New approaches in understanding the Yilgarn Craton

by

RH Smithies, Y-J Lu, K Gessner, TJ Ivanic, S Wyche, JR Lowrey[1], PA Morris and DC Champion[2]

The integration of ongoing detailed surface mapping with continuously expanding and increasingly refined geophysical, geochemical and geochronological datasets allows us to test and expand our understanding of how the lithospheric architecture of the Yilgarn Craton has evolved. Future work by the Geological Survey of Western Australia (GSWA) will continue to update and improve detailed surface mapping with the aim of a craton-wide 1:100 000 scale interpreted bedrock map, but will increasingly concentrate on the collection and interpretation of datasets that allow us to map lithospheric volumes through time. Two recent projects utilizing current whole-rock geochemical datasets to provide new insights into the geological evolution of the craton are discussed. The recently initiated 'greenstone geochemical barcoding' project is also described. This project promises to provide a significant aid to mineral explorers throughout the Eastern Goldfields Superterrane (EGST) by developing geochemically well-constrained volcanic stratigraphies for all greenstone belts.

Two distinct origins for Archean greenstone belts

Opinion is divided on whether Archean greenstones reflect plume or subduction tectonics. One approach to assessing any potential role of subduction processes in greenstone evolution has been to compare the geochemistry of basaltic and intermediate rocks in greenstone belts to geochemical proxies of modern subduction processes. Whereas many such proxies identify a 'crustal' signature in the bulk source of many Archean magmas, they cannot uniquely identify whether crustal components were added to a mantle source region prior to melting, or were later acquired by mantle-derived magmas during their emplacement within the crust. The Th/Yb vs Nb/Yb plot of Pearce (2008) offers a simple diagnostic means of interpreting how mantle-derived magmas and crust may have interacted. Using ~2200 high-quality, stratigraphically and geographically constrained analyses, the Th/Yb vs Nb/Yb plot (Fig. 1) shows that individual volcanic sequences of the Yilgarn Craton evolved through one of two distinct processes reflecting different modes of crust–mantle interaction. The BIF-rich, komatiite-poor, volcanic stratigraphy of the 2.99 – 2.71 Ga Youanmi Terrane, and of rare pre-2.73 Ga stratigraphic components of the EGST, evolved through processes leading to Th/Yb vs Nb/Yb trends with a narrow range of Th/Nb ('constant-Th/Nb' greenstones). In contrast, the younger, more widespread 2.71 – 2.66 Ga volcanic stratigraphy of the EGST evolved through processes leading to Th/Yb vs Nb/Yb trends showing a continuous range in Th/Nb ('variable-Th/Nb' greenstones).

Constant-Th/Nb greenstones are very rare worldwide, and may reflect derivation from a mantle source already with a high and constant Th/Nb ratio. This, and a lithological association including boninite-like lavas and calc-alkaline andesites, all within a narrow Th/Nb range, resembles compositions typical of modern-style subduction settings. The similarities between the Youanmi greenstones and the older greenstone components of the EGST suggest a once continuous terrain.

Variable-Th/Nb trends dominate greenstone sequences in Australia and worldwide. These greenstones are typically accompanied in the early stages by komatiite. They are also temporally associated with peaks in granite magmatism. The increasing Th/Nb in basaltic rock (Fig. 1) correlates with decreasing ε_{Nd}, reflecting variable amounts of crustal assimilation during emplacement of mantle-derived magmas. Their Th/Nb trends are very difficult to reconcile with modern-style subduction processes, but strong links with komatiite probably implicates plume tectonics. The simplest interpretation of these data is that the EGST developed as plume-related rift over existing granite–greenstone crust — in this case the Youanmi Terrane. A corollary is that the dominant north-northwest structural trend of the Yilgarn Craton might not be relevant to pre-2.71 Ga crustal evolution.

The scarcity of constant-Th/Nb trends suggests either that processes forming them never dominated Archean greenstone evolution, or that such greenstones simply were rarely preserved. Formation of granite promotes crustal preservation and so Youanmi greenstones were probably only preserved because of the 2.71 Ga 'EGST event'.

1 School of Geosciences, The University of Sydney, NSW 2006, Australia
2 Geoscience Australia, GPO Box 378, Canberra, ACT 2601, Australia

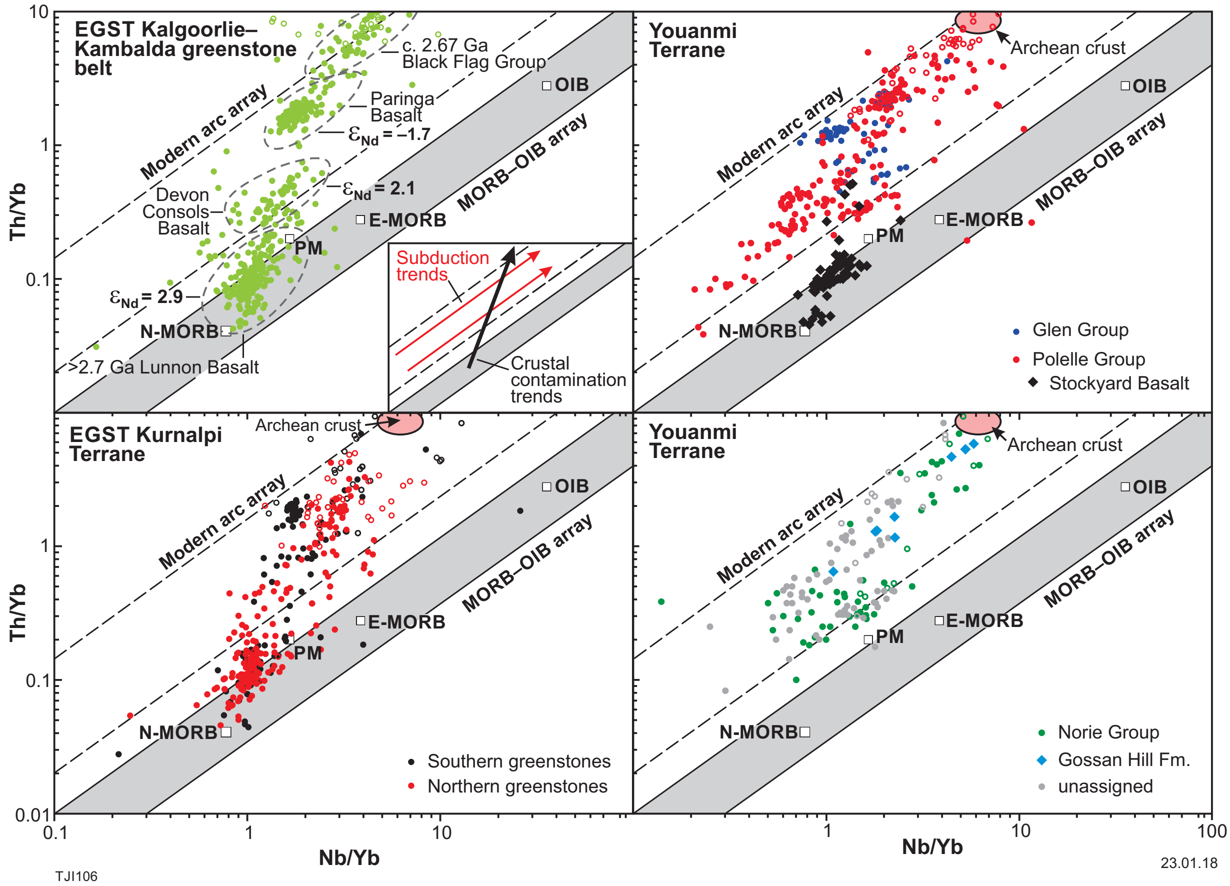

Figure 1. **The Th/Yb vs Nb/Yb plot of Pearce (2008). Values for various mantle reservoirs are from Sun and McDonough (1989) and the field for Archean crust encompasses Archean felsic average from Pearce (2008) and average Yilgarn Craton granite. Inset in the top, left-hand diagram shows compositional vectors expected for magma series derived from a subduction-enriched mantle source (red arrows), or from contamination of a magma derived from an unmodified mantle source (as in the case of MORB) that subsequently undergoes variable degrees of contamination (assimilation) by crust with a composition typical of average Archean felsic crust (black arrow)**

Imaging the southwest Yilgarn basement through granite geochemistry

A new dataset of ~250 new whole-rock geochemical analyses of granitic rocks has been compiled to better constrain the geological evolution of the poorly understood South West Terrane. Of particular interest was the insight these data might provide into the origins of a lower-crustal density anomaly (Fig. 2) that follows the southern and western margins of the South West Terrane, and which has been attributed to eclogite residuum from Archean crustal differentiation. In addition, these data are used to test the (craton-wide) assumption that basement terranes (i.e. granite source regions) parallel the late north-northwest structural trend of the Yilgarn Craton.

The dataset has been simplified into three groups. Group 1 comprises granitic rocks of dominantly high-Ca composition, with low K_2O/Na_2O (average 0.6) and high Sr, Sr/Y, La/Yb and Nb/Ta, reflecting true high-Al TTG derived through high-pressure melting of a sodic, mafic source. Group 2 comprises high- and low-Ca granitic rocks, with a wide compositional range but generally higher K_2O/Na_2O (average 1.0), and lower Sr, Sr/Y, La/Yb and Nb/Ta, reflecting lower-pressure melting of a less homogeneous source. Group 3 also comprises high- and low-Ca granitic rocks (dominantly low-Ca). Their compositions are mainly similar to group 2 but lie within the upper range of group 2 in terms of K_2O/Na_2O (average 1.16) and La/Yb, and within the lower range in terms of Sr and Sr/Y. However, they have distinctly higher Nb/Ta and typically higher Dy/Yb, perhaps reflecting melting, over a range of pressures, of an inhomogeneous, hornblende-rich source that locally included high-Al TTG components from which high La/Yb and Nb/Ta signals were inherited.

Extraction of felsic magma, leaving a dense crustal residuum of garnet-rich, or eclogitic, mineralogy imparts distinctively high Sr/Y, La/Yb and Nb/Ta characteristics on those magmas. Variation in such melting-pressure proxies shows no spatial relationship with the high density (gravity) anomaly identified in the lower crust of the southern and western parts of the region (Fig. 2). This anomaly does not appear to be directly related to Archean felsic magmatism, but more likely relates to the Proterozoic evolution of the craton margin.

In addition, the geographical distribution of the three granite groups defines northeast trends (Fig. 2) that truncate the north-northwest trends that characterize

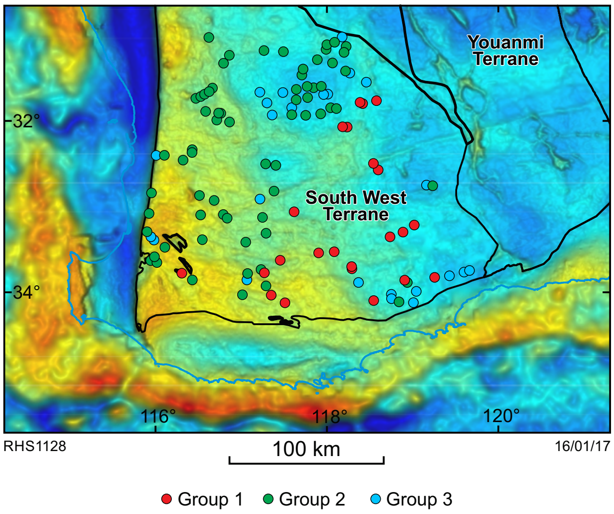

Figure 2. Gravity image of the southwestern part of the Yilgarn Craton showing the distribution of new granite samples

the more obvious structural trend of the Yilgarn Craton, including terrane boundaries. The northeast trends in granite composition potentially reflect similar trends in basement source domains; i.e. northeast-trending belts of either compositionally distinct crust or of crust undergoing melting at specific conditions, or both. Preliminary data further suggest that these northeasterly basement trends may extend across the entire craton. The idea that the Yilgarn Craton evolved through processes leading to northeast domainal trends that were later overprinted by (intracratonic?) north-northwest trends perhaps deserves further consideration.

Greenstone geochemical barcoding project

Establishing a stratigraphy is the most fundamental step in geological understanding. In a region of poor outcrop that stubbornly resists yielding any helpful information, geochemistry is well suited in terms of constraining stratigraphy. The greenstone geochemical barcoding project was designed to add geochemical credence to the EGST lithostratigraphy and 1:100 000 scale interpreted bedrock mapping projects, and will ultimately provide a detailed geochemical characterization of individual greenstone sequences throughout the EGST.

A relatively simple, basalt–komatiite–basalt–basalt–felsic-volcanic or volcaniclastic stratigraphy has long been recognized within the Kalgoorlie Terrane of the EGST, but equally well established is that the detail within that stratigraphy is often poorly known, extremely complex, and highly variable within and between individual greenstone belts. Moreover, the long-recognized <2.72 Ga stratigraphy does not take into account the local existence of older greenstone stratigraphies (i.e. basement). Nor is it clear if any of the Kalgoorlie Terrane stratigraphy is relevant to the east, in the adjoining Kurnalpi Terrane, except, perhaps, for a common c. 2.71 Ga komatiite event marker.

Hence, in a craton where geological context is often particularly difficult to establish, and where limited drillcore or rock-chip intervals might provide the only samples, the geochemical barcoding project aims to determine to what extent stratigraphic correlation can be established both within and between greenstone belts. In particular, this project aims to establish geochemical protocols or proxies that will allow the matching of limited stratigraphic intervals against an established chemical stratigraphy for any particular area.

The success of this project depends on the collection of high-quality major and trace element whole-rock geochemical data from a very large number of representative samples from all regions where a volcanic stratigraphy can already be established or reasonably inferred. The amount of existing, publicly available, high-quality whole-rock geochemical data from EGST greenstones is remarkably low. Over the past year, the amount of available data has almost doubled, through the addition of a further ~1800 new analyses, mainly from diamond drillcore samples of greenstones in the region between Kalgoorlie and Norseman. All samples have been analysed using a common analytical approach at a single laboratory to ensure internal consistency of data. The success of this project critically depends on the willingness of companies to provide access to stratigraphic drillcore.

References

Pearce, J 2008, Geochemical fingerprinting of oceanic basalts with applications to ophiolite classification and the search for Archean oceanic crust: Lithos, v. 100, p. 14–48.

Sun, S-S and McDonough, WF 1989, Chemical and isotopic systematics of oceanic basalts: implications for mantle compositions and processes, *in* Magmatism in ocean basins *edited by* AD Saunders and MJ Norry: Geological Society London, Special Publications, v. 42, p. 313–345.