So, how many sands does it take to make the McMurray Formation?

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Introduction

The Athabasca Oil Sands of northeastern Alberta represent one of the largest reserves of hydrocarbons in the world. Barren fluvial sandstones of the Lower Cretaceous (Aptian) McMurray Formation form the principal reservoir in this play. However, despite extensive research, the detailed correlation of these stacked amalgamated sandstone sequences remains problematic. The incising nature of the McMurray Formation's deposition has resulted in a complex stratigraphic architecture. In many cases this results in heavily oil saturated sand-on-sand contacts thereby making it difficult to distinguish individual channel sequences. Furthermore, the McMurray Formation sandstones are mineralogically mature (typically comprising >95% quartz) with only minor to trace amounts of feldspars, clays and heavy minerals. As a result, the differentiation and correlation of individual channel packages is challenging using bulk mineralogical data from petrographic or XRD methods. The present study aims to ascertain whether individual channel packages can be differentiated and correlated using a forensic multi-disciplinary approach including high resolution chemostratigraphy, heavy mineral analysis and zircon U-Pb geochronology.

Chemostratigraphy

Whole rock inorganic geochemical analysis (chemostratigraphy) that has been undertaken on over 2000 samples from more than 100 wells provides high resolution compositional data for 50 elements. This dataset enables the McMurray Formation to be subdivided into at least four channelized sequences that can be correlated on a field to sub-regional scale. Locally, on a field scale these sequences can be further subdivided into a series of chemostratigraphic packages which correspond to individual channel complexes. This chemostratigraphic framework is based on variations in TiO_2, Fe_2O_3, Na_2O, K_2O, P_2O_5, Ba, Cr, Zr, Ga and Rb that correspond to subtle fluctuations in detrital minerals such as feldspar, detrital clays, and heavy minerals.

One of the great advantages of chemostratigraphy is that thousands of samples can be analyzed within a few months, ensuring that a large number of wells can be investigated and interpretations presented to the operators within a development program. However, it is important to ensure that the chemostratigraphic framework is calibrated and that the mineralogical affinities of elements are corroborated. In this study detailed clay fraction XRD, heavy mineral analysis and detrital zircon U-Pb dating has been undertaken on a subset of samples in order to strengthen the mineralogical interpretations inferred from the chemostratigraphic data, and to strengthen the differentiation of individual sand bodies in a series of type wells.

Heavy Mineral Analysis

Heavy mineral analysis has proven to be a rewarding technique for sedimentary provenance studies and correlations of barren strata. The advantage of this technique is that there are over 60 different heavy mineral species present in sands and sandstones in sedimentary basins across the world. Many of these species are of restricted parageneses and can be used as reliable provenance indicators. Mineral shapes (e.g. roundness) and surface morphologies (e.g. surface pitting and frosting) add valuable insights into the transport history of each individual heavy mineral species.

Previous heavy mineral studies show that the McMurray Formation contains first-cycle granitic-metamorphic and reworked detritus derived from the Canadian Shield. However, this technique has never been used for subdivision of the McMurray Formation. To augment chemostratigraphic correlations, we have analyzed heavy mineral assemblages and characterized morphological types of dominant heavy mineral species in 48 McMurray Formation samples.

How many different McMurray sands?

In the study area eight chemically distinctive sandstone packages have been identified. Several sandstones have very similar chemical signatures; where separated by another chemically distinct sandstone it is possible to confidently distinguish them from one another. However, where two very similar sandstone packages lie directly on top of one another, telling them apart becomes more challenging. This is where heavy mineral analysis comes into play and assists with answering the question of how many truly different McMurray sands there are.

Preliminary results have identified a total of 15 different heavy mineral species in the McMurray Formation. Of these, zircon and tourmaline are the most dominant. A wide diversity of morphological types of both minerals shows that they are derived from a mixture of granitic-metamorphic and reworked sedimentary sources. High-grade and medium grade metamorphic minerals including staurolite, kyanite, garnet and chloritoid are abundant in most samples. Rutile, anatase, apatite, and diaspore are consistently present, but not abundant. The presence of diaspore, a weathering product of metamorphic and sedimentary bauxite ores, is diagnostic, because this mineral is rare in sedimentary rocks elsewhere. Minor amounts of Cr spinel (<1 %) indicate minor contribution from ophiolitic rocks. Titanite, monazite, and epidote are present locally in small amounts (<3 %).

Heavy mineral assemblages do not show any dramatic changes within the McMurray Formation, suggesting a similar provenance throughout its deposition. However, the sands of the McMurray Formation have been differentiated into chemostratigraphic packages based on subtle variations in the abundance of key elements and morphology of the common heavy minerals.

In addition to heavy mineral analyses, we are also collecting zircon laser ablation ICP-MS U-Pb age data from 45 McMurray Formation sand samples. Previous authors have shown that the McMurray Formation contains Canadian Shield- and Appalachian-derived zircons, acknowledging that some of these may be reworked from sedimentary rocks in southern Canada or the U.S. In the present study we aim to cross-reference zircon U-Pb ages with zircon morphological characteristics, in order to identify reworked populations.

Why is it important?

The resultant chemostratigraphic framework has been integrated with wireline data to establish a relatively robust reservoir model that in turn can be used to ground truth seismic models, thereby enabling individual channel sequences to be mapped around the field. Once a consistent reservoir interval has been identified and chosen as a production target, it is important to ascertain if there are any lithological barriers/baffles that could hamper communication between an injector-producer pair. Due to the incising nature of McMurray Formation deposition, sand-on-sand contacts are relatively common. Heavy mineral lags can be found between two sand packages and they have the potential to act as barriers to the steam being driven through the succession. For example, a very fine-grained sand overlying a coarse-grained sand would generate porosity-permeability differences that could affect the movement of steam. The incising nature of the depositional environment can also produce rip up clasts which when incorporated in the base of the overlying channel creates a lithological discontinuity that will impact on the movement of steam through the succession. Therefore when trying to optimize well locations and specifically horizontal well placement, an integrated study such as this provides a vital tool for a more thorough understanding of the stratigraphic architecture of the McMurray Formation

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