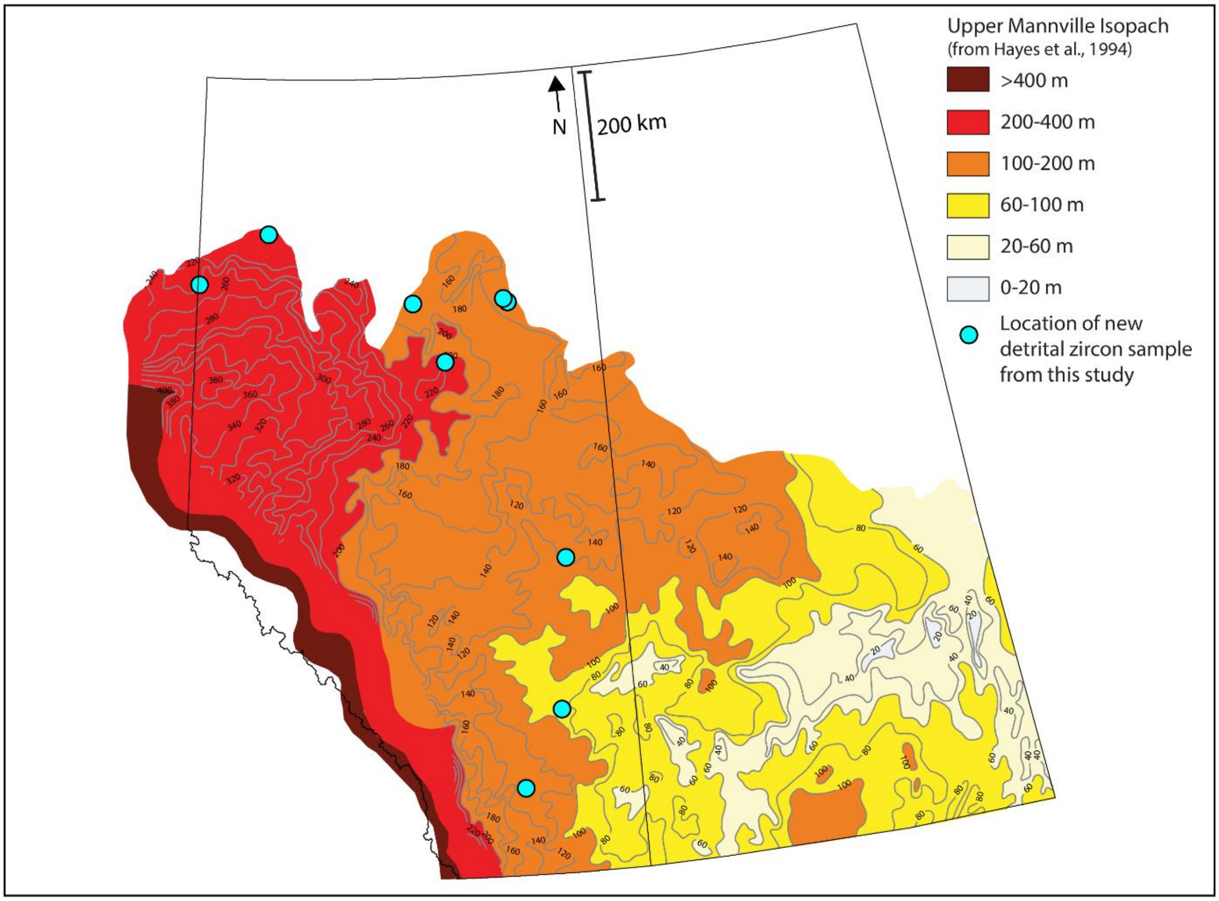

Figure 2. Overview of new detrital zircon samples associated with deposits of the Upper Mannville Group that are featured in this study. Outlines of the provinces of Alberta and Saskatchewan are provided for geographic context. Background colours and associated contours correspond to measurements of total Upper Mannville Group isopach thickness derived from subsurface data sets (e.g., cores, well logs) and outcrop data (see Hayes et al., 1994 for additional information). Contours modified from Hayes et al. (1994).