Timing of Source Rock Deposition in the Georgina Basin, Australia

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Summary

This paper presents preliminary results and relevant background information from an ongoing study of the geochemistry and geochronology of source rocks in the Neoproterozoic to Devonian Georgina Basin, Australia. The objectives of this study include: determination of the depositional age of the Arthur Creek and Hay River Formations in the southern Georgina Basin; determination of the timing of hydrocarbon generation from these two source rocks; comparison of rhenium and osmium isotope signature in hydrocarbons to delineate migration; comparison of organic richness (TOC) and source rock quality to rhenium and osmium concentrations; and basin-wide correlation of these source rock units. Initial Re-Os geochronologically derived ages indicate that the two source rocks for the region are significantly younger than trilobite zonation has previously suggested.

Introduction

The Georgina Basin was discovered in the 1950s as a result of a gas explosion in a drilling operation for water. The basin still remains underexplored with less than 30 exploration wells drilled in the 100,000 km^2 prospective southern region. Petroleum exploration activity in the basin has increased recently with a focus on shale gas and shale oil, primarily from the lower Arthur Creek Formation with secondary targets in the underlying Hay River Formation. Deformation of the Georgina Basin has produced two major depo-centres: the Toko Syncline to the east and the Dulcie Syncline to the west, with the former showing thickening of the lower Arthur Creek Formation. Stratigraphic correlations across the synclines are not particularly well constrained.

There are two dominant source rocks in the Georgina Basin: the Arthur Creek Formation and the Hay River Formation. Organic geochemical (biomarker and stable carbon and hydrogen isotopes) studies indicate that the lower Arthur Creek Formation “Hot Shale” contributed was the primary source of the majority of oil in the basin (Boreham and Ambrose, 2007). The Arthur Creek Formation is separated into two lithologies. The lower Arthur Creek is dominantly a carbonate-rich, type II oil prone organic matter source rock (Ambrose et al., 2001; Smith et al., 2013a; Smith et al., 2013b). The lower Arthur Creek Formation is particularly organic rich with TOC ranging up to 16% (Ambrose et al., 2001; Laurie, 2012), and thermal maturation indices ranging from immature in the north to over-mature in the south. The upper Arthur Creek Formation consists of a number of regressive carbonate facies associated with an upper carbonate ramp. Deposition of the lower Arthur Creek Formation occurred unconformably over the Hay River Formation in an anoxic off ramp setting during the Age 5 stage of the Cambrian period (Ambrose et al., 2001). There is limited trilobite information for constraining the ages of these rocks (Laurie, 2012) but deposition of the Arthur Creek Formation is diachronous from west to east. In core, the Arthur Creek Formation contains limited bioturbation and algal mats.

The upper section of the Hay River Formation is also an oil- and gas-prone source rock that is partially to fully eroded across the basin. TOC in the thickest organic rich mudstone averages 1.9% and reaches a maximum of 8%, with primarily oil-prone type II kerogen (Ambrose et al., 2001). Until quite recently, the Hay River Formation was considered an extension of the Thorntonia Limestone, which is present in the northern regions of the Georgina Basin. Re-evaluation of fauna in both limestone formations indicated that the two formations are different. This Re-Os geochronology study will help clarify the age relationships between the Arthur Creek and Hay River formations across the two depo-centers, since limited biostratigraphic, petrophysical, drill core and seismic data is publically available.

Samples and Method

Drill cores were collected from four wells: BMR Mount Isa-1 (10 Arthur Creek samples over a 1.16 m interval), MacIntyre-1 (9 Arthur Creek samples over a 3.43 m interval), NTGS99-1 (10 Arthur Creek samples over a 2.85 m interval) and Owen-2 (15 Arthur Creek samples over a 1.83 m interval and 8 Hay River samples over a 0.82 m interval). The cores were cut into two pieces, one of which was kept as a hand sample. The other half of the core was cleaned and crushed using an agate mill. Between 3 and 5g of sample was kept for Re-Os analysis in Edmonton. The rest of the powder was returned to Geoscience Australia for XRD, XRF and ICP-MS analysis and organic geochemistry.

Between 0.2 and 1g of rock powder was isolated, mixed with $^{187}Re/^{187}Os$ spike and digested using the CrO_3-H_2SO_4 method. Os was extracted using $CHCl_3$ and micro-distilled. Re was isolated using anion chromatography of 2mL CrO_3-SO_4 solution and 6mL milli-Q water. After, the Re was further refined using single bead anion chromatography. Procedural blanks were completed periodically with sample analysis to ensure internal consistency. Procedural blanks were below 0.014 and 1.366 pg for Re and Os respectively.

Re and Os standards were used to calibrate the Negative Thermal Ionization Mass Spectrometer before samples were analyzed. Re standard values where within uncertainty of the $^{185}Re/^{187}Re$ of 0.59840 ± 0.00066, while the $^{187}Os/^{188}Os$ standard ratio was 0.10683 ± 0.00014. Both of these values are within the accepted DROsS values. Determining the age of this suite of rocks considered uncertainty from procedural blanks, NTIMS analyses, and sample and spike masses. The decay constant used was 1.666×10^{-11} a^{-1} (Smoliar et al., 1996). Isochron plots of $^{187}Os/^{188}Os$ versus $^{187}Re/^{188}Os$ were generated using IsoPlot.

Conclusion

Results from this study show source rock ages are younger than indicated by trilobite biostratigraphy. Central Australia Trilobite zonation in the Arthur Creek and Hay River Formations indicate ages of 505 Ma and 510 Ma respectively (Smith et al., 2013a), of Series 3, Age 5 and Series 2, Age 4. Initial Re-Os ages from these two source rocks indicate an Arthur Creek Formation age of 469 ± 14 Ma in the Dulcie Syncline and a Hay River Formation age of 483.2 ± 7.4 Ma in the Toko Syncline. The reason(s) for the age discrepancy between biostratigraphic and radiogenic ages is being further investigated.

Hydrocarbons are present in the basin with all phases present, although the most prospective region is in the southern basin. There are two proposed phases of oil generation based on thermal maturation modelling (Morris et al., 1986; Ambrose et al., 2001). These phases are based on vitrinite reflectance, which only reflects the hottest thermal event, and relative age constraints, related to orogenic events surrounding the basin. The timing of oil and gas generation has been bracketed but not well constrained. In this study, we hope to use the oils collected from across the basin to establish an absolute age of hydrocarbon generation from the Arthur Creek and Hay River Formations.

Figure 1. The location of the Georgina Basin relative to major Australian cities.

Acknowledgements

Chris Boreham published with the permission of the CEO, Geoscience Australia.

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