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.
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.

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Where did the sand come from?

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Where did the sand come from?
Results

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 represent chronofacies ii and are characterized by abundant zircons with U-Pb ages of ca. 1.0-1.3 Ga and 2.5-2.6 Ga zircons. Chronofacies ii (samples 2-6) are characterized by ca. 1.8-1.9 Ga and ca. 1.0-1.3 Ga zircons. Sample 7-9 (green) represent chronofacies iii and are characterized by ca. 1.8-1.9 Ga zircons.

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 Mississippian-age strata deposited in the Appalachian foreland basin of the Appalachians in Virginia and West Virginia. The map of North America shows the Grenville (grey) and Appalachian (light grey, stippled area) areas of North America. The black line represents the border between Alberta (this study) and Mississippian-age strata deposited in the Appalachian foreland basin of the Appalachians in Virginia and West Virginia (adapted 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 samples are from Park et al. (2010). N = number of samples, n = number of detrital zircon ages.

Interpretation

Samples

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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 McMurray 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.

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

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

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

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

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