LITHOSPHERIC CONTROLS ON THE LOCALIZATION OF KOMATIITE-HOSTED NICKEL-SULFIDE DEPOSITS

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Introduction

Since the nickel boom of the 1960s, research into komatiite-hosted nickel sulphide systems has focused on the deposit and mine-scale environment (e.g. Gresham & Loftus-Hills, 1981; Beresford et al. 2002). This has led to a greater understanding of the geochemical, physical and stratigraphic interactions favourable to the formation of nickel sulphide systems. However, very few projects have looked at komatiite systems on a regional-craton scale. In this project, we look to investigate how geotectonic setting, nature of the lithosphere and 4D lithospheric architecture affect the characteristics and prospectivity of komatiites in the Archaean greenstone belts of the South Yilgarn, and how these interactions may localise komatiite systems to form large, world-class Ni deposits or 'camps'.

The importance of early lithospheric architecture on the formation and evolution of a terrane has been highlighted in recent studies by Champion & Cassidy (2007), Foley (2008) and Begg et al. (2009). Champion & Cassidy (2007) used an integrated isotopic (Sm-Nd), geochemical and geochronological approach to constrain the 4D history of the Yilgarn craton. This project takes this work further by using LA-ICP-MS Lu-Hf analyses and U-Pb SHRIMP dating to document lithospheric evolution through time. This method, based on the Terrachron® technique (Griffin et al. 2004) developed at GEMOC, is innovative as it creates a number of 'time-slices' which represent the Lu-Hf lithospheric architecture at a given time period. The study area for this project comprises the south-central Yilgarn Craton, from the Marda region in the north down to Ravensthorpe, including the western region of the Eastern Goldfields.

Results

In order to analyse the data spatially and temporally, the Lu-Hf data were placed in a 'time-slice' based on U-Pb age and plotted as a geo-referenced contour map. This allowed the documentation of changing lithospheric architecture in space and time. The results for each time-slice are presented below.

2.6-2.7 Ga time-slice

This time-slice corresponds to that of the Sm-Nd map of Champion & Cassidy (2007) and also Ni mineralisation in the Eastern Goldfields. Although the data points are widely distributed, the general trends agree closely with that of the Sm-Nd work. The Youanmi Terrane (YT) is comprised of much older, more re-worked crust, with a strong crustal Hf signature, particularly around the Marda region. In contrast, the Eastern Goldfields Superterrane (EGST) shows a much more juvenile, depleted mantle (DM)-derived signature.

2.7-2.8 Ga time-slice

Moving back 100 Ma, this timeslice shows that the YT appears to have two distinct isotopic regions. The region at the centre of the terrane, covering the Marda greenstone sequence, is extremely evolved ($\varepsilon Hf = -6.02$ to -0.88). This indicates that the crust of the Marda region is long-lived, crustally-derived and has

been significantly reworked since its formation. In contrast, the crust south of the Marda region, encompassing the Forrestania, Lake Johnston and Ravensthorpe greenstone belts, shows a more juvenile signature ($\varepsilon Hf = +0.66$ to -1.2). There is only one sample from the EGST in this time-slice, in the far north of the craton (Mt Keith). This sample continues the trend shown in the 2.6-2.7 Ga time-slice, in that the EGST consists of crust which is much more juvenile ($\varepsilon Hf = +2$) and DM-derived than that of the YT.

2.8-3.1 Ga time-slice

This time-slice, although consisting of only 5 sample points, gives a first indication of the lithospheric architecture of the south-central Yilgarn at 2.8-3.1 Ga – the period of komatiite emplacement and Ni mineralisation in the YT. The region around the Marda complex remains extremely evolved, with εHf of -4.63 and -5.6, indicating that even at 2.8-3.1 Ga, this region had undergone significant crustal re-working and evolution. The region south of the Marda complex, as at 2.7–2.8 Ga, is much more juvenile than the northern region, and is also more juvenile than the same area at the younger time-slice, with εHf values of +2 to +2.5.

Discussion

The results of the first stage of this project have significant implications for crustal and cratonic evolution in the south-central Yilgarn, and indeed the craton as a whole. There also appears to be a strong spatial and temporal correlation between the location and character of magmatic events and the lithospheric architecture.

Craton evolution in space and time

The time-slices of lithospheric architecture presented in Figure 1 document the evolution of the central Yilgarn, particularly the YT, through the Late Archean from 3.1 to 2.6 Ga, and show a number of key features:

1. The crust of the Marda region is highly evolved for

the entire period of 3.1-2.6 Ga, indicating that the crust of this area is long-lived and much older than the surrounding material. This reinforces the work of previous studies (Chen et al. 2003; Wyche et al. 2004) which indicate that this central region may form the cratonic nuclei of the Yilgarn. The discovery of very old (4350-3130 Ma) detrital zircons in the basal quartzite of greenstones in this region also supports this (Compston et al. 1984; Wyche et al. 2004).

2. The results also confirm that the isotopic signatures of the EGST and YT at 2.6-2.7 Ga are fundamentally different, as first shown by the Sm-Nd map of Champion & Cassidy (2007). The YT consists of much older, long-lived crustally-derived material, whereas the EGST is made up of younger, DM-derived crust. This supports the idea that the YT and EGST evolved separately and were tectonically juxtaposed at some point during the Late Archean (Champion & Sheraton, 1997).
3. A key observation is the identification of a younger, more juvenile region in the YT, south of the Marda region. The time-slices show that at 2.8-3.1 Ga, the crust of this region is very juvenile, showing DM-derived εHf (+2 to +2.5) values. As the area youngs to 2.7-2.8 Ga, it evolves isotopically, indicating crustal melting and re-working has occurred. As the region youngs by a further 100 Ma to 2.6-2.7 Ga, the region evolves further and becomes fully cratonised to the rest of the YT. The changing lithospheric architecture of this area through time indicates that it evolved differently to the central YT and may represent a new domain in terms of crustal genesis, history and evolution.

Lithospheric architecture: implications for magmatism and Ni-Cu-PGE prospectivity

Using this time-resolved Lu-Hf lithospheric architecture, we investigated the variations in komatiite properties, geochemistry and prospectivity within the new crustal framework, focusing on the 2.9 Ga komatiite systems of the YT. The 2.8-3.1 Ga time-slice constrains the lithospheric architecture at the time of komatiite emplacement in this region, and consists of the evolved, crustally-derived central region covering the Marda and northern Southern Cross greenstone belts, and the juvenile, DM-derived southern region encompassing Forrestania, Lake Johnston and Ravensthorpe greenstone belts. A number of significant correlations were noted between the komatiites, greenstone packages and lithospheric architecture of these distinct areas:

1. The greenstone sequences as a whole are dominated by tholeiitic magmatism, however the volume of komatiite increases in the juvenile southern region (Perring et al. 1995; Witt, 1998), whereas belts of the more evolved northern area are almost completely mafic in nature (Chen et al. 2003). This indicates lithospheric architecture may control melt fractionation and geochemistry, and subsequently temperature.
2. Komatiites occurring in the central belts are generally made up of thin sheet flows, with no thick cumulate bodies (Chen et al. 2003). However in the more juvenile southern region, komatiites are much thicker and feature channelized flows with thick dunite/cumulate bodies (Perring et al. 1995; Witt, 1998). This indicates that lithospheric architecture may control the volume of a magmatic event.
3. In terms of Ni-Cu-PGE prospectivity, the belts in the central, more evolved region are currently unprospective, with no known deposits. The southern, more juvenile region contains a number of historical (RAV 1-8) and active (Flying Fox, Spotted Quoll) komatiite-hosted nickel sulphide deposits. Hence lithospheric architecture appears to acts as a first-order control on nickel sulphide prospectivity.

These observations suggest that lithospheric architecture exerts a significant control on the properties of magmas. We propose that this is due to the coupling of lithospheric architecture and geometry. Figure 2 shows a cross-section of inferred lithospheric geometry (at 2.8-3.1 Ga) using εHf as a proxy for lithosphere thickness. When a plume impinges on this geometry a number of scenarios can occur: (1) In regions of thick lithosphere (e.g. Marda area), smaller volumes of melt are generated due to high pressures and these melts are obstructed by thick ensialic crust, leading to significant assimilation and fractional crystallisation (AFC). Resultant lavas in this area are likely to be less voluminous, lower-Mg and hence

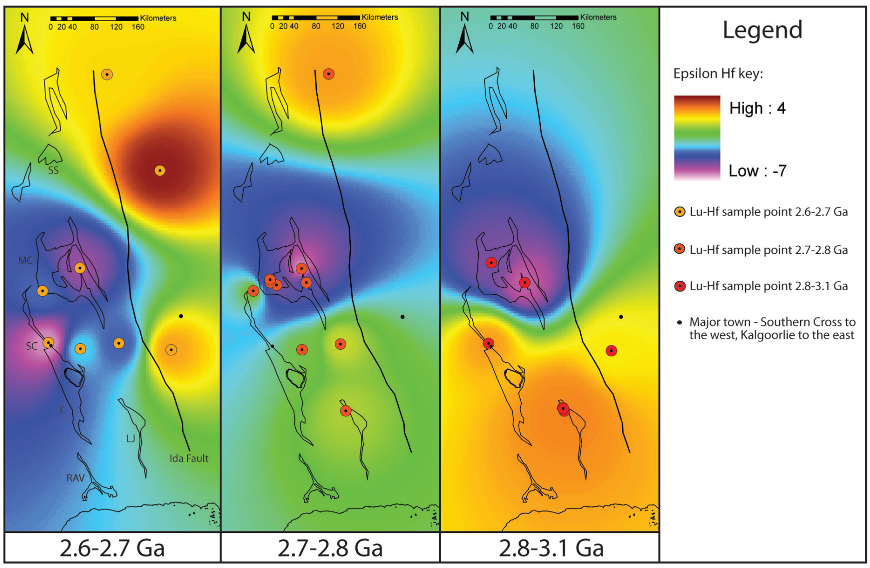

Figure 1. Lu-hf (εHf) lithospheric architecture time-slices for 2.6-2.7 Ga, 2.7-2.8 Ga and 2.9-3.1 Ga.

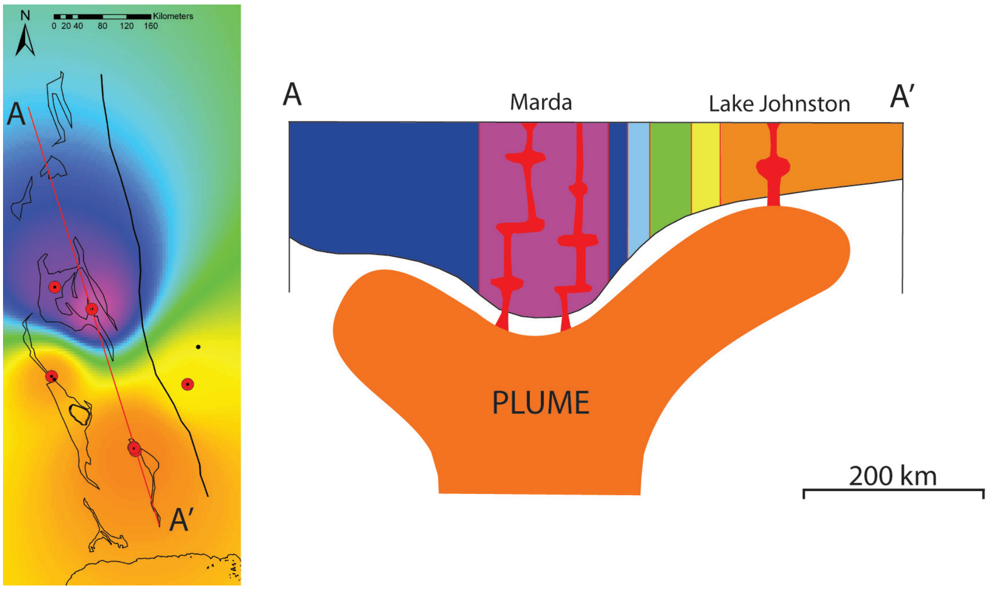

Figure 2. Cross-section through the Lu-Hf lithospheric architecture at 2.8-3.1 Ga.

cooler. This correlates well with the tholeiite-dominated sequence observed in the Lower sequence of the Marda greenstone belt. Such igneous environments are not favourable to the formation of nickel sulphide deposits. (2) In regions of thin lithosphere (e.g. Forrestania), the plume can rise to shallower levels and larger volumes of melt are generated. These melts have a less obstructed route to the surface and therefore experience less AFC. As a result, erupted melts are more voluminous, have higher Mg and are hotter. This correlates with observations in the southern belts of komatiite-abundant greenstone sequences with thick cumulate piles (Perring et al. 1995) (indicating high effusion rate), conducive to the formation of nickel sulphide deposits, verified by the presence of multiple komatiite-hosted nickel sulphide deposits (i.e. Digger Rocks, Flying Fox, Maggie Hays).

Conclusion

The new time-resolved Lu-Hf lithospheric architecture of the South Yilgarn has demonstrated significant potential to delineate crustal domains and elucidate crustal and cratonic history of the south Yilgarn, notably identifying the different genesis and crustal history of the south YT compared to the central YT. This study has also shown that lithospheric architecture appears to play a significant first-order control on the location, character, geochemistry and prospectivity of a komatiite system.

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