The complexity of sediment recycling as revealed by common Pb isotopes in K-feldspar

by

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Comparing the age and chemical or isotopic signature of minerals in sedimentary rocks to those in potential basement hinterlands is a fundamental tool used to fingerprint source to sink relationships. Detrital zircon geochronology has evolved as the choice for provenance studies because zircon grains are ubiquitous in sandstones, highly resistant to both chemical and physical weathering, amenable to U–Pb dating and carry other isotopic and chemical signatures (e.g. Lu–Hf, rare earth elements [REE]) that may uniquely link a zircon grain to its basement source. However, although the refractory nature of zircon provides the benefit of recording much of the high-temperature history of a geological terrane, its resistance to erosion provides a challenge to provenance reconstruction as it can be recycled numerous times (e.g. Dickinson et al., 2009; Dickinson and Gehrels, 2009; Anderson et al., 2016; Johnson et al., 2018).

One elegant approach to address the primary source to sink relationship is to compare the common Pb isotopic signature of detrital K-feldspar, a mineral unlikely to survive more than one erosion–transport–deposition cycle, with the signature of potential source basement terranes (e.g. Tyrrell et al., 2006, 2007, 2009; Flowerdew et al., 2012; Zhang et al., 2017; Lancaster et al., 2017; Johnson et al., 2018). K-feldspar is a common mineral in many clastic rocks and is a major constituent of arkosic sandstones. Lead isotope variations ($^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$) in igneous and metamorphic crustal rocks define broad spatial patterns that make the Pb signature of detrital K-feldspar grains a useful provenance tool. Regional patterns in Pb isotopic composition can be identified by characterizing a relatively small number of feldspar grains from potential granitic basement sources.

The Edmund Group

The Paleoproterozoic to Mesoproterozoic Edmund Group in the Capricorn Orogen of Western Australia (Fig. 1) is a mixed siliciclastic and carbonate sedimentary unit up to 9.5 km thick, comprising predominantly sandstone and siltstone, with subordinate conglomerate, dolomite, stromatolitic dolostone, carbonaceous siltstone and chert (Martin and Thorne, 2004; Martin et al., 2008; Cutten et al., 2016). The sedimentary rocks were deposited in a variety of fluvial to marine shelf or basinal environments, the distribution of which was strongly controlled by fluctuations in relative sea-level and synsedimentary movement on major, pre-existing basement faults (Cutten et al., 2016). The group has been divided into four informal depositional packages that includes 11 formations (Fig. 2). Each package is defined by a basal unconformity or a major marine flooding surface, both of which are the result of differential fault movements or fluctuations in sea level (Martin and Thorne, 2004).

The Edmund Group is dominated by sandstone units containing detrital zircons that are similar in age and isotopic composition to the underlying basement magmatic rocks of the Gascoyne Province (Martin et al., 2008; Cutten et al., 2016). However, abundant, well-developed paleoflow indicators throughout the basin suggest a primary source outside the province to the north (Martin et al., 2008), implying that the zircon detritus has been recycled, presumably through older sedimentary basins. In this study, we report the common Pb isotopic signature of detrital K-feldspar from two arkosic sandstones in the group, and compare the results to the composition of magmatic K-feldspar from various basement granitic rocks in order to address this issue and further clarify source to sink relationships in this basin.

Pb isotope compositions of detrital and magmatic K-feldspar

Detrital K-feldspar from two samples of arkosic sandstone from the Edmund Group, and magmatic K-feldspar from four samples of felsic magmatic rocks from the underlying Gascoyne Province and three from the southern Pilbara were analysed for their Pb isotope compositions. A total of 211 Pb isotopic analyses was collected from 211 K-feldspar crystals. Zones of alteration and inclusions identified by SEM imaging were avoided during the laser ablation analysis.

The detrital K-feldspar yields a wide range of $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ compositions similar to the basement granitic rocks of the southern Pilbara, whereas the granitic rocks of the Gascoyne Province yielded a relatively narrow and well-constrained range of Pb isotope compositions that are significantly different in composition

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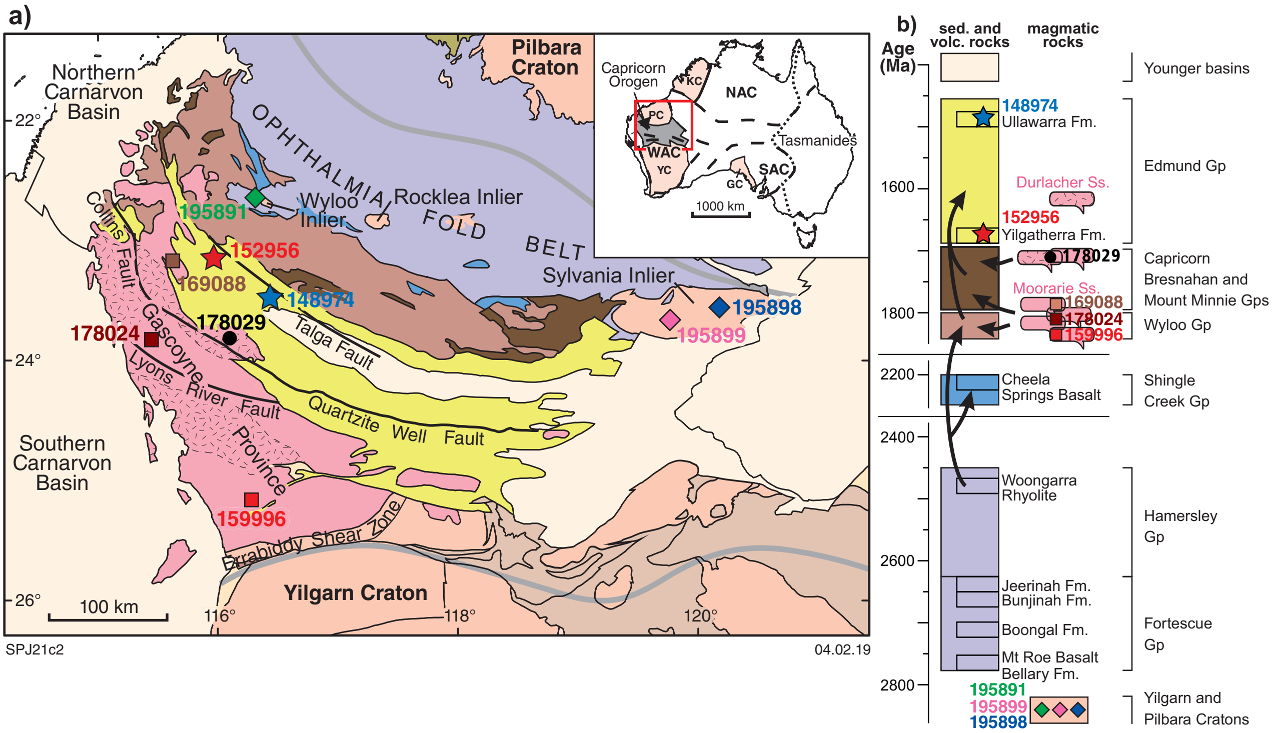

Figure 1. a) Simplified geological map of the Capricorn Orogen of Western Australia, showing the location of samples studied. Thick pale grey lines show the northern and southern limit to the Capricorn Orogen. Inset is a simplified tectonic map of Australia; b) the geological legend is provided as a stratigraphic column, showing possible pathways for recycling of detrital zircons. Abbreviations: GC, Gawler Craton; KC, Kimberley Craton; NAC, North Australian Craton; PC, Pilbara Craton; SAC, South Australian Craton; WAC, West Australian Craton; YC, Yilgarn Craton

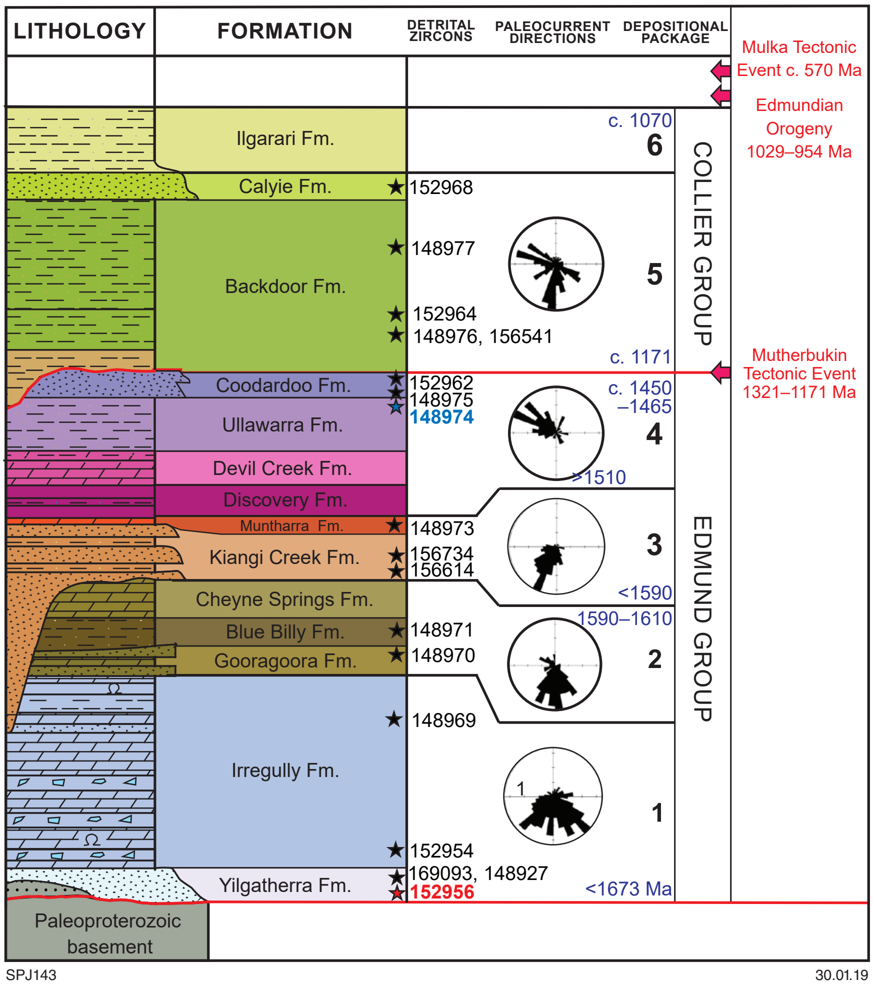

Figure 2. Stratigraphy of the Edmund and Collier Groups (after Cutten et al., 2016) showing subdivision into informal depositional packages and formations. The location of samples in this study (coloured) as well as those from Martin et al. (2008) are shown along with the timing of tectonic events and rose diagrams showing paleocurrent directions for each of the depositional packages

from the detrital grains (Fig. 3). This indicates that the detrital K-feldspar could not have been sourced from the Gascoyne Province magmatic rocks.

Implications for source provenance

The age and Hf isotopic composition of detrital zircons from the two arkosic sandstones, as well as from other sedimentary rocks of the Edmund Group, suggest that the zircon detritus was derived predominantly from the 1820–1775 Ma Moorarie Supersuite, with minor components from the 1680–1620 Ma Durlacher Supersuite and some older rocks of the Gascoyne Province. However, the Pb isotope compositions of the detrital K-feldspar within these sandstones do not match those from the potential granitic source rocks of the Gascoyne Province, particularly in the $^{206}Pb/^{204}Pb$ vs $^{208}Pb/^{204}Pb$ system. Therefore, despite these rocks containing a major cargo of detrital zircon derived from the Gascoyne Province, the basement rocks could not have been the direct source of the sediment detritus. Instead, the detrital K-feldspar compositions closely match those of Archean granitic rocks from basement inliers along the southern Pilbara margin, suggesting that this region was the primary source of detritus feeding the Edmund Basin (Fig. 3).

The K-feldspar common Pb isotope data and detrital zircon U–Pb data together suggest that the Edmund Basin was fed with detritus derived directly from the southern Pilbara margin, with most zircon recycled through older sedimentary basins such as the Capricorn, Bresnahan and Mount Minnie Groups. This interpretation is consistent with macroscopic paleoflow indicators, which suggest flow from upland regions to the north of the Edmund Basin (Martin et al., 2008).

The data indicate that during the extensional Mangaroon Orogeny, the northern margin of the orogen was subject to uplift and erosion. Detritus was shed towards the south into the Edmund Basin, which developed in the central part of the orogen as a continued expression of this extensional event. The southern part of the orogen however, remained passive, a conclusion that could not have been made from the detrital zircon data alone. This interpretation is supported by new in situ U–Th–Pb phosphate dating showing that, during this event, the northern margin of the orogen was subject to repeated fault reactivation, low-temperature hydrothermal fluid flow and associated gold mineralization (Fielding et al., 2017, 2018).

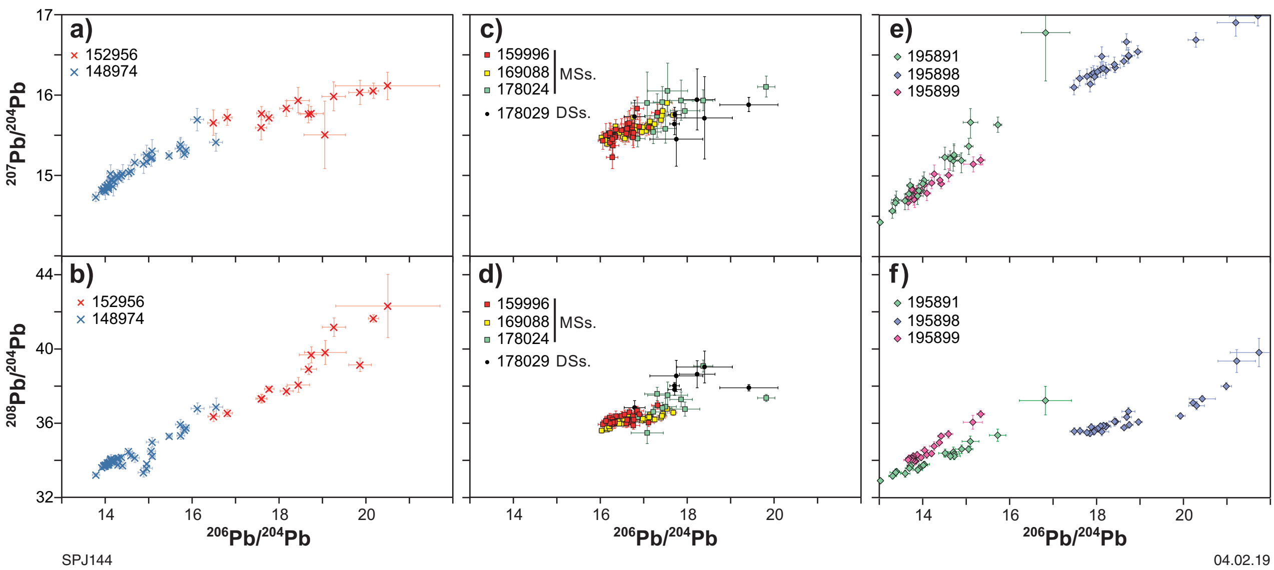

Figure 3. **a,b) Lead isotope composition of detrital K-feldspar from sedimentary rocks of the Edmund Group; c,d) Pb isotope composition of magmatic K-feldspar from felsic magmatic rocks of the 1820–1775 Ma Moorarie Supersuite (MSs.) and 1680–1620 Ma Durlacher Supersuite (DSs.) of the Gascoyne Province; e,f) Pb isotope composition of magmatic K-feldspar from felsic magmatic rocks along southern margin of the Pilbara. Uncertainties are at the 2σ level. Sample localities shown in Figure 1**

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