Musgrave Province Reconnaissance Using *TerraneChron*™

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SUMMARY

PIRSA has begun regional geological mapping of the high-grade, metamorphic Musgrave Province, which is the last Proterozoic terrane in Australia to undergo modern geological analysis.

GEMOC's *TerraneChron*™ methodology was trialed on the drainage network across the province, to provide a U-Pb age spectrum and information on the source of the parent magma obtained from zircon Hf-isotopic composition. Regional scale reconnaissance of the composition of the different crustal components will provide a framework to direct further geological investigations.

A creek sampled along the eastern margin of the Province contained a 1630 Ma population with a strong component of inherited 2800 Ma zircon. Neither of these ages have been recognised in the province before and the Archean zircons are one of the oldest populations identified in SA. Further investigation of the drainage area suggests that the zircon is derived from a fault-bounded domain consisting predominantly of granitic gneiss.

Hafnium isotope data indicate juvenile mantle-derived sources for all the samples with minor reworking of older Archean crust supported by the presence of the inherited Archean population.

Trace element analysis of the zircons shows the greater majority to be derived from felsic igneous rocks (80–90%). A small group of mafic derived zircons was found within the Archean population.

Possible tectonic links with the Arunta and Curnamona Provinces are suggested by these ages. The Leibig Orogeny (1640 Ma) on the southern edge of the Arunta region is the closest area of similar age, but shows no inherited Archean zircon.

Key words: Musgrave Province, geochronology, tectonics.

INTRODUCTION

The Musgrave Province is one of the last Proterozoic terranes in Australia to come under the scrutiny of modern geological analytical methods. This has chiefly been due to limited access to freehold aboriginal land. The last five to ten years has seen a dramatic increase in access to this remote area for industry and research organisations.

Increasing access for PIRSA has been successfully transferred onto academic institutions through the commencement of an ARC Linkage grant in association with the University of Adelaide, Monash University and the Northern Territory Geological Survey. PIRSA's contribution to the grant is facilitation of access to the Musgrave Province for the grant members and detailed regional mapping across wide areas of the province.

There is a very limited body of high quality, modern U-Pb geochronology in the SA portion of the province. This is one of the reasons why the Musgrave Province, which sits at the junction of the Yilgarn, Mawson and North Australian Cratons, is so poorly understood. Understanding the Musgrave Province is the key to help resolve the assembly of the Australian continent during the Proterozoic.

It was decided that using GEMOC's *TerraneChron*™ methodology on the extensive drainage across the Musgrave Province would provide a foundation for further investigations. This would also extend academic collaboration in the Musgrave Province to Macquarie University.

METHOD AND RESULTS

TerraneChron™ is GEMOC's recently developed methodology for terrane evaluation and studies of crustal genesis. Using laser ablation ICP-MS technology, the U-Pb age, Hf isotope and trace element compositions of individual zircon grains are analysed. Analysis of large numbers of grains obtained from detrital concentrates generates *U-Pb age* spectra that can be used to characterise fundamental terrane-scale events - sedimentary provenance, magmatic episodes, metamorphism and hydrothermal activity. The Hf isotopic data provides information on the source of the parent magma, specifically if it is from old reworked crust or from young juvenile mantle; the trace elements provide information about the composition of the parent rock. The combination of age, composition and magma sources for a large number of grains yields an "Event Signature" that gives a clear fingerprint of crustal evolution in the terrane. The *TerraneChron*™ methodology typically is applied to zircons in drainage samples collected from a defined catchment.

The Musgrave Province commonly contains two types of drainage. Short to moderate length creeks draining proximal sources and extended ephemeral river system, which drain very large areas. The short drainages are often isolated from the larger systems in the surface environment, but are considered to be part of the same palaeo-drainage systems sub-surface.

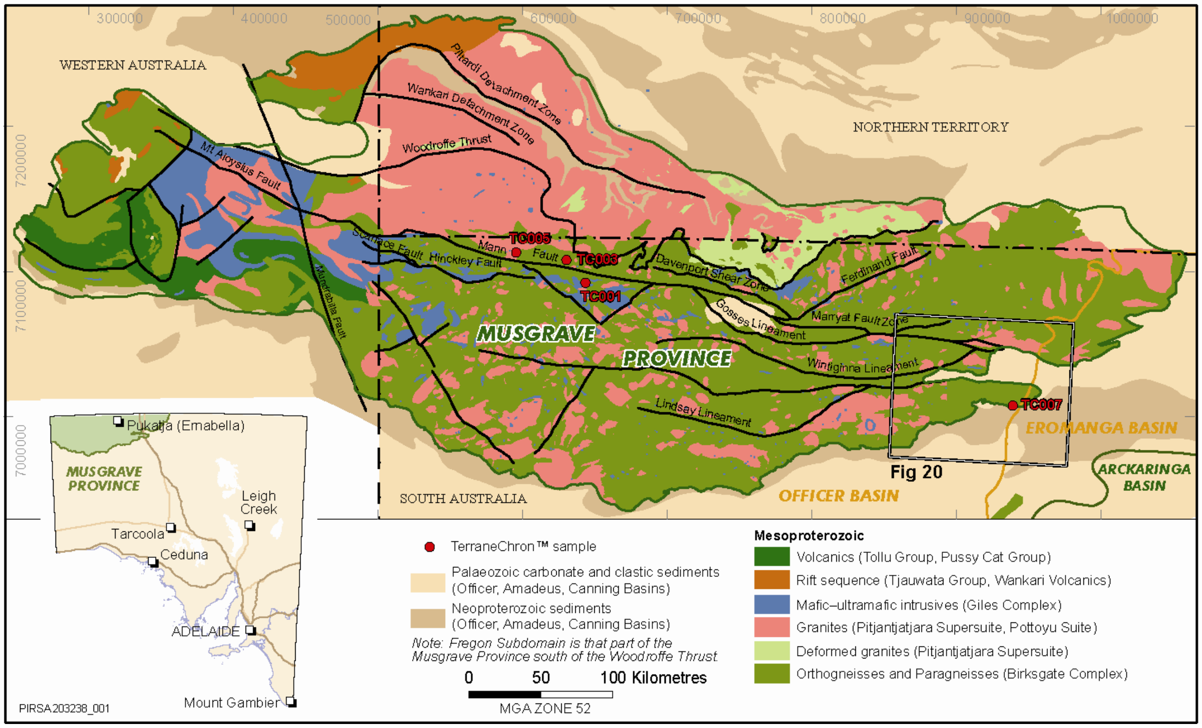

Figure 1: Interpreted bedrock lithologies and sample location map, Musgrave Province.

To test the potential of the *TerraneChron*^{TM} method in the Musgrave Province, four samples were collected from examples of both types of drainage, in the areas that PIRSA had negotiated access (Fig. 1).

Three samples were from the western region of the Musgrave Province, south of the Mann Fault. Two of these samples (Nyapari and Kanypi) are from drainage systems sourced from the Mann Ranges (Figs 2 and 3).

The third sample from this area, Hanging Knoll, was collected from a very short, isolated creek exclusively draining a large Giles Complex leucogabbro (Fig. 4). It was assumed that this sample would mainly contain Giles Complex ages and could act as a control sample.

The last sample (Fig. 5) was collected from Indulkna Creek on the Stuart Highway. This sample was taken to compare the detrital zircon populations of the eastern end of the province with those of western end and determine if significant differences were present.

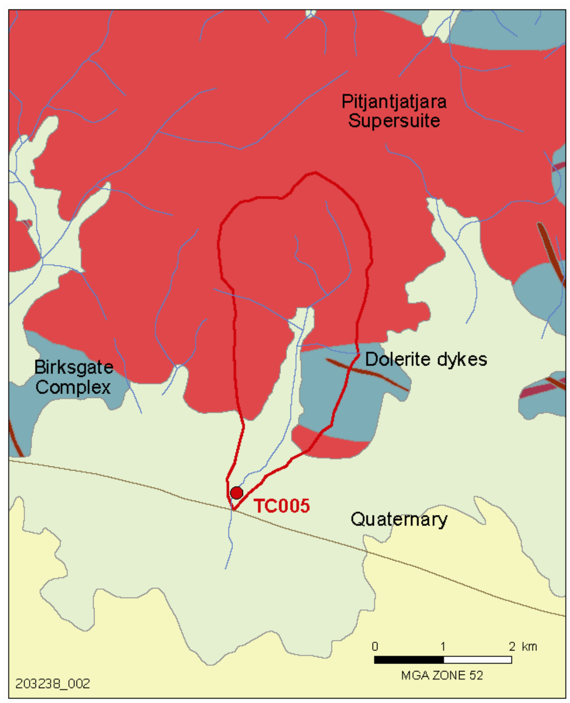

Figure 2: Catchment for Kanypi sample site showing drainage from predominantly Pitjantjatjara Supersuite felsic intrusives (pink) and minor Birksgate Complex felsic granulites (blue).

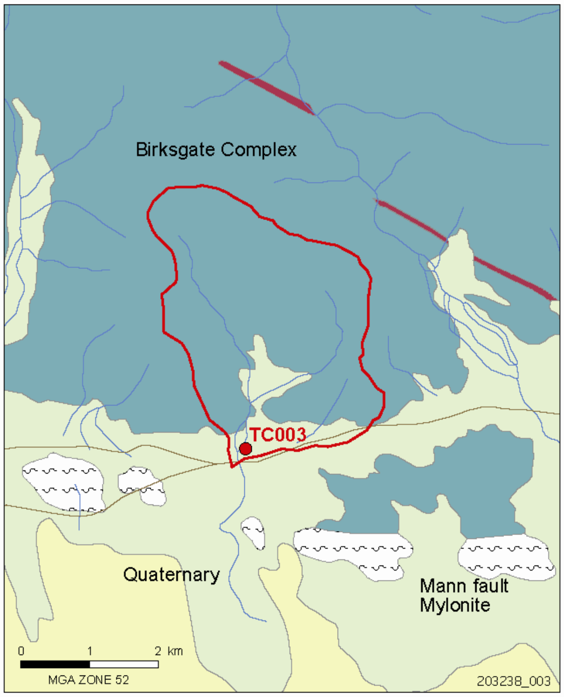

Figure 3: Catchment for Nyapari sample showing drainage from exclusively Birksgate Complex felsic granulites (blue).

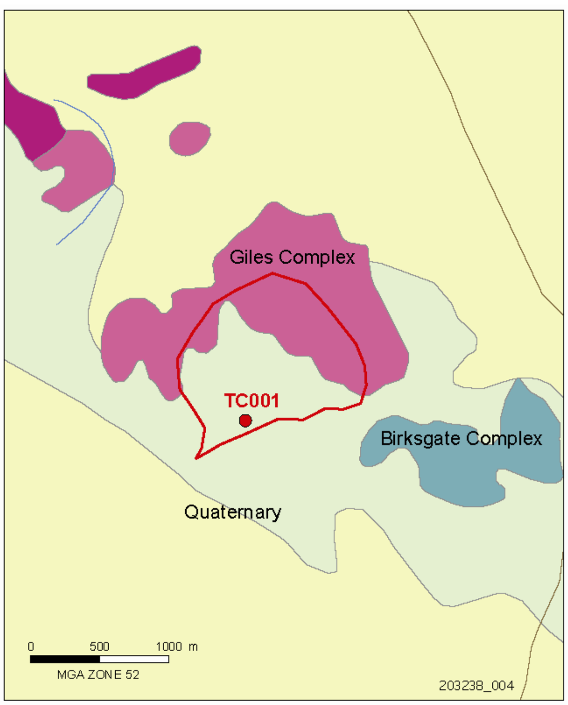

Figure 4: Catchment for Hanging Knoll sample showing drainage from exclusively Giles Complex leucogabbro (purple).

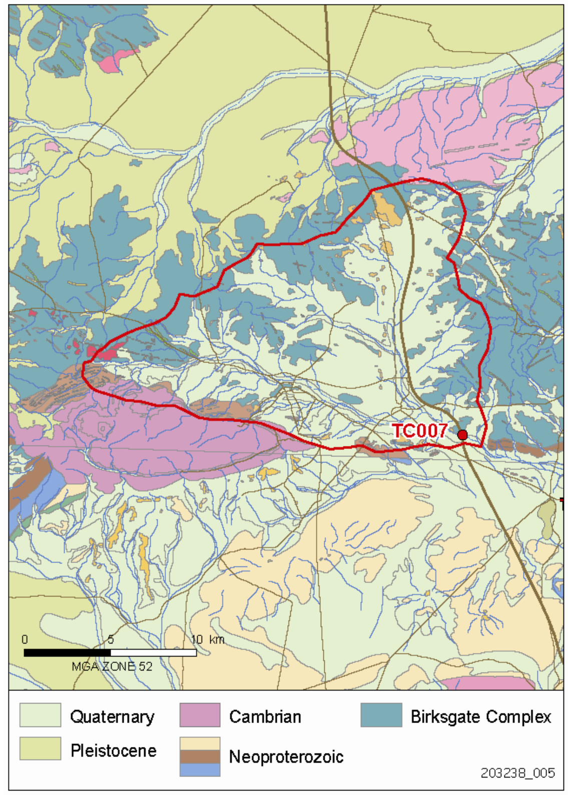

Figure 5: Catchment for Indulkna Creek sample showing drainage from a complex series of lithologies including Birksgate Complex felsic granulites (blue), mafic dykes (dark brown), Ordovician sediments (purple) and Quaternary cover (yellow).

U-Pb Zircon Ages

58 grains have been analysed in the Indulkna sample totalling 61 analyses including core and rim on 3 grains. There are two major and 3 minor age populations as shown on the Relative Probability diagram (Fig. 6). The two major populations were differentiated by weighted mean age calculations as follows: 1627 ± 11 Ma and 2808 ± 14 Ma. The other three minor peaks are: 1181 ± 14 Ma, 1468 ± 28 Ma, and 1766 ± 29 Ma.

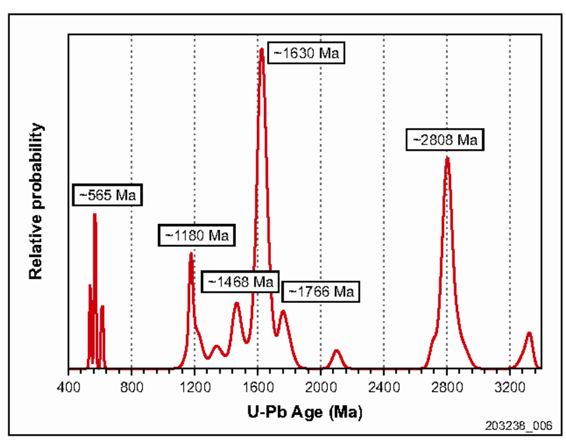

Figure 6: Indulkna Creek Zircon Populations (n=61) showing five main populations and several minor components.

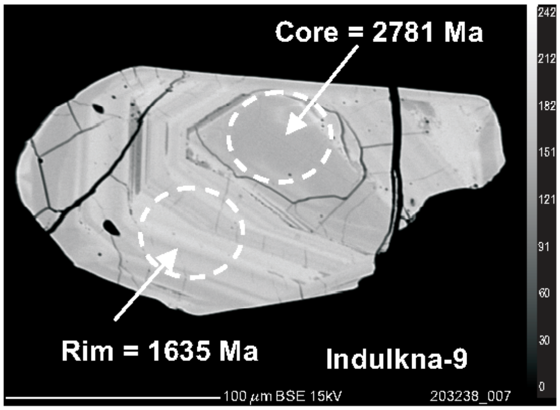

Figure 7: Backscattered Electron images showing rim and core in zircons from Indulkna.

Only the ~1468 Ma (Wade et al 2004) and ~1181 Ma (Major and Conor, 1993) populations have previously been documented in the Musgrave Province. The current age for the deposition of the oldest unit of the Musgrave Province (Birksgate Gneiss) is 1580 Ma. The 1630 Ma age significantly predates this. Many of these zircons have well defined zonation indicating a magmatic origin.

One of the 1630 Ma dates is a magmatic rim to a 2800 Ma core (Fig. 7). Very few Archean age zircons have been found in previously dated Musgrave rocks.

The number of zircons present suggests a proximal intrusive source. A reworked detrital source is unlikely to have such a large number of limited ages.

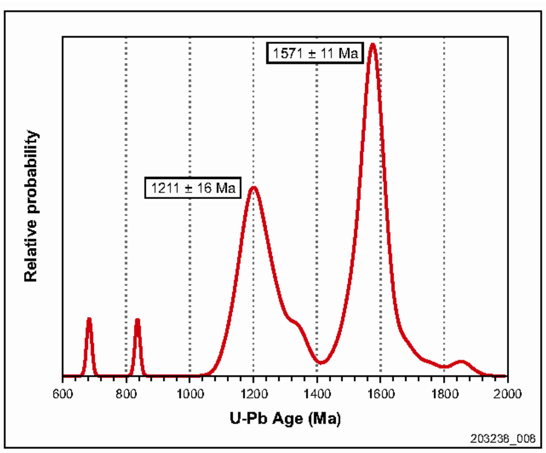

Figure 8: Nyapari Zircon Populations (n=61) showing two main populations at ~1205 Ma and ~1580 Ma.

The Nyapari sample drains primarily from the Mann Ranges. The headwaters of this creek are mapped as Birksgate Gneiss. 55 grains have been analysed with 61 analyses including core and rim on some grains. There are two major peaks at around ~1205 Ma and ~1580 Ma as shown in Figure 8. The largest age population fits well with a Birksgate Complex origin. The backscattered electron image of zircon 27 in this sample (Fig. 9), shows an apparent metamorphic 1261 Ma rim around a 1611 Ma core. The 1205 Ma population may therefore reflect a Musgrave orogeny overprint on the Birksgate Gneiss Alternatively, there may be unrecognised Pitjantjatjara Supersuite felsic intrusives present in the catchment.

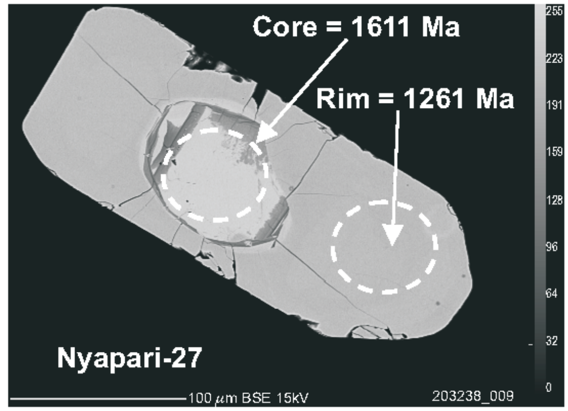

Figure 9: Backscattered Electron images showing rim and core in zircons from Nyapari.

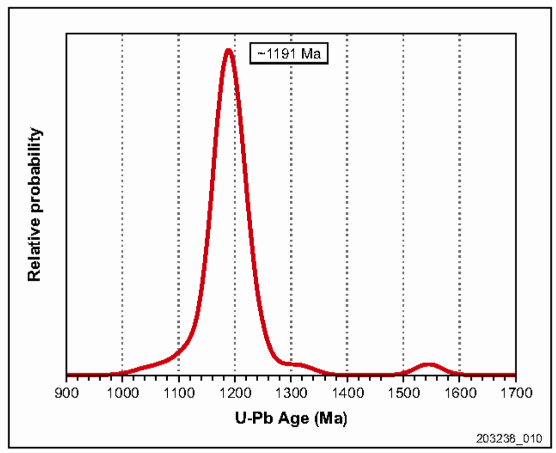

Figure 10: Kanypi Zircon Populations (n=42) showing a single population of ~1191Ma.

Only 41 grains have been analysed from this sample, due to the homogeneity of the results, totalling 42 analyses including core and rim on grain #1. Most of the data are concordant or near concordant. A single major population gave weighted mean age of 1191 ± 8 Ma (Fig. 10).

The Kanypi sample contains almost exclusively Pitjantjatjara Supersuite zircon. This is reflected in the predominance of Pitjantjatjara felsic intrusives mapped in the catchment (Fig. 2). A significant area of mapped Birksgate Complex gneiss has very little expression in the age distribution. This probably reflects incorrect mapping/photo interpretation of the area. During the previous mapping of this region in the 1970s, cheap, high quality geochemistry was not available and regional lithological interpretation relied heavily on petrology. This combined with remote access issues, meant that many outcrops have been misinterpreted in this area. The current mapping program is locating large regions of deformed Pitjantjatjara Supersuite granites that have been interpreted as Birksgate Complex granite gneiss. This adequately explains the distribution of ages in both the Nyapari and Kanypi samples.

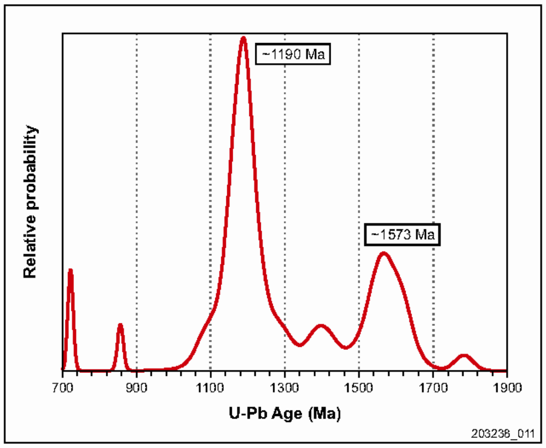

Figure 11: Hanging Knoll Zircon Populations (n=62)

In the Hanging Knoll sample, 58 grains have been analysed with 62 analyses including core and rim on some grains. There are two major peaks at around the same age as in the Nyapari sample. These major peaks were differentiated by weighted mean age calculations as follows: 1188 ± 9 Ma and 1578 ± 19 Ma (Fig. 11).

The Hanging Knoll sample was collected from a restricted drainage as described above. It was anticipated to contain a strong component of 1080 Ma Giles Complex magmatic zircon but it has a major peak at 1188 ± 9 Ma and has a minor population at 1578 ± 19 Ma. As this is basically the same as the Nyapari age distribution, it suggests that all the zircon was inherited from assimilated Birksgate Complex and Pitjantjatjara Supersuite. The ultramafic/mafic Giles Complex may not contain a large amount of zircon or the zircons/rims present may not be robust enough to survive the transport process. The very proximal nature of the stream sample should have retained some zircon of Giles Complex age if any was present.

Hafnium Isotope Analysis

Hafnium data has currently only been collected for the Nyapari, Hanging Knoll and Indulkna samples.

Most of the data for the Nyapari Sample plot between CHUR (Chondritic Universal Reservoir) and DM (Depleted Mantle) lines (Fig. 12) and show a significant juvenile contribution with εHf values ranging predominately from 0 to about 7. A large proportion of zircons from the ~1580 Ma population show stronger juvenile signatures compared to ~1205 Ma group, plotting on or just below the Depleted Mantle line. These two populations have similar TDM crustal model ages of around 1.8 Ga (Fig. 16). The younger ~1205 Ma population could be generated by recycling the ~1580 Ma older crust. There are two younger grains with ages 684 ± 16 Ma and 836 ± 16 Ma that have much lower 176Hf/177Hf ratios and εHf values at around –6. This data suggest the reworking of ancient continental crust.

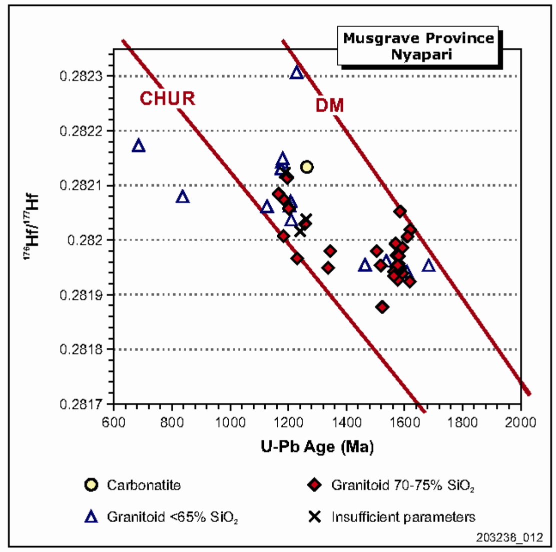

Figure 12: Hafnium isotopic data and lithological discriminations for the Nyapari sample.

The Hanging Knoll sample contains zircons that show juvenile Hf-isotopic signatures identical to those described for the Nyapari zircons (Fig. 13). It also contains younger populations around 700 Ma with much lower 176Hf/177Hf ratios and εHf values at around –6.

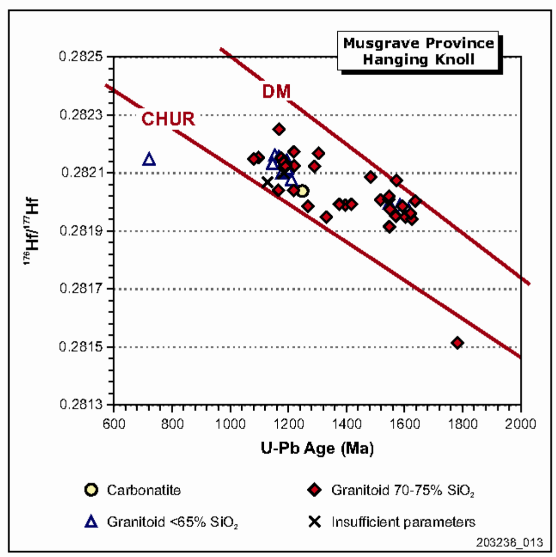

Figure 13: Hafnium isotopic data and lithological discriminations for the Hanging Knoll sample.

Data from the Indulkna sample mainly plot between CHUR and DM line and have positive εHf values, also suggesting juvenile mantle-derived sources (Fig. 14). However, there are a few zircon grains in different time intervals (500–600 Ma, 1600–1800 Ma, ~2100 Ma and 2800–2900 Ma) that plot below the CHUR line, have negative εHf values and Archean Model ages (Fig. 15). These zircons most likely came from rocks derived by reworking of the Archean crust and supports the findings of the 2808 ± 14 Ma Archean population in the area.

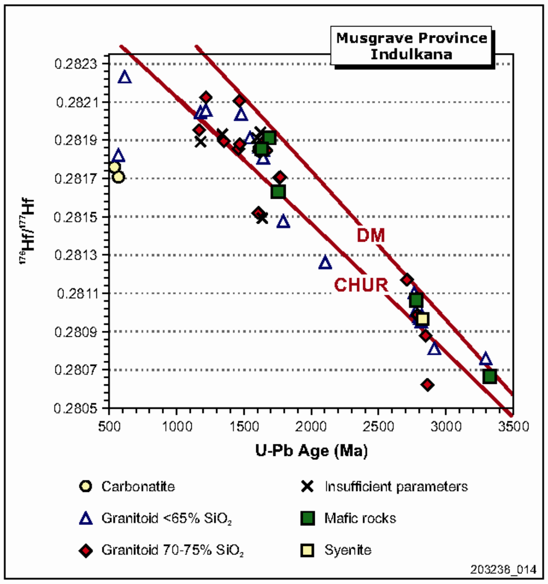

Figure 14: Hafnium isotopic data and lithological discriminations for the Nyapari sample.

Zircons in the samples from the Musgrave Province show largely positive εHf values that range mainly from 0 to + 8 (Fig. 15). The Hf-isotopic signatures indicate juvenile mantle-derived sources for those rocks. Reworked older crust is a very minor component and evidence for the recycling of the Archean crust was found in the Hf-isotopic characteristics (eg negative εHf values, TDM crustal model ages as old as 2.8–3.3 Ga) of some minor zircon populations (Fig. 15). However the existence of the Archean source is supported by the discovery of significant Archean (2808 ± 14 Ma) population in the sample from Indulkna.

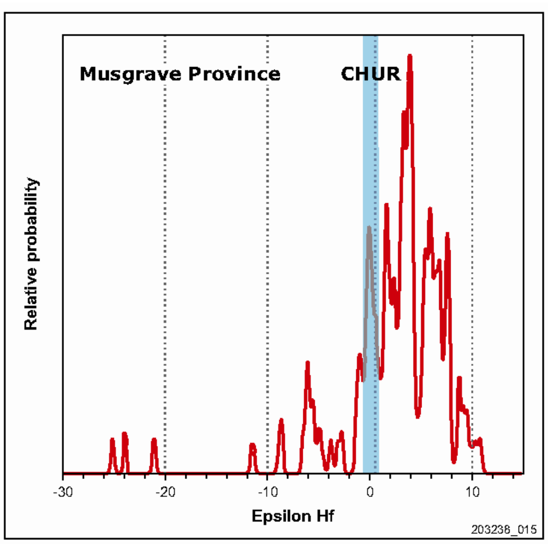

Figure 15: Relative probability of ε_{Hf} data (n=157) for zircons from the Musgrave Province.

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Figure 16: Plot of $^{176}Hf/^{177}Hf$ vs. U-Pb age for the analysed zircons, where DM is Depleted Mantle, CHUR is Chondritic Reservoir and red dashed lines show evolution of mean continental crust generated at 3.28 Ga, 2.76 Ga and 1.8 Ga.

Modelled Lithologies

An extensive study of the trace-element patterns of zircons (Belousova et al. 2002) has shown good correlations between these patterns and the composition of the magmatic host rocks. A database of U, Th, Y, Yb, Lu and Hf concentrations acquired during the electron microprobe, U-Pb and Hf-isotope analyses was evaluated using the CART statistical software (Breiman et al. 1984). This analysis created a classification tree based on simple binary switches, that allows classification of an individual zircon grain in terms of its rock type.

The trace-element analysis of zircons from the Musgrave Province shows that about 50 to 70% are probably derived from high-SiO2 felsic rocks and about 30 to 40% have trace-element compositions similar to zircons from low-SiO2 granitoids (Figs 17–19). Only the sample from Indulkna shows a slightly different distribution of source rock types (Figs 14 and 19), where 5 grains (about 10% of the total number of grains analysed) were classified as derived from mafic rocks, 2 grains are similar to those found in carbonatites and 1 could be derived from a syenitic rock. The 'mafic' grains are found only in older populations (older than 1600 Ma and Archean), 'carbonatitic' grains belong to the youngest ca 500–600 Ma population and the only 'syenitic' grain is a part of the Archean population (grain #108, 2829 ± 42 Ma).

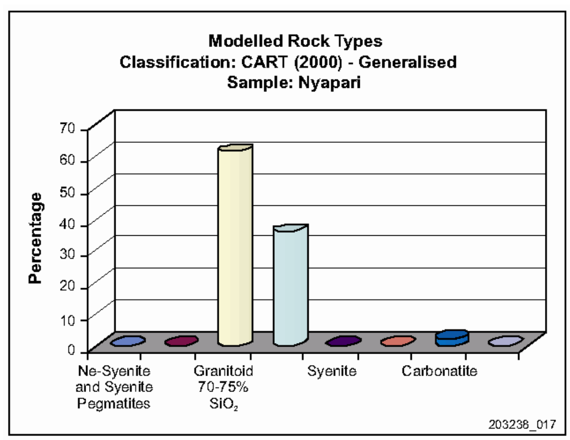

Figure 17: Nyapari sample zircon trace elements.

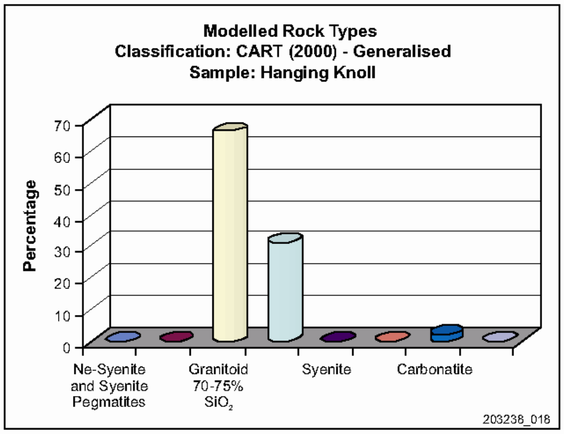

Figure 18: Hanging Knoll sample zircon trace elements.

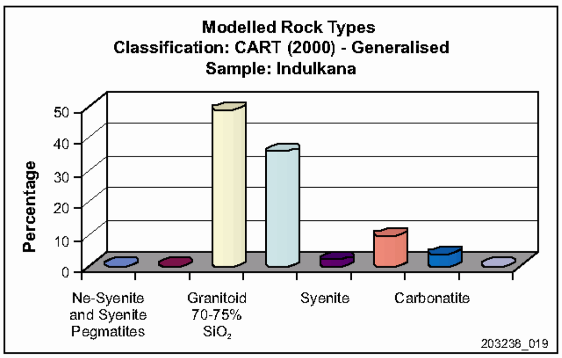

Figure 19: Indulkna sample zircon trace elements.

DISCUSSION

The three western samples all contain ages that are consistent with previous geochronology for the Musgrave Province. Variation of the age distributions from mapped geology in the drainage of the Nyapari and Kanypi samples can be explained by incorrect mapping/interpretation in the past.

The absence of Giles Complex ages in the Hanging Knoll sample may indicate that the majority of the zircon is inherited. Mapping and geochemistry has shown the Giles Complex assimilated significant amounts the host lithologies in some areas (Woodhouse and Gum, 2005). Rims of magmatic zircon associated with the Giles Complex magma may not have survived transport or may not have formed. This suggests that future attempts to date Giles Complex zircon may prove difficult.

The Indulkna Creek sample contains three unique populations previously undocumented in the Musgrave Province. The nearest outcropping rocks with 1640–1630 Ma ages are the Yaya Metamorphic Complex in the NT. The Liebig Orogeny (Scrimgeour et al 2005) reflects the accretion of the Warumpi Province onto the North Australian Craton at this time. It is possible that the source of the 1630 Ma zircon population in the Indulkna sample reflects a southern correlative of the Yaya Metamorphic Complex. Exactly how these lithologies relate to those on the northern side of the Amadeus Basin is open to conjecture at this stage. The magmatic rocks of the Yaya Metamorphic Complex however show very little Archean inheritance. The Archean ages here may represent an Archean basement component of the nearby Gawler Craton underlying both the possible Yaya Complex equivalents and the Musgrave Province lithologies.

The TMI data (Fig. 20) show a magnetically distinct area bounded by major structures on the margins of the Mooryilana Trough. The presence of the tectonically derived trough and the evidence for large vertical and lateral movements on similar types of structures elsewhere in the Musgrave Province supports the concept that this domain may be tectonically emplaced.

The 565 Ma ages possibly reflect a component of the Neoproterozoic Petermann Orogeny or cover sequences of the Officer Basin to the south.

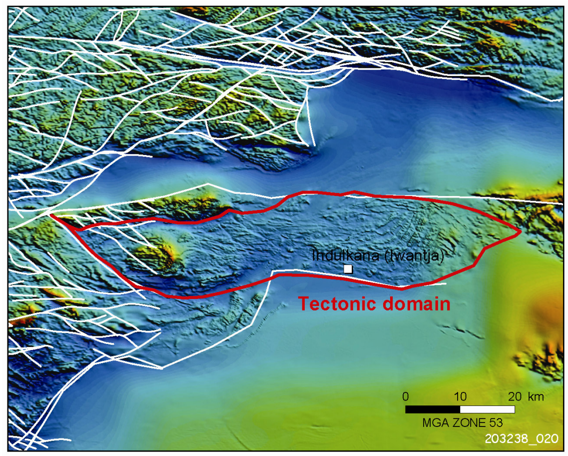

Figure 20: PIRSA 400 m line spaced TMI image of the eastern Musgrave Province, showing the distinct magnetic character of the Indulkna sample region.

CONCLUSIONS

The TerraneChron™ method has proven to be an invaluable technique to rapidly characterise the regional nature of a terrane. Any areas of anomalous character can be broadly defined and this allows concentration of effort on understanding key issues in a terrane.

The preliminary results from the three western samples confirm previous interpretations of the area, but also outline further subtlety within the region, which will be the subject of further detailed geochronological investigation.

The sample from Indulkna Creek has the potential to define a new domain, within the Musgrave Province. This highlights the south-eastern margin of the Musgrave Province as a highly significant region for the investigation of the relationship between this province and the Gawler Craton. Further detailed work will be necessary to explore this relationship.

Following the success of the initial TerraneChron™ reconnaissance program, further sampling is underway to infill the rest of the South Australian and interstate parts of the province. Four further samples have been collected from the main drainages along the South Australian section of the Stuart Highway. Further samples will be collected as access is granted. This work will be followed up with detailed mapping as well as geochemical/petrological sampling and SHRIMP dating of outcrops to positively identify the sources of these populations and their field relationships to the currently known formations of the Musgrave Province.

ACKNOWLEDGMENTS

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