Provenance signals in Upper Cretaceous-Paleogene strata, Alberta Basin, Canada

Samantha Super, Stephen M. Hubbard, William Matthews, Ranjot S. Brar., Daniel S. Coutts, Sean Horner, and Marco Venieri*

Department of Geoscience, University of Calgary

Summary

The Upper Cretaceous-Paleogene stratigraphic wedge of the Alberta foreland basin records the final major contractional period of uplift and deformation in the Canadian Cordillera. Recent work has emphasized the usefulness of U-Pb geochronology to better constrain orogenic belt uplift and denudation based on the analysis of sedimentary units in the associated foreland. In this study, we employ detrital zircon geochronology to consider: (1) the relationship between Cordilleran tectonics and associated foreland strata during the final stages of Canadian Cordilleran development; (2) the provenance of Cretaceous-Paleogene wedge sediments; (3) the relative timing of events in the orogen and the foreland basin; and (4) the origin of large volumes of near depositional aged detrital zircons in the late Cretaceous – Paleogene strata. Geochronology data are subject to statistical similarity analysis and considered with respect to detrital spectra of potential source regions and recently obtained thrust-faults ages. A vast database of igneous and metamorphic detrital zircon ages from within the Cordillera and beyond is assembled from literature to constrain syn-depositional potential magmatic zircon sources.

Cretaceous-Paleogene strata of the Alberta basin (N = 15 samples; n = 3176 ages, total) cluster into 4 distinct groups using statistical analysis and identify large quantities of approximately syn-depositional magmatic detrital zircons. Statistical analysis of U-Pb geochronology data identifies alternating trends in the detrital zircon signature of Cretaceous-Paleogene sediments, which can be used to infer the spatial and temporal evolution of sediment provenance in relation to the tectonic evolution of the associated orogen. We interpret detrital zircon spectra trends to represent the progressive incision and erosion of a package of orogenic wedge-top Cordilleran magmatic arc derived sediments present at the onset of Belly River Group deposition (ca. 81 Ma). A flux of recycled material within the K-Pg stratigraphic wedge, characterized by a diverse passive margin spectra, was coincident with thrusting (72.3-75.6 Ma) based on recently acquired radiometric fault gauge ages (Pana and van der Pluijm, 2015). We interpret this to record a major phase of orogenesis in the hinterland (ca. 76-68 Ma). Cordilleran magmatic ages assembled from literature are used to infer the importance of magmatic derived input to detrital zircon populations of Cretaceous-Paleogene Alberta foreland strata. Collectively these data provide important insight into hinterland uplift and denudation during the final stage of Cordilleran development.

Background

Foreland basins develop in response to the evolution of an adjacent mountain belt (DeCelles and Giles, 1996). Consequently, the sedimentary fill of a foreland basin provides a record of the evolution and erosion of the associated mountain belt (Cant and Stockmal, 1989; Ross et al., 2005). The stratigraphic framework for the Mesozoic-Paleogene strata of the Alberta foreland basin has been extensively studied with numerous authors recognizing linkages between tectonic processes in the adjacent orogen and sedimentary packages of the foreland basin fill (Cant and Stockmal, 1989; Leckie and Smith, 1992; Ross *et al.* 2005; Pana and van der Pluijm, 2015; Quinn et al., 2016). These linked sedimentary packages, or wedges, provide a framework for comparison between tectonic events in the Cordillera and the timing of sedimentation and hiatus events in the foreland basin (Quinn et al. 2016). Recent studies have focused on linking Alberta basin fill to tectonic processes from the upper Jurassic to the lower Cretaceous, however little work has been done on younger sediments (Leier and Gehrels, 2011; Raines et al., 2013; Quinn et al., 2016). The Upper Cretaceous-Paleogene aged uppermost stratigraphic wedge of the Alberta basin, spanning from the Belly River Group to the Paskapoo Formation, collectively records the final major phase of contraction and mountain building in the Canadian Rocky Mountains (Ross et al., 2005).

Detrital zircon analysis is a well-established method of comparing foreland basin stratigraphy and tectonic evolution, as sedimentary detrital zircon populations provide a detailed record of the evolution of sediment input into a basin (Leier and Gehrels, 2011; Benyon et al., 2014; Blum and Pecha, 2014). By age dating the detrital zircon populations within the stratigraphic units, we can infer sediment origin by linking zircon ages back to sediment source ages (Thomas, 2011). We can also identify the erosion and recycling of previous deposits within detrital zircon populations (Hadlari et al., 2015). Shifts in the nature of the detrital zircon populations (recycled vs. non-recycled) reflect shifts of what is exposed in the hinterland in response to tectonics during deposition and therefore can be used as a record of the timing of thrusting and denudation during the tectonic evolution of the Canadian Cordillera.

Methods

The sampling strategy adopted in this study is designed to best capture the uppermost Cretaceous-Paleogene tectonostratigraphic wedge in its entirety, as well as variations that may exist between proximal and distal wedge sediments. The study area focuses on a roughly 200 kilometer-wide east-west transect of Alberta spanning from the Foothills of the Rocky Mountains into Saskatchewan centered on Calgary. In order to highlight any differences between proximal and distal wedge sediments, we sampled sandstone outcrop of three representative successions of Cretaceous-Paleogene wedge strata: western foothills, central plains, and eastern plains.

U-Pb age analysis of approximately 200-300 detrital zircon grains per sample was conducted at the Centre for Applied Thermochronology and Tectonics (CPATT) at the University of Calgary using quadrupole laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). Ablation and isotope ratio measurement were conducted following the methodology of Matthews and Guest (2016). Kernel density estimate (KDE) plots of detrital zircon populations were created in accordance with the methodology of Sircombe and Hazelton (2004).

Multidimensional scaling (MDS) plots were created to aid in visualization and interpretation of statistical differences between detrital zircon populations using MATLAB™ code and graphical-user interface from Vermeesch, 2013.

Resulting detrital zircon geochronology data is then used to constrain maximum depositional ages of units, provide a proxy for the degree of sediment recycling, compared to potential source signatures to determine sediment provenance, and compared to recently acquired radiometric fault gauge ages to evaluate relationships and relative timing of foreland basin sedimentation and tectonic evolution of the Canadian Cordillera.

Results and Implications

The 15 sandstone samples yielded a total of 3176 U-Pb ages with approximately 210 ages obtained per sample. From data collected, several interesting trends have emerged. Statistical analysis of our detrital zircon geochronology data indicates an alternating pattern of strata dominated by Cordilleran magmatic aged zircons and strata characterized by zircon spectra indicative of mixed recycled cordilleran sources. We interpret detrital zircon spectra trends to represent the progressive incision and erosion of a package of orogenic wedge-top Cordilleran magmatic arc derived sediments present at the onset of Belly River Group deposition (ca. 81 Ma). The first appearance of a mixed signature of recycled and younger syn-depositional detrital zircons was coincident with thrusting (72.3-75.6 Ma) based on recently acquired radiometric fault gauge ages (Pana and van der Pluijm, 2015). We infer this to record a major phase of orogenesis in the hinterland, which interestingly post-dates initial basin subsidence by 4-6 Ma (interpreted from out data). This preliminary work illustrates the potential significance of this study in constraining the timeline and controlling processes of foreland basin evolution. We believe that this research will be instrumental in expanding our understanding of foreland-orogen relationships as well as key to developing an accurate timeline for Alberta basin evolution.

Acknowledgements

Funding for this research was provided by a NSERC discovery grant awarded to SMH. Additional support was provided by the University of Calgary Department of Geoscience, as well as the Grant Mossop Graduate Scholarship in Geology awarded to SS.

References

Benyon, C., A. Leier, D. A. Leckie, A. Webb, S. M. Hubbard, and G. Gehrels (2014), Provenance of the Cretaceous Athabasca Oil Sands, Canada: Implications for continental-scale sediment transport, Journal of Sedimentary Research, 84(2), 136-143.

Blum, M. and M. Pecha (2014), Mid-Cretaceous to Paleocene North American drainage reorganization from detrital zircons, Geology, 42(7), 607-610.

Cant, D. J. and G. S. Stockmal (1989), The Alberta foreland basin: relationship between stratigraphy and Cordilleran terrane-accretion events, Canadian Journal of Earth Sciences, 26(10), 1964-1975.

DeCelles, P. G. and K. A. Giles (1996), Foreland basin systems, Basin research, 8(2), 105-123.

Eberth, D. A. (2005). 3. The Geology. Dinosaur Provincial Park: A spectacular ancient ecosystem revealed, 1, 54.

Eberth, D. A., & Deino, A. (2005). New 40Ar/39Ar ages from three bentonites in the Bearpaw, Horseshoe Canyon, and Scollard formations (Upper Cretaceous-Paleocene) of southern Alberta, Canada. Royal Tyrrell Museum Special Publications. 23-24

Hadlari, T., G. T. Swindles, J. M. Galloway, K. M. Bell, K. C. Sulphur, L. M. Heaman, L. P. Beranek, and K. M. Fallas (2015), 1.8 billion years of detrital zircon recycling calibrates a refractory part of Earth's sedimentary cycle, Public Library of Science, 10(12), e0144727.

Hamblin, A. P. (1997). Stratigraphic architecture of the Oldman Formation, Belly River Group, surface and subsurface of southern Alberta. Bulletin of Canadian Petroleum Geology, *45*(2), 155-177.

Hathway, B. (2011), Tops of the Horseshoe Canyon, Wapiti and Battle formations in the west-central Alberta Plains: subsurface stratigraphic picks and modelled surface; Energy Resources Conservation Board, ERCB/AGS Open File 2011-08, 1-24.

Leckie, D. A. and D. G. Smith (1992), Regional Setting, Evolution, and Depositional Cycles of the Western Canada Foreland Basin: Chapter 1, AAPG Special Volumes.

Leier, A. and G. E. Gehrels (2011), Continental-scale detrital zircon provenance signatures in Lower Cretaceous strata, western North America, Geology, 39(4), 399-402.

Mack, G. H. and T. Jerzykiewicz (1989), Provenance of post-Wapiabi sandstones and its implications for Campanian to Paleocene tectonic history of the southern Canadian Cordillera, Canadian Journal of Earth Sciences, 26(4), 665-676.

Matthews, W. A. and B. Guest (2016), A Practical Approach for Collecting Large-n Detrital Zircon U-Pb Data sets by Quadrupole LA-ICP-MS, Geostandards and Geoanalytical Research.

Pană, D. I. and van der Pluijm, Ben 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, 127(3-4), 480-502.

Quinn, G. M., S. M. Hubbard, R. van Drecht, B. Guest, W. A. Matthews, and T. Hadlari (2016), Record of orogenic cyclicity in the Alberta foreland basin, Canadian Cordillera, Lithosphere, 8(3), 317-332.

Raines, M. K., S. M. Hubbard, R. B. Kukulski, A. L. Leier, and G. E. Gehrels (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, 125(5-6), 741-755.

Ross, G. M., P. J. Patchett, M. Hamilton, L. Heaman, P. G. DeCelles, E. Rosenberg, and M. K. Giovanni (2005), Evolution of the Cordilleran orogen (southwestern Alberta, Canada) inferred from detrital mineral geochronology, geochemistry, and Nd isotopes in the foreland basin, Geological Society of America Bulletin, 117(5-6), 747-763.

Sircombe, K. and M. Hazelton (2004), Comparison of detrital zircon age distributions by kernel functional estimation, Sedimentary Geology, 171(1), 91-111.

Thomas, W. A. (2011), Detrital-zircon geochronology and sedimentary provenance, Lithosphere, 3(4), 304-308.

Vermeesch, P. (2013), Multi-sample comparison of detrital age distributions, Chemical Geology, 341, 140-146.