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Provenance of early Mississippian Bakken Clastics Based on Detrital Zircon and Detrital Conodonts

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Summary

The middle Bakken member contains significant amount of clastic sediments. Detrital zircon geochronology and conodont colour alteration index (CAI) and preservational observations of detrital conodonts suggest multiple sources for the middle Bakken clastics. These sources are associated with the Franklinian clastic wedge and the Ellesmerian orogeny along the north Laurentian margin, the Canadian Shield east of the Williston Basin as well as Mazatzal-Yavapai province.

Introduction

The middle sandstone member of the Bakken Formation (MBM) is a widespread silty sandstone sheet that accumulated in shallow marine settings across the Williston Basin during the latest Devonian- early Mississippian. The deposition of such widespread sandstone sheets depends on accommodation space, major sediment-dispersal systems and continuous sediment supply typically associated with uplifted regions. In the case of MBM, neither provenance nor sediment dispersal systems have been identified. Reconstruction of Devonian-Mississippian (D-M) paleogeography is crucial in refining the depositional models and stratigraphic frameworks of D-M strata, therefore, should be addressed by constraining the sediment provenance and understanding the process involved in sediment transportation. This study aims to (1) constrain the provenance of MBM clastic deposits and to (2) understand the sediment dispersal system of these deposits in southeast Alberta and southwest Saskatchewan (Fig. 1).

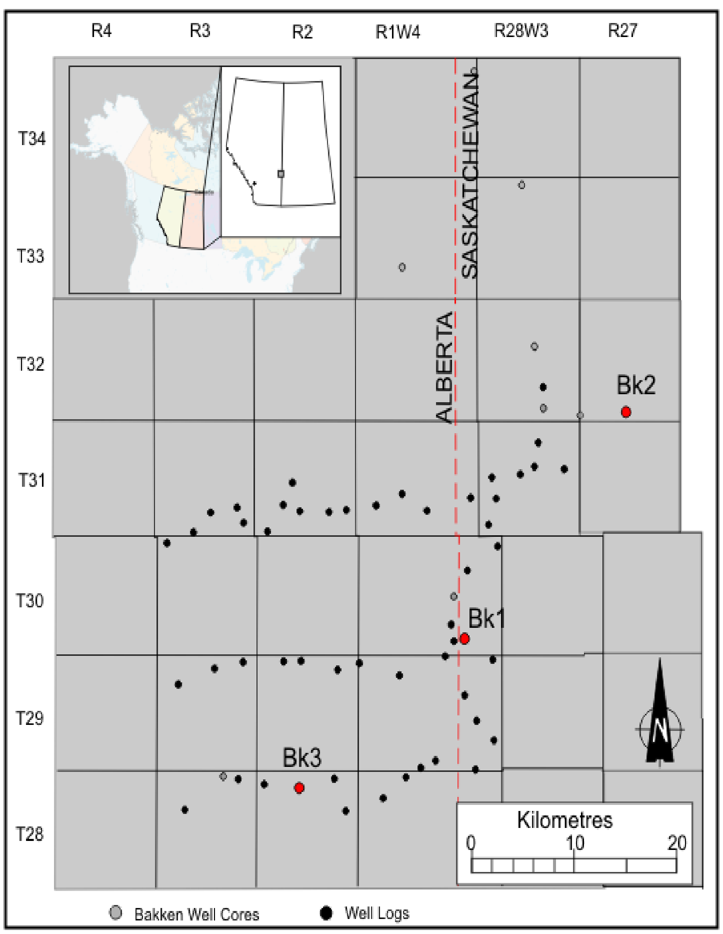

Fig. 1. Study area, red circles indicate location of cores sampled in this study.

Methods

Detrital zircon U-Pb geochronology is a proven technique in identifying crystallization ages of the grains, constraining potential source areas for sediment and reconstructing sediment dispersal systems (Gehrels and Dickinson, 1995). However, multi-cycle sedimentation and recycling of sedimentary rocks have always been a challenge in defining sedimentary provenances accurately (Thomas, 2011). Conventionally, this challenge has been addressed by combining petrography and detrital geochronology (Dickinson, 1985), a technique proved to be successful in some cases (*e.g.* Lawton *et al*., 2009). In this study we propose a novel approach to address this challenge for the Bakken deposits; this approach utilizes two types of detrital materials including detrital zircons and reworked conodonts that are rounded and have elevated CAI values. Detrital zircon geochronology is used to identify and constrain source rock ages while detrital conodont colour alteration index (CAI) is used to define ages as well as the thermal history of the sedimentary source area for the Bakken clastic sediments. This combined approach may constrain possible source areas for sediment with great degree of precision compared to zircon only studies.

Three samples (Bk1, Bk2 and Bk3) were collected from the Bakken Formation in southeastern Alberta and southwestern Saskatchewan and analyzed for detrital geochronology and conodont colour alteration index (CAI) and preservation (See Fig. 1 for sample location, Fig. 2 for stratigraphic position and Table 1 for samples information). U-Pb age analysis were conducted at the Isotope Geology Laboratory, Boise State University and conodont samples were processed at the micropaleontology laboratory at the University of Calgary.

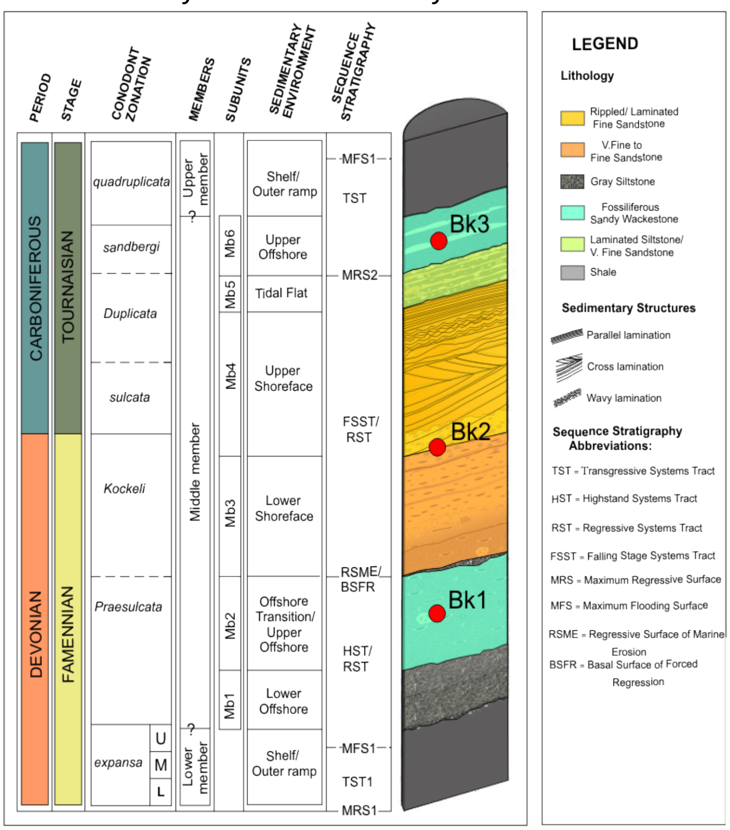

Fig. 2. Generalized core log depicting sedimentologic and biostratigraphic characteristics, depositional environments and sequence stratigraphic surfaces of the Bakken Formation. Conodont zonation from Johnston et al. (2010), core log modified from Angulo and Buatois (2012).

Table 1. Sample Information

Sample name	Unit/ Formation	Lithology/ Thickness	Location/ Well ID.	Depth	Depositional Environment
Bk1	Mb2	Sandy wackestone/ packstone	101/10-03-30-29W3	888 m	Upper offshore to offshore transition
Bk2	Mb3/ Mb4	Moderately sorted, fine to v. fine sandstone	111/04-06-32-27W3	833/ 837 m	Foreshore, lower shoreface to Upper shoreface
Bk3	Mb6	Sandy wackestone/ packstone	10/06-33-28-02W4	919 m	Upper offshore to offshore transition

Mb= Middle Bakken

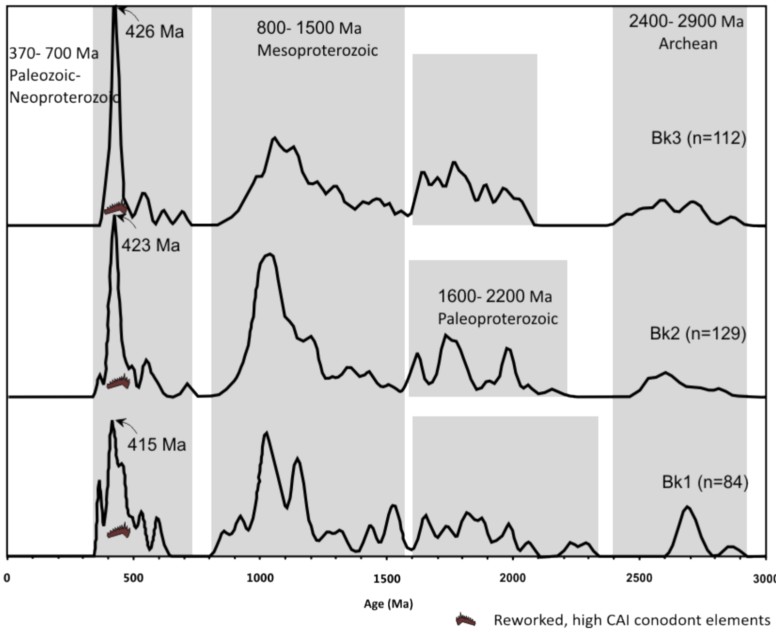

Fig. 3. Detrital zircon probability curves for Bakken Formation samples. Zircons ages can be subdivided into four distinct age groups that are present in similar concentrations in all three samples (Bk1, Bk2 and Bk3). Age groups are outlined with grey rectangles shown in the figure

Findings:

Detrital zircon U-Pb analysis yielded four detrital zircon age populations: (1) middle Paleozoic to late Neoproterozoic 370- 700 Ma grains, (2) Mesoproterozoic 850- 1500 Ma grains, (3) Paleoproterozoic 1600- 2100 Ma grains, and (4) early Paleoproterozoic to late Archean grains 2400-2900 Ma (Fig. 3). CAI and age analysis of MBM conodonts indicate that population 1 (370- 700 Ma grains) is accompanied by reworked conodonts of Chirognathidae and Protopanderodontidae, possibly, of Ordovician age (445- 470 Ma) and other elements may be as young as L-M Devonian (385- 420 Ma). These conodonts have much higher CAI values (CAI ~4) and exhibit wear patterns consistent with reworking and transportation (Fig. 4).

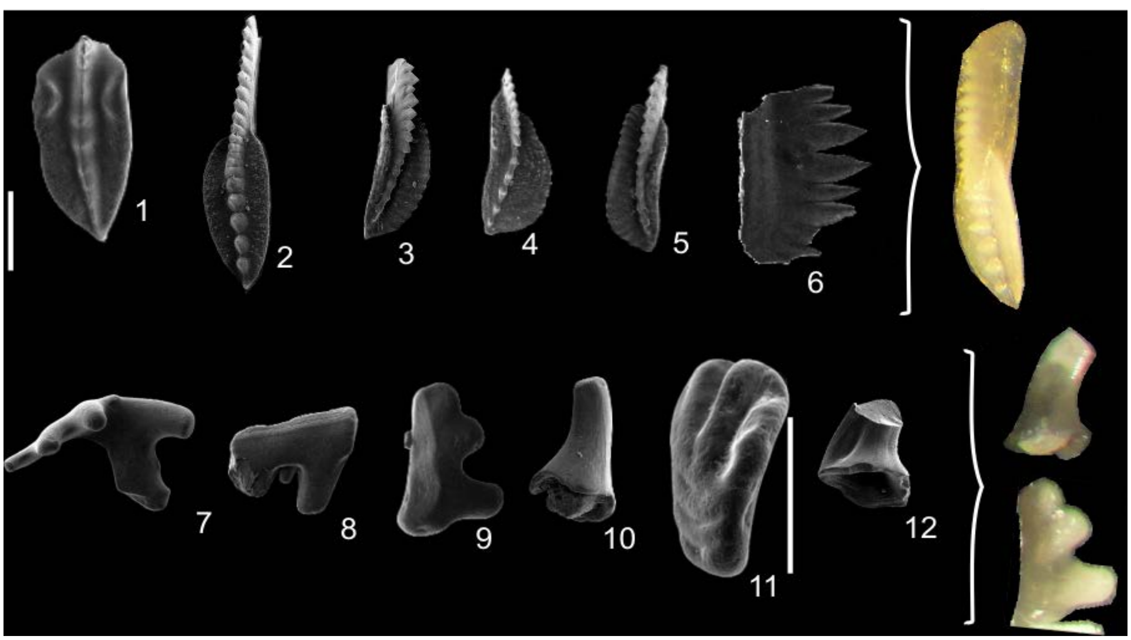

Fig. 4. Conodont plate showing two conodont populations with distinct CAIs recognized in the Bakken Formation. Population 1 (elements 1 to 6) has a CAI of 1.25 which suggests that this fauna had only been buried to depths of ~ 1 km; this combined to the generic age and environmental preferences indicate that this population is indigenous to Bakken deposits. Population 2 (elements 7-12, consists of reworked elements of Chirognathidae and Protopanderodontidae) has a CAI value of ~4, elements, exhibits a greater degree of roundness and suggests an age range from latest Silurian to middle Devonian. The CAI (~ 4) observed in this population indicates that these elements were exposed to a temperature range of 190°C to 300°C (Epstein *et al*, 1977).

Conclusions

Detrital zircon U-Pb analysis and reworked conodonts indicate sediment transport from local basement as well as thrust-belt sources to the north, northeast and south. These sources include (1) middle Paleozoic to late Neoproterozoic Franklinian and Caledonian sources (370- 700 Ma), (2) Mesoproterozoic Grenville province (850-1500 Ma grains), (3) Paleoproterozoic source consistent with Yavapai-Mazatzal provinces (1600- 2100 Ma grains), and (4) early Paleoproterozoic to late Archean Canadian Shield source (grains 2400-2900 Ma). The reworked Chirognathidae and Protopanderodontidae conodonts suggest Middle to Upper Ordovician sources (445- 470 Ma) that could be as young Lower to Middle Devonian (385- 420 Ma). The higher CAI values (CAI ~4) suggest that they may have been buried to depths in excess of 3 km prior to uplift and exhumation. Ages and high CAI of these elements suggest that they were likely sourced from the Franklinian mobile belt that consists of deformed Upper Neoproterozoic to Upper Devonian clastic rocks (Embry, 1991; Anfinson *et al.*, 2012).

Our data suggest derivation of at least 25% of Bakken clastics from northern sources exhumed and recycled during the middle Devonian Franklinian orogeny. This interpretation underlines the significance of the Ellesmerian orogeny in providing sedimentary budget to the interior of North America during middle Paleozoic time. This interpretation supports long distance sediment transportation most likely by fluvial and long-shore drift. Sediments from eastern and southern sources (Canadian Shield, Grenville, Yavapai-Mazatzal provinces) were likely delivered via fluvial systems and reworked by shallow marine processes.

Acknowledgements

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