Orogens to oil: government–industry–academia collaboration to better understand the greater McArthur Basin

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The greater McArthur Basin covers a wide extent of northern Australia, spanning from Western Australia to Queensland and stretching from near Tennant Creek in the south to an unknown extent beneath the Arafura Sea to the north. As such, a consortium of universities, industry and the NT Government obtained a three-year Australian Research Council Linkage grant to research both tectonic and palaeo-environmental importance of the basin. The grant will allow the consortium to focus on unravelling the history of the basin leading to improved understanding of the tectonic evolution of Australia at the time, as well as that of the setting, origin and controls on the formation of the petroleum resources within the basin. In addition, the basin spans the Palaeoproterozoic–Mesoproterozoic, a fascinating time where eukaryotes gained a foothold and oxygenation of the atmosphere and ocean commenced. Consequently, the basin is an essential geological archive for global earth system development through this time.

The partners in this project are the Australian Research Council, the Northern Territory Geological Survey, Origin Energy Limited, Santos Limited, The University of Adelaide, The University of Wollongong, The University of South Australia and the Czech Academy of Sciences. The consortium's philosophy is to identify new data to complement existing datasets and to build a spatial and temporal framework of the chemostratigraphy, age, detrital chronology, and low-temperature thermochronology of the basin. These data will be used to a) correlate effectively between sequences and drillholes up to 1000 km apart; b) illuminate the tectonic evolution of the basin and its margins by examining source-to-sink pathways for sediments through time; c) determine the palaeo-environmental conditions that persisted during deposition using geochemical proxies for redox, biological activity and nutrient influx; and d) study the thermal history of the basin by using low temperature thermochronometers to examine both the basin thermal history and that of the surrounding basement to better understand the ancient surface movements.

The project started in the second half of 2017 and to date we have undertaken the following projects (the details of many of which are on the posters in the AGES 2018 foyer).

a) We have dated the crystallisation of the Derim Derim Dolerite dykes in Altree-2 to 1312.9 ± 0.7 Ma by separating baddeleyite crystals and using U–Pb isotopes with thermal ionisation mass spectrometry. Furthermore, we have shown that these dykes differ in chemistry from the coeval Galiwinku Dolerite dykes of Arnhem Land although both represent the same intra-continental magmatic event.
b) The thermal perturbation of the Derim Derim Dolerite dykes' emplacement in the shales of the upper Roper Group has been modelled, demonstrating the importance of these intrusions in maturity models. This modelling shows that these sills have likely contributed significantly to the thermal maturity of a large part of the shale subcrop.
c) Whole-rock geochemistry data reveal that most of the Neoproterozoic Jamison sandstone and Hayfield mudstone were deposited in a suboxic environment, whereas the Kyalla Formation (top formation of the underlying Roper Group) was deposited in an anoxic environment with total organic carbon (TOC) enrichment at the top of this formation. Whole-rock Sm–Nd isotope data suggest that this TOC-enriched section was sourced from a relatively juvenile provenance. Juvenile rocks (eg basalt) usually contain higher P contents, which is considered the limiting nutrient for photosynthesis on timescales >200 000 yr. So the weathering of this type of rock would deliver significant nutrients to the basin resulting in high primary productivity, as recorded by the higher TOC concentration in the top of the Kyalla Formation. We suggest that this juvenile influx may be related to the Derim Derim mafic event.

Herein we shall focus on two of our main projects: 1) spatial and temporal variation in detrital zircon age provenance of the hydrocarbon-bearing upper Roper Group, Beetaloo Sub-basin; and 2) isotope constraints on intra-basin correlation and depositional settings of the mid-Proterozoic carbonates and organic-rich shales in the greater McArthur Basin

1) Spatial and temporal variation in detrital zircon age provenance of the hydrocarbon-bearing upper Roper Group, Beetaloo Sub-basin, Northern Territory, Australia (Yang *et al* 2017)

The subsurface Beetaloo Sub-basin of the McArthur Basin comprises a succession of shallow-water, dominantly marine, clastic sedimentary rocks that formed in the main depocentre of the Mesoproterozoic Roper Group. This group contains the oldest commercial hydrocarbons known, whose presence has been linked to changing nutrient flux controlled by a changing provenance. LA–ICP–MS detrital zircon U–Pb age

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data provide new age constraints on the upper Roper Group. The results reveal spatial and temporal provenance variations that indicate the evolution of the basin and its margins are linked to a major provenance change caused by the coeval collision of the combined South Australian Craton/North Australian Craton with the West Australian Craton.

The maximum depositional ages of the Bessie Creek Sandstone and the Velkerri Formation of the Roper Group are constrained to 1386 ± 13 Ma and 1308 ± 41 Ma respectively, whereas the overlying Moroak Sandstone has no younger detrital zircons so its maximum depositional age is also constrained as 1308 ± 41 Ma. The Kyalla Formation was deposited after 1313 ± 47 Ma, and two latest Mesoproterozoic to Neoproterozoic sedimentary units, the lower and upper Jamison sandstone, have maximum depositional ages of 1092 ± 16 Ma and 959 ± 18 Ma respectively. Large detrital zircon age datasets (of 1204 near-concordant analyses) indicate that zircons from the Maiwok Subgroup were originally sourced from Palaeoproterozoic and earliest Mesoproterozoic rocks. These are consistent with derivation from the surrounding exposed basement. Detrital zircon age variations up-section suggest a systematic temporal change in provenance. The oldest formation analysed (Bessie Creek Sandstone) has a major source dated at ca 1823 Ma. Rocks of this age are common in northern basement exposures. Samples from the overlying Velkerri Formation show derivation from a ca 1590 Ma source, consistent with rocks exposed in Queensland and the Musgrave Province. The Moroak Sandstone and the Kyalla Formation show progressively more ca 1740 Ma detritus, which likely reflects new sources in the Aileron Province to the south.

We suggest that the provenance variation initially records exposure and denudation of western Queensland rocks at ca 1400 Ma due to rifting between Laurentia and the North Australian Craton. From then until at least ca 1320 Ma, the increased ca 1740 Ma detritus indicates uplift of the Aileron Province, which we interpret as reflecting collision between the southern North Australian Craton and the West Australian Craton at ca 1300–1400 Ma. This tectonically controlled provenance change is interpreted to have included erosion of nutrient-rich arc-rocks, which may have caused a bacterial bloom in the Roper seaway. The Jamison sandstone and overlying Hayfield mudstone signify a marked change in provenance; they were deposited after the 1220–1150 Ma Musgrave Orogeny and represented a newly recognised siliciclastic basin that may have formed a shallow, long wavelength foreland basin to areas uplifted during the Musgrave Orogeny (**Figure 1**).

2) Isotope constraints on intra-basin correlation and depositional settings of the mid-Proterozoic carbonates and organic-rich shales in the greater McArthur Basin

Palaeoproterozoic sedimentary successions of the Glyde package of the greater McArthur Basin (ie the McArthur and Limbunya groups) are dominated by carbonate rocks (ie dolostones) deposited in various shallow marine to more restricted lagoonal and sabkha/playa evaporitic environments; associated organic-rich shales (ie the Barney Creek and Fraynes formations) likely formed in relatively deeper depositional settings. These formations have long been thought to be coeval. Herein we test whether chemostratigraphy can be used to correlate over hundreds of kilometres in this basin, and discuss the implications for the observed isotope and element variations for the earth system.

In this study, we use a multi-proxy approach based on the isotope tracers of carbon ($d^{13}C$) and strontium ($^{87}Sr/^{86}Sr$), and selected palaeo-redox proxies (eg cerium anomalies: Ce/Ce*) to further constrain the temporal and spatial changes in the palaeo-depositional environments and redox-structure of the basin. This approach also tests the applicability of the above isotope proxies for intra-basin correlations within the greater McArthur Basin. We present the first continuous high-resolution $d^{13}C$ and $^{87}Sr/^{86}Sr$ isotope records acquired from two drill cores: LV09001 and Manbulloo-S1 (located more than 400 km apart; **Figure 2**). These drillholes intersect Glyde package sedimentary sequences (ie the Barney Creek and Fraynes formations, dated at ca 1640 ± 5 Ma) deposited in the central and western parts of the basin respectively.

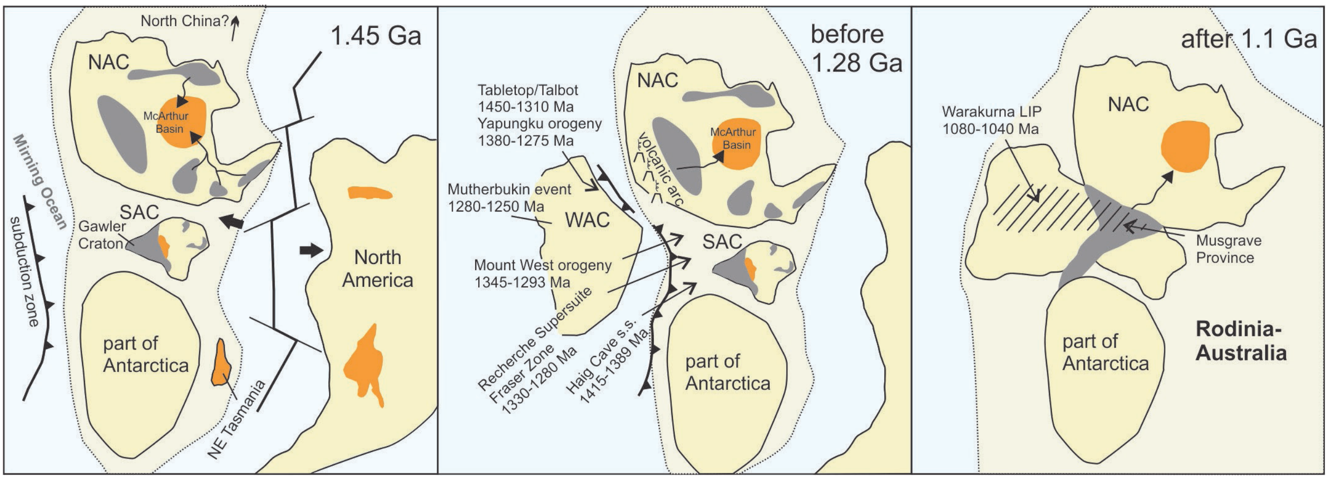

Figure 1. Interpretive cartoon of the changing Mesoproterozoic provenance through the Upper Roper Group from a broadly Queensland source in the Bessie Creek Sandstone times to a (modern day) southerly source in the Velkerri Formation and Moroak Formation, coeval with a nutrient bloom, anoxia and high carbon levels in the shales. Modified from Yang *et al* (2017).

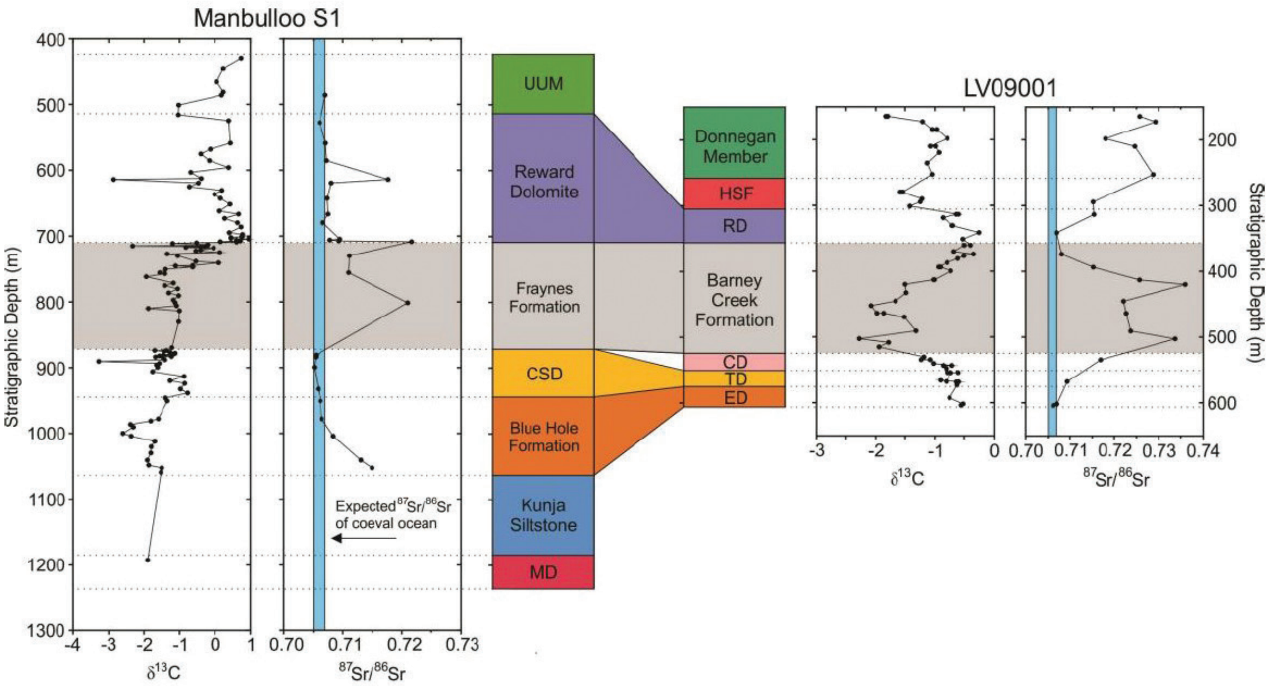

Figure 2. Comparison of high-resolution C and Sr isotope trends from the Manbulloo-S1 and LV09001 cores from the greater McArthur Basin, showing systematic shifts in measured $d^{13}C$ and $^{87}Sr/^{86}Sr$ values during the deposition of presumably correlated organic-rich shales (Fraynes and Barney Creek formations) and carbonates (Reward Dolostone). After Bullen (2017) and Giuliano (2016).

Importantly, our composite isotope trends from the greater McArthur Basin (based on data from LV09001 and Manbulloo-S1) show consistent and systematic variations in the carbonate-based $d^{13}C$, $^{87}Sr/^{86}Sr$ and Ce/Ce* proxy records, which are tightly coupled to changes in the local depositional environments. The latter variations are interpreted as oscillations between relatively redox stratified open marine conditions and more restricted (anoxic to euxinic) conditions. Overall, the results indicate coherent basin-wide isotope patterns with characteristic isotope anomalies during the purported basin restriction event (ie the deposition of organic-rich shales). The measured $d^{13}C$ and $^{87}Sr/^{86}Sr$ trends shift to isotopically lighter and more radiogenic values respectively. These coherent isotope trends acquired from LV09001 and Manbulloo-S1 cores thus supports the proposed connectivity of the central and western parts of the basin, particularly during deposition of the Barney Creek and Fraynes formations, while also showing subtle intra-basin/sub-basin variability. These data also show the potential of multi-proxy isotope approach for future intra-basin correlation studies in the greater McArthur Basin.

References

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Popular science articles related to this study

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