[PS]Detrital Zircon Provenance of the McMurray Formation, Alberta, Canada*

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Abstract

The Athabasca Oil Sands of northeastern Alberta represent one of the largest reserves of hydrocarbons in the world. Of these deposits, the Lower Cretaceous (Aptian) McMurray Formation is the principal reservoir sandstones in the region. Despite intense investigation, the origin and transport history of the sediment within the McMurray Formation remains poorly understood. Petrographic evidence suggests much of the sand in the McMurray Formation was derived from the nearby Canadian Shield, whereas early paleogeographic maps imply the sand was derived from a large south-to-north drainage network that extended from the southwestern U.S. to northern Alberta. Resolving these issues can help improve our understanding of the depositional history and better predict reservoir characteristics.

Nine sandstone samples from the McMurray Formation were analyzed using detrital zircon U-Pb geochronology to better understand the sandstone provenance of this key hydrocarbon unit. Preliminary results indicate three distinct detrital zircon signatures within the McMurray Formation. The first signature is characterized by zircons of Archean and Early Proterozoic age, which are interpreted as indicating a provenance associated with the nearby Canadian Shield. The second signature is characterized by zircons of Grenville (ca. 1,000 Ma) and early Paleozoic age. This latter zircon population suggests an Appalachian source originally; however, these zircons may be multi-cyclic, having been reworked from deposits in southern Canada or from the northern U.S. The third signature is dominated by relatively young zircons (<300 Ma) with a lesser population of Early Proterozoic ages, which are interpreted to indicate a Cordilleran provenance. These three signatures suggest a complex provenance history that evolved through time. First-order calculations based on fluvial channel dimensions and deposits provide important constraints on the location and extent of the paleo-watershed. Ongoing analyses will improve provenance reconstructions and provide a more refined sedimentary history.

1 Introduction

The bitumen and heavy oil of the Lower Cretaceous (Aptian) McMurray Formation in Alberta, Canada represent one of the largest hydrocarbon accumulations in the world. Sandstones, siltstones and shales of the McMurray Formation were deposited in fluvial, estuarine, and marginal marine environments along the southern margin of the Western Interior Seaway during the Cordilleran Orogeny.

The Question...

Where did the sand come from?

Petrographic evidence suggests much of the sand in the McMurray Formation was derived from the nearby Canadian Shield. However, paleogeographic maps imply the sand was derived from a large south-to-north drainage network that extended from the southwestern United States to northern Alberta.

We would like to thank Nexen for their financial support and samples, the University of Arizona LaserChron Center for the use of their equipment, and the Centre for Applied Basin Studies for their feedback.

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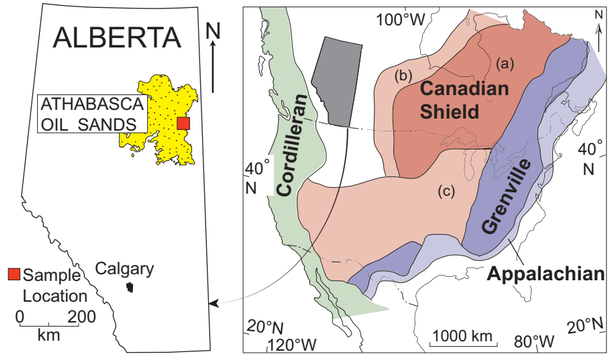
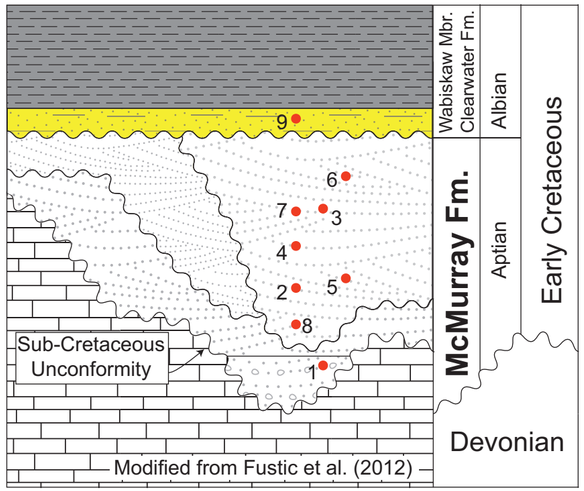
2 Study Area

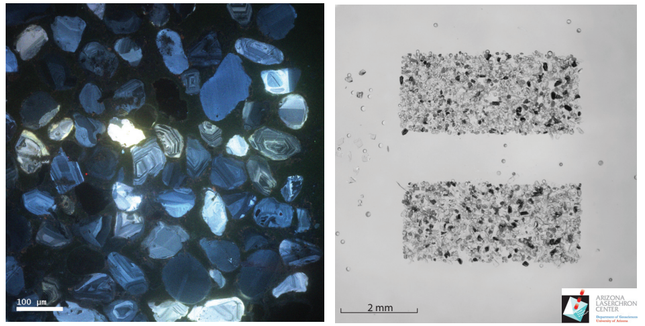


Study area and sample location. Distribution of the Athabasca Oil Sands is represented by yellow stippled region. Samples were collected from 3 wells drilled in the eastern portion of the Athabasca area. Precambrian and Phanerozoic age belts from Dickinson and Gehrels (2009) are displayed on the right: (a) represents the Superior Province of the Canadian Shield (>2.5 Ga); (b) represents the Trans-Hudson Province (ca. 1.8 Ga); and (c) represents additional ca. 1.8 Ga provinces. Other principal age belts (discussed shortly) are labeled.



Stratigraphy of Lower Cretaceous deposits in the Athabasca region (modified from Fustic et al. 2012). Lower Cretaceous strata of the McMurray Formation unconformably overlie Devonian carbonate strata. The McMurray Formation is typically divided into a lowermost unit (below black line), a middle unit that contains several incised valleys, and an upper unit that contains shallow marine deposits. It is overlain by the Wabiskaw Member of the Clearwater Formation. Yellow represents coarser sediments in the Wabiskaw, and grey represents shale. Samples numbers and their relative stratigraphic locations are shown.

3 Methodology

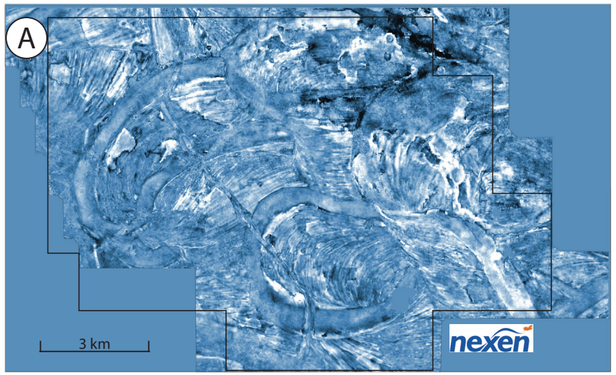


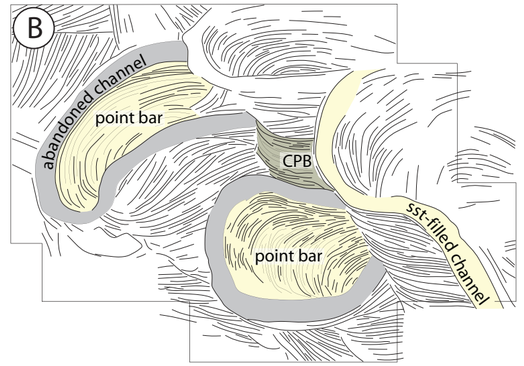
-Detrital zircon (U-Pb) geochronologic data was collected from 9 samples of core from 3 wells in the Athabasca Oil Sands area

-Core samples of 2-5 kg were processed using procedures outlined in Gehrels (2011)

-~100 zircons per sample were analyzed using Laser Ablation - Multicollector -Inductively Coupled Plasma - Mass Spectrometry (LA-MC-ICP-MS) at the Arizona LaserChron Center

4 McMurray Fm. - Seismic Time Slice





(A) Seismic time slice (amplitude from a 3D prestack, time migrated volume) taken ~ 8 m below the top of the McMurray Formation. The slice shows a highly sinuous system with downstream accretion point bars and associated abandoned channels. Paleoflow is to the north. The image is 16.8 km wide. (B) Line-drawing trace of the main features in (A). Main depositional elements include abandoned channels, point bars, and counter point bars (CPB). Modified from Hubbard et al., 2011.

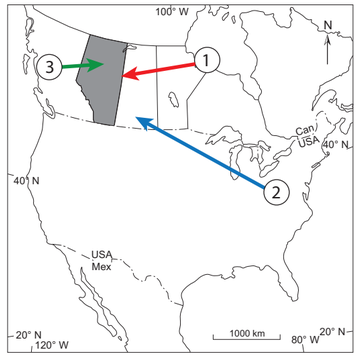
5 Key Findings

-Much of the sand in the Oil Sands is originally from the Appalachians

-The Cretaceous Foreland Basin has sediments derived from:

1) The Canadian Shield
2) The Appalachians
3) The Cordillera

-Sediment source changes through time



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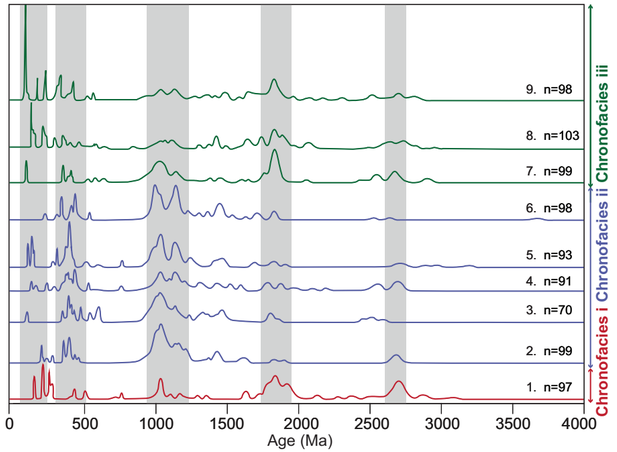
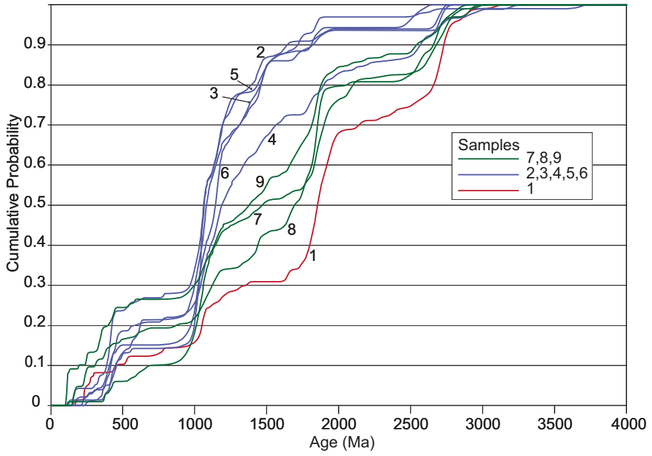
6 Results



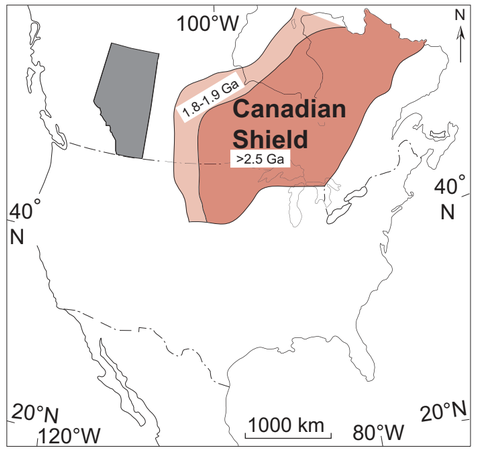
Detrital zircon normalized probability plots from the nine samples; n is number of analyses. Highlighted areas in grey depict primary age populations. Sample 1 (red) represents chronofacies i, and is characterized by ca. 1.8-1.9 Ga and ca. 2.6-2.8 Ga grains. Samples 2-6 (blue) represent chronofacies ii, and are characterized by zircons with U-Pb ages of ca. 300-600 Ma, and ca. 1000-1200 Ma. Samples 7-9 (green) represent chronofacies iii and are characterized by abundant grains less than 250 Ma. Local recycling of strata likely account for the presence of distinct populations within successive chronofacies.



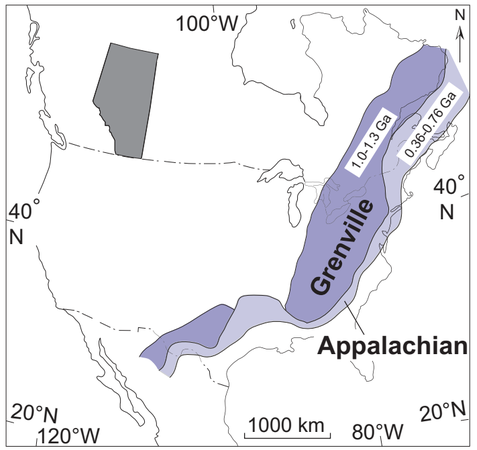
Detrital zircon cumulative probability plot from the nine samples. Red represents chronofacies i (sample 1), blue represents chronofacies ii (samples 2-6), and green represents chronofacies iii (samples 7-9). Numbers next to the curves are the sample numbers. Note that samples display distinct groupings. Like in the above plot, it can be seen that chronofacies i is characterized by ca. 1.8-1.9 Ga and 2.6-2.8 Ga zircons. Chronofacies ii is characterized by zircons with U-Pb ages of ca. 300-600 Ma and ca. 1000-1200 Ma. Chronofacies iii is characterized by abundant zircons less than 250 Ma.

7 Interpretation

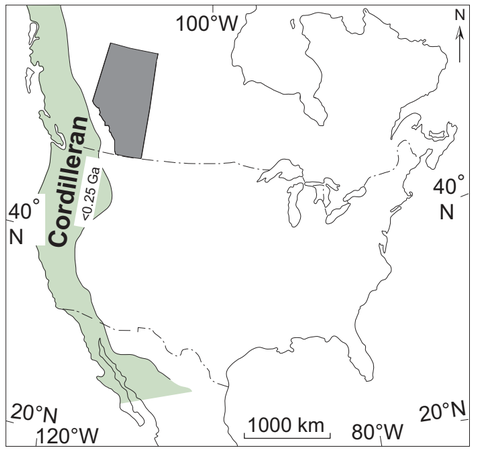
Preliminary results indicate 3 distinct detrital zircon signatures:



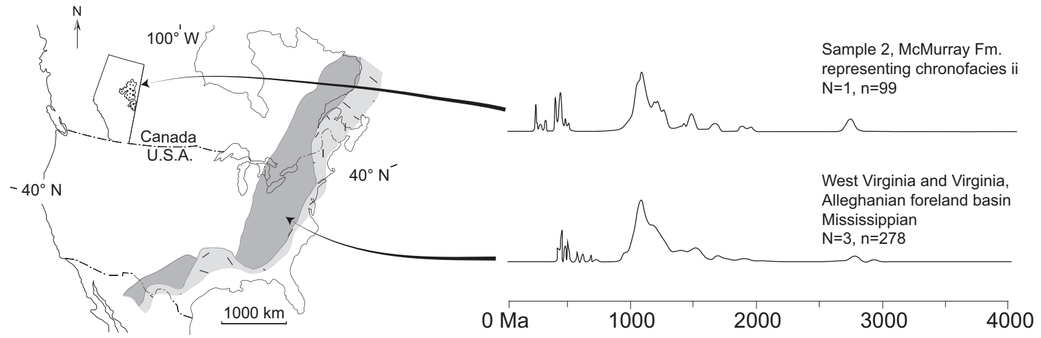
1) Zircons of Archean and Early Proterozoic age. These are interpreted to indicate a provenance associated with the Canadian Shield.



2) Zircons of Grenville (ca. 1000 Ma) and early Paleozoic age. These ages suggest an Appalachian source originally; however these zircons may have been recycled (see Discussion).



3) Relatively young zircons (<300 Ma) with a lesser population of Early Proterozoic ages. This is interpreted to indicate a Cordilleran provenance.



Comparison between detrital zircon ages in the McMurray Formation in Alberta (this study) and Mississipian-age strata deposited in the Alleghanian foreland basin of the Appalachians in Virginia and West Virginia. The map of North America shows the Grenville (grey) and Appalachian (light grey, hatches) provinces from Dickinson and Gehrels (2009), and the McMurray Formation (stippled area). Both samples contain very similar detrital zircon age populations, most notably populations of ca. 1000-1300 Ma and ca. 300-600 Ma. The presence of Grenville- and Appalachian-age detrital zircons in the McMurray Formation of Alberta is interpreted to indicate that some of the sediment in this unit (chronofacies ii) was originally derived from eastern North America. How and when the sediment was transported from eastern North America to western Canada is not yet resolved (see Discussion). Mississippian-age sample is from Park et al. (2010). N = number of samples, n = number of detrital zircon ages.

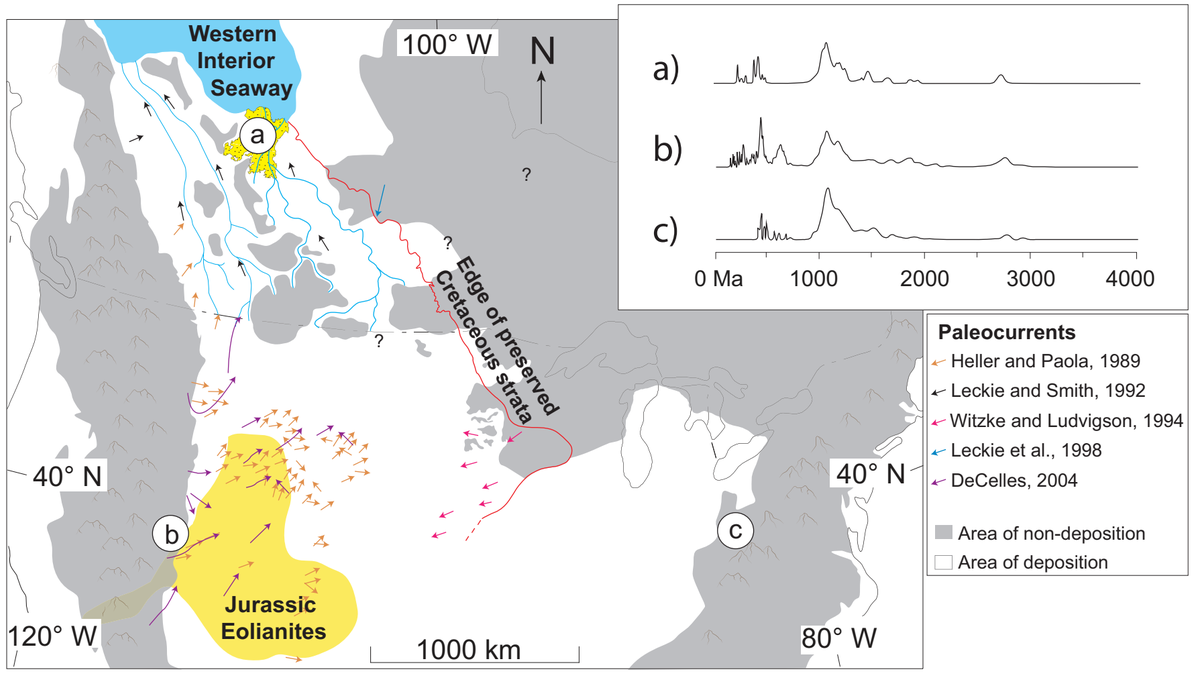
8 Summary and Discussion

We analyzed detrital zircons (U-Pb geochronology) from 9 McMurray Formation samples in order to better understand the provenance of the Athabasca Oil Sands.

Three distinct detrital zircon populations have been observed, making up the basis of 3 chronofacies, and are interpreted to be from 3 distinct source areas:

1) **The Canadian Shield**
2) **The Appalachians**
3) **The Cordillera**

The relative input from these 3 sources changed through time:
- Lowermost deposits contain sediment from the Canadian Shield
-The bulk of the McMurray Formation and the majority of the reservoir sand contains zircons derived from the Appalachians
-The uppermost deposits and overlying strata contain zircons from the Cordillera



Generalized Early Cretaceous paleogeography. Regions inferred as areas of non-deposition are shown in gray (adapted, in part, from Christopher 2003; Blakey 2012). Areas of general deposition are depicted in white. Smaller arrows represent compiled paleocurrent indicators. Representative detrital zircon signatures from different parts of North America are shown in the inset: a) Lower Cretaceous McMurray Formation, this study; b) Mesozoic eolianites, Colorado Plateau (Dickinson and Gehrels 2009); c) Mississippian strata, Virginia and West Virginia (Park et al. 2010).

How did Appalachian zircons end up in the McMurray Formation in Western Canada ?

Sediment transport models for "Appalachian" zircons. Large arrows represent hypothesized pathways of sediment from eastern North America to the Athabasca region of Canada.

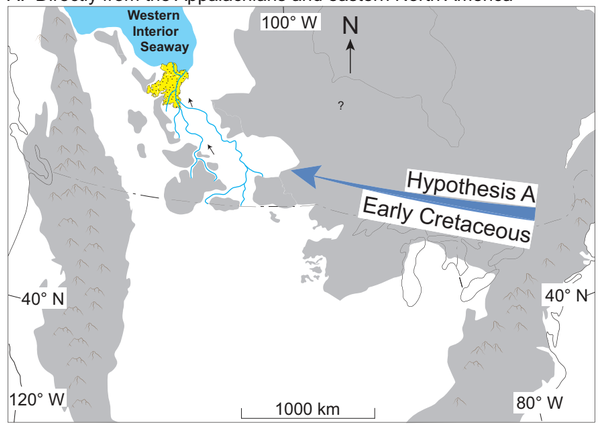
-***Hypothesis A*** involves direct transport of material from east-to-west during the Early Cretaceous;

-***Hypothesis B*** involves pre-Cretaceous transport of sediment from eastern North America to southwestern North America, followed by northward transport during the Early Cretaceous; and

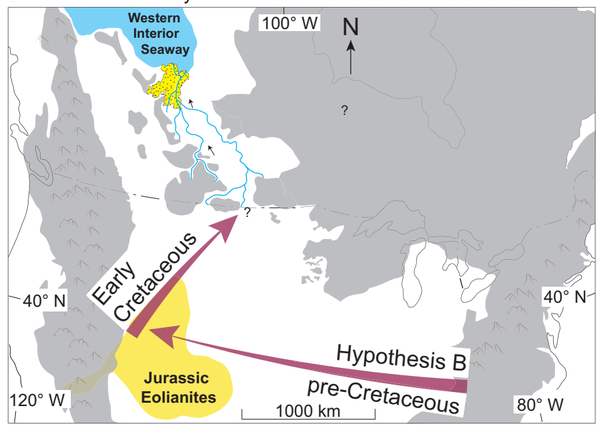
-***Hypothesis C*** involves pre-Cretaceous transport of sediment from eastern North America to western Canada, followed by local recycling during the Early Cretaceous.

At this time, it is not clear which of these options is correct. We are analyzing additional samples in an effort to constrain the most likely sediment transport history.

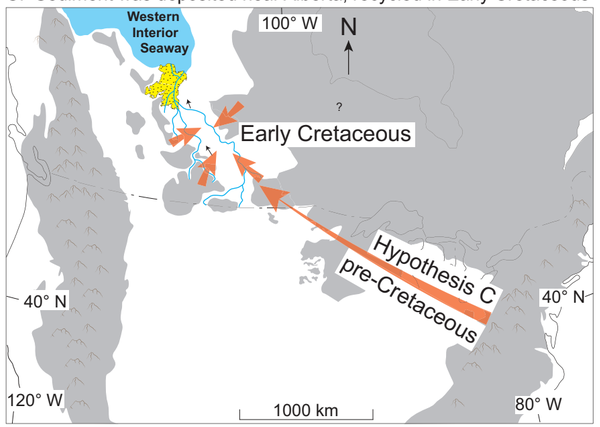
A. Directly from the Appalachians and eastern North America



B. Sediment was recycled from eolianites in the southwestern U.S.A.



C. Sediment was deposited near Alberta, recycled in Early Cretaceous



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**Other references available upon request*