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Spatial and temporal variation in detrital zircon age provenance of the hydrocarbon-bearing upper Roper Group, Beetaloo Sub-basin, Northern Territory, Australia

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A B S T R A C T

The subsurface Beetaloo Sub-basin of the McArthur Basin, Northern Territory, Australia, 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 data presented here provide new age constraints on the upper Roper Group and reveal spatial and temporal provenance variations illustrating the evolution of the basin and its margins that 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, as yet, informally defined and ungrouped 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, or the Musgrave Province. The Moroak Sandstone and the Kyalla Formation show progressively more ca. 1740 Ma detritus, which we suggest likely reflects new sources in the Arunta Region 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 suggests uplift of the Arunta Region that we interpret as reflecting collision between the southern North Australian Craton and the West Australian Craton as ca. 1300–1400 Ma. This tectonically-controlled provenance change is interpreted to have included erosion of nutrient rich arc-rocks that may have caused a bacterial bloom in the Roper Seaway. The Jamison sandstone and overlying Hayfield mudstone represent a marked change in provenance and were deposited after the Musgrave Orogeny, representing a newly-recognised siliciclastic basin that may have formed a shallow, long wavelength foreland basin to areas uplifted during the Musgrave Orogeny.

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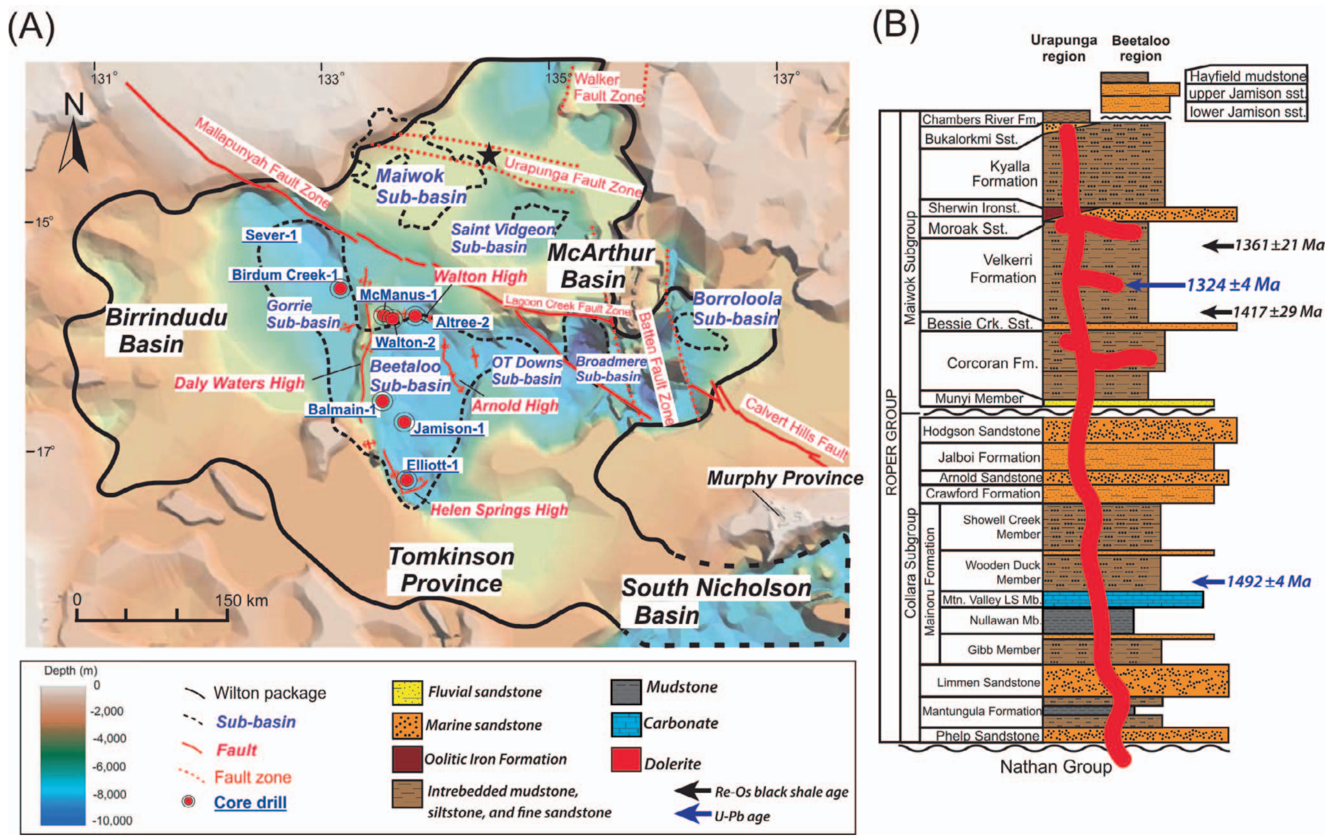

Fig. 1. (A) Extent of Wilton package based on Proterozoic SEEBASE™ basement surface, showing the locations of drillholes and major structural highs. SEEBASE™ image after De Vries et al. (2006); black star represents outcrop samples from Urapunga region from Munson et al. (2016). (B) Stratigraphic column of upper Roper Group modified after Cox et al. (2016). SHRIMP U-Pb zircon ages from Abbott et al. (2001) and Jackson et al. (1999). Re-Os ages for the Velkerri Formation from Kendall et al. (2009). Dolerite (Derim Derim Dolerite) U-Pb SHRIMP baddeleyite age reported in Abbott et al. (2001).

1. Introduction

The occurrence and formation processes of vast Proterozoic supracontinental basins throughout the world (e.g. the Cuddapah, Chhattisgarh and Vindhyan basins of India, Athabasca Basin of North America and Centralian Superbasin of Australia, amongst many others) have long been the subject of speculation. It is specifically unclear how such basins remained depocentres for periods of time that span supercontinent cycles, albeit punctuated by periods of uplift and non-deposition (e.g. Sandiford et al., 2001; Allen et al., 2015; Saha, 2017). Much of this uncertainty is due to the incomplete preservation of many of the basinal successions and subsequent modification of the basin by continent dispersal or orogenesis. In recent years, the volume and quality of detrital isotopic data has begun to provide key constraints on the evolving provenance of these basins and has assisted in unravelling the tectonic setting of their formation and subsequent evolution (e.g., Cuddapah Basin; Collins et al., 2015).

The informally named greater McArthur Basin (Close, 2014) is a Proterozoic basin system that extends over large parts of northern Australia (Fig. 1A). It contains a thick sedimentary pile that was deposited over a time span of up to a billion years of Earth history from the Palaeoproterozoic to the Neoproterozoic (Rawlings, 1999; Ahmad and Munson, 2013; Munson, 2016; Munson et al., 2016). The upper part of this basin contains the Mesoproterozoic Roper Group, which is the focus of this study. This is a siliciclastic succession characterised by alternating mudrock-rich and cross-bedded sandstone formations that are lithologically laterally continuous over extensive areas. The upper part of the group is notably rich in high organic carbon shales and is of considerable economic interest for unconventional petroleum (Cox et al., 2016; Revie, 2017); one shale interval (Velkerri Formation) has recently been demonstrated to host a major shale-gas resource (Close et al., 2017)—the oldest commercial hydrocarbons yet known. Moreover, Cox et al. (2016) demonstrated that the organic carbon correlated with phosphorous (P) contents that they suggested were a) a limitation for bacterial growth (see also Horton, 2015) and b) were derived from mafic igneous sources, i.e. from a changed provenance.

Detrital zircon grains contain valuable information about the source region of clastic sedimentary formations as they are incredibly resilient and preserve their radiometric clocks and chemical properties through metamorphic deformation and erosional processes, making them one of the most powerful tools for provenance analysis (Dickinson and Gehrels, 2009; Cawood et al., 2012; Gehrels, 2014). With the use of laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), the U-Pb age of detrital zircon grains can be obtained rapidly (Machado and Gauthier, 1996; Gehrels, 2014). Moreover, the increasing magnitude of datasets enable the use of new statistical techniques to identify and study trends in the temporal and spatial evolution of a basinal successions and their provenance (e.g. Cawood et al., 2012; Vermeesch, 2013, 2014; Shaanan and Rosenbaum, 2016; Spencer and Kirkland, 2016).

In this contribution, we present new detrital zircon U-Pb data from the Beetaloo Sub-basin, providing new constraints on basin age and provenance. Samples were collected from core samples drilled throughout the Beetaloo Sub-basin. Several formations of the Maiwok Subgroup (Bessie Creek Sandstone, Velkerri Formation, Moroak Sandstone, and Kyalla Formation) were sampled as well as the overlying, informally named Jamison sandstone, which has previously been correlated with the Bukalorkmi Formation found in the Urapunga region (Gorter and Grey, 2012), approximately 180 km to the north of the Beetaloo Sub-basin (Abbott et al., 2001; Fig. 1A and B). Data are