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

D.R. Mole¹, M. Fiorentini¹, N. Thebaud¹, C. McCuaig¹, K.F. Cassidy¹, S.J. Barnes², E.A. Belousova¹, I. Mudrovská¹ & M. Doublier¹

¹Centre for Exploration Targeting, University of Western Australia, 35 Stirling Highway, Crawley, 6009, Western Australia
²CSIRO Earth Science & Resource Engineering, 26 Dick Perry Ave, Kensington WA 6151, Australia
³Centre for Geochemical Evolution and Metallogeny of Continents, Macquarie University, Macquarie, NSW 2109, Australia
⁴Geological Survey of Western Australia, 100 Plain Street, East Perth, WA 6004, Australia

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 time-slice 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 (εHf = -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 (εHf = +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 (εHf = +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 (Compton 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
genearly 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.**
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.

**Acknowledgements**
We would like to acknowledge the ARC Linkage grant and industry sponsors BHP Nickel West, Norilsk and St Barbara Ltd for providing funding for this project. The Geological Survey of Western Australia (GSWA) is also acknowledged for logistical support in the field, provision of archived samples and technical expertise.

**References**