ROYALTIES FOR REGIONS

EXPLORATION INCENTIVE SCHEME

A multi-isotopic approach to the crustal evolution of the west Musgrave Province

by

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The timing and mechanism of crust formation are both important factors in understanding the mineral wealth of a region, as juvenile addition from the mantle into the crust directly or indirectly controls the mineral endowment. Hafnium and neodymium isotopic evolution can constrain the timing of crust formation, provided that the recorded isotopic signal is not a mixture between materials formed at different times.

The Mesoproterozoic Musgrave Province of central Australia possibly represents one of the most extreme cases of an extension-related, high field strength element (HFSE)-enriched, magmatic province. This enrichment has had a profound influence on the evolution patterns for isotopes of HFSE (e.g. hafnium and neodymium), which warrants special consideration. Known magmatism in this region extends from c. 1400 to c. 1040 Ma, and is characterized by four major magmatic events, of which at least two were intracratonic (Smithies et al., 2010; Smithies et al., 2011). Although the nature of basement to the province is cryptic, the neodymium and hafnium isotopic evolution of nearly all rocks in the Musgrave Province requires the presence of a Paleoproterozoic to early Mesoproterozoic juvenile basement with a minor Archean component (Smithies et al., 2010; Wade et al., 2006). The oldest exposed rocks in the west Musgrave Province was previously thought to be the calc-alkaline igneous rocks of the 1345–1293 Ma Wankanki Supersuite, interleaved with near-contemporaneous paragneisses of the Wirku Metamorphics; however, new geochronology has revealed the presence of exposed 1402 ± 4 Ma crystalline rocks of the Papulankutja Supersuite (Howard et al., 2011). The Papulankutja Supersuite defines the earliest component of the isotopic dataset that constrains crust formation within the Musgrave Province.

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Isotopic constraints on crust formation

Neodymium and hafnium isotopic model ages and evolution diagrams, from magmatic rocks and sediments throughout the Musgrave Province, indicate a major juvenile-crust formation event at 1950–1900 Ma (Fig. 1). Although there are no physical remnants of this 1950–1900 Ma juvenile material, contemporaneous radiogenic addition into the crust at this time is required to account for the consistent hafnium and neodymium isotopic evolution patterns in rocks that sourced this material. Furthermore, the correspondence between this mantle extraction age and the time at which reworking of Archean material commenced strongly indicates that these ages reflect a real 1950–1900 Ma crust-formation event. The general trend of hafnium and neodymium isotopic evolution apparently implies reworking of a dominant 1950–1900 Ma source, with only minor additional unradiogenic and radiogenic input through time. However, the crust had become so HFSE-enriched during the prolonged intracontinental Musgrave Orogeny (1220–1150 Ma) that it was insensitive to later inputs of mantle material, which had very low concentrations of hafnium and neodymium. This makes the addition of juvenile material during and after the Musgrave Orogeny difficult to distinguish from crustal reworking isotopic trends. Although the Musgrave Province is an extreme case of a HFSE-enriched magmatic province, it is possible that considerable amounts of juvenile input have gone undetected in isotopic data in other intracratonic orogens; as a corollary, estimates of the amount of juvenile crustal growth in intracratonic extensional settings may also have been underestimated.

Oxygen isotopes from zircons in magmas incorporating near-surface rocks (those with $\delta^{18}O_{SMOW}$ > 6.3 ‰) are likely to yield mixed model ages; these model ages are unlikely to represent discrete crust-forming events (Hawkesworth and Kemp, 2006). Zircons in equilibrium with mantle-derived melts will have $\delta^{18}O_{SMOW}$ values of 5.3 ± 0.6 ‰, and will more likely yield model ages that reflect juvenile crust formation (Valley, 2003). The $\delta^{18}O$ values from Papulankutja Supersuite gneisses indicate that the most uncontaminated melts have model ages of 1950–1900 Ma, consistent with model ages reflecting crust generation (Fig. 2). The oldest model ages generally have the most elevated $\delta^{18}O$ components, and are consistent with unradiogenic sediment incorporation into those magmas.

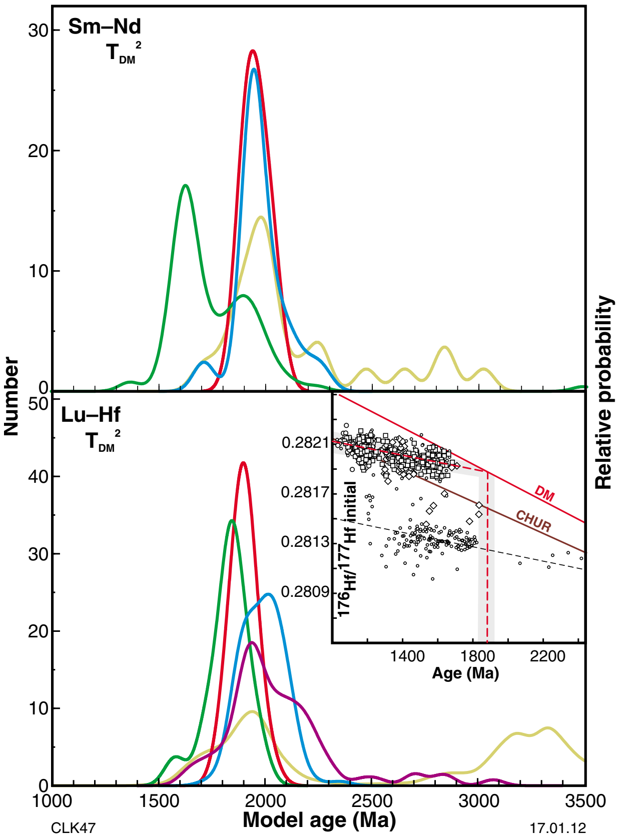

Figure 1. Probability density diagrams of model ages from the west Musgrave Province (top: samarium–neodymium whole-rock, bottom: lutetium–hafnium zircon). The y-axis records the number of data points contributing to the probability curve. Curve colours used: blue = Pitjantjatjara Supersuite; red = Wankanki Supersuite; green = Warakurna Supersuite; yellow = Wirku Metamorphics; purple = Papulankutja Supersuite. Inset chart shows an initial $^{176}Hf/^{177}Hf$ evolution diagram, with the hypothesized crust-formation event indicated by the red dashed line at c. 1900 Ma.

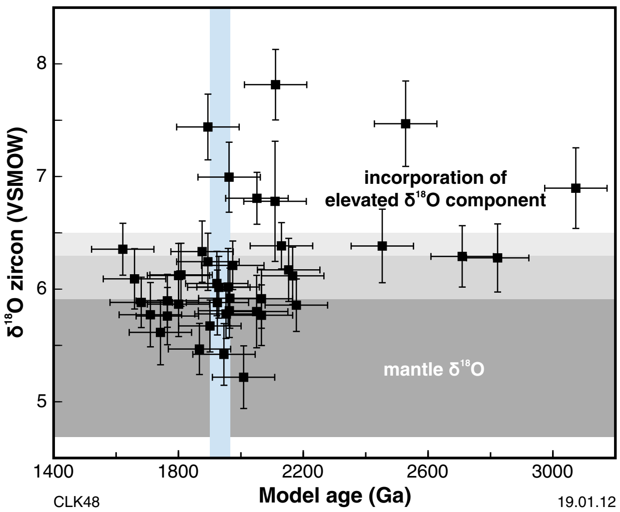

Figure 2. Zircon $\delta^{18}O$ (VSMOW) versus hafnium crustal model ages from the same zircon crystals. Vertical bar indicates time of hypothesized crust-formation event. Values within grey horizontal bars indicate zircon with minimal (<6.3 per mil) and no influence of crustal material. Note the generally higher $\delta^{18}O$ values for zircon grains with model ages >1950 Ma.

Implications for crustal evolution of the west Musgrave Province

The Papulankutja Supersuite comprises c. 1400 Ma calc-alkaline granodioritic and monzogranitic basement rocks. Neodymium and hafnium data from this exposed basement, and its derivative products, imply an isotopically homogeneous juvenile source with a mafic to intermediate bulk composition, isolated from the mantle at 1950–1900 Ma. This source dominates the subsequent isotopic evolution of the province through apparent recycling events at c. 1400, 1345–1293, 1220–1150, and 1085–1040 Ma. Although the hafnium and neodymium isotope arrays for the Musgrave Province are dominated by apparent recycling trends, the range of geological data requires significant mantle contribution associated with the 1220–1150 Ma Musgrave Orogeny and the 1085– 1040 Ma Giles Event. Both of these younger magmatic events coincide with marked changes in felsic magma composition, towards an extreme enrichment in HFSE.

Reworking of an Archean source was near-synchronous with the formation of the 1950–1900 Ma mafic to intermediate basement. In addition, neither the 1950–1900 Ma juvenile crust, nor a subsequent 1650–1550 Ma juvenile component identified in the Musgrave Province basement, provide any evidence of a direct link between the province and the currently proximal Proterozoic terranes to the north (the Arunta, and specifically, the Warumpi Province) and southwest (Albany–Fraser Orogen) before c. 1400 Ma. Hence, the Musgrave Province likely formed in isolation from the southern margin of the North Australian Craton. It is possible that the 1950–1900 Ma basement developed as an active margin underplate, at or near the Archean Gawler Craton to the south.

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