The link between zircon behaviour and ages in high-grade metamorphism: constraints from zircon-garnet REE relationships.

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Introduction

The timing of zircon growth during metamorphism with respect to prograde, peak and/or retrograde metamophism is commonly ambiguous. However, knowing when zircon forms or is modified along a P-T path is key to placing tighter constraints on the rates of orogenic processes. Supporting textural and mineral chemical criteria are essential in order to place such zircon ages in a P-T, reaction and assemblage context, and to discriminate between various processes of metamorphic zircon formation. Rare earth element (REE) signatures in zircon and co-existing metamorphic minerals such as garnet are one key to addressing such problems, and has been applied here to better constrain the timing of peak UHT metamorphism in the Archaean Napier Complex, east Antarctica.

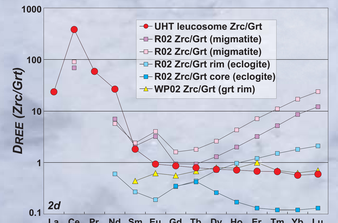
Napier Complex, east Antarctica

The Archaean Napier Complex (Figure 1) contains orthogneiss precursors as old as ~3800 Ma (Black et al., 1986; Harley & Black, 1997) and preserves evidence for some of the highest grades of metamorphism recorded in the continental crust (T=1050-1120°C, P=7-11 kbars; Harley, 1998). At least three major episodes of deformation and metamorphism affected the terrane between ~2980 Ma and ~2450 Ma (Sheraton et al., 1987). Although UHT metamorphism is now acknowledged to have occurred between ~2600-2485 Ma (Grew & Manton, 1979; Harley et al., 2001; Carson et al., 2002; Hokada et al., 2003; Kelly & Harley, in press), its exact timing is still debated due to ambiguity over the timing of metamorphic zircon growth. Pre-UHT ~2626 Ma tonalitic orthogneiss places a maximum age on the onset of metamorphism (Carson et al., 2002), and although metamorphic zircon ages pre-dominantly fall within the period 2500-2485 Ma, it is not clear if this episode of zircon growth is linked to peak metamorphism.

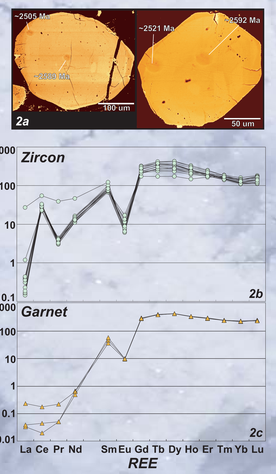
Figure 1: *Location of the Napier Complex in east Antarctica.*

DREE relationships in UHT leucosome

* **D_{REE}** (Zrc/Grt) coefficients were calculated empirically using zircon and garnet that crystallised in equilibrium in garnet-bearing leucosome (***McIntyre Island***) that cuts across UHT fabrics.
* Texturally simple zircon grains (*Fig. 2a*) have flat HREE depleted patterns (*Fig. 2b*) similar to garnet (*Fig. 2c*) that produce **D_{REE}** (Zrc/Grt) values in the range ***1.0 (Eu)*** decreasing to ***0.7 (Yb***; *Fig. 2d*).
* Grains typically have ages between 2590-2550 Ma, with older ages not confined to cores of grains.
* Crystallisation of zircon in equilibrium with garnet is interpreted to have occurred at ~2590 Ma, a minimum estimate for peak UHT conditions.

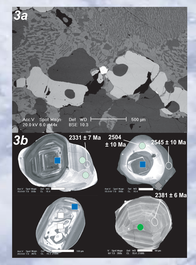


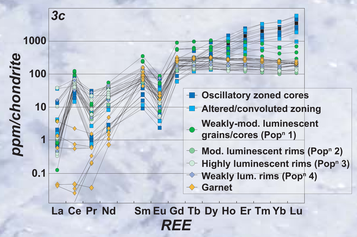
R02 - Rubatto et al. (2002)
WP02 - Whitehouse & Platt (2002)

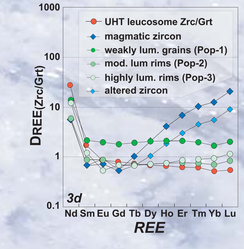


Garnet-Mesoperthite Paragneiss

* Feldspathic paragneiss (***Zircon Point***) contains coarse-grained garnet and mesoperthite (Fig. 3a), interpreted to reflect equilibration at UHT conditions.
* Three generations of metamorphic zircon can be identified: low-moderate CL cores, low CL outer rims and mod-high CL rims (Fig. 3b) - *all* have flat, HREE-depleted patterns, reflecting growth in the presence of garnet (Fig. 3c).
* REE concentration in zircon decreases with age, suggesting sequential growth and depletion of the REE reservoir during different stages in the UHT event.
* **D_{REE}** (Zrc/Grt) values for each generation (Fig. 3d) suggest that ~2550 Ma zircon is enriched relative to garnet and therefore not in equilibrium with the UHT assemblage, and ~2510-2490 Ma zircon is close to equilibrium but MREE-depleted relative to garnet.
* Although the younger zircon population may have approached equilibrium with garnet, these rims grew *after* the peak of UHT metamorphism.

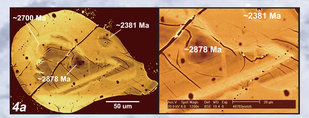


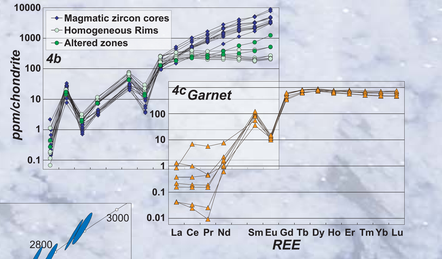


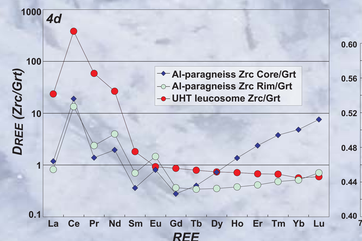


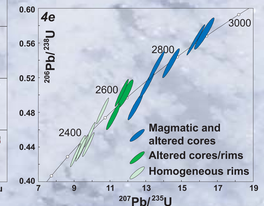
Aluminous Paragneiss

* Reaction textures suggest garnet-breakdown to orthopyroxene and sapphirine following peak metamorphism.
* Zircon grains have zoned, detrital magmatic cores with ~2800 Ma ages, and weakly zoned, lobate rims with ages between 2600-2400 Ma (Fig. 4a).
* Zircon cores have steep REE profiles typical for magmatic zircon, whereas rims have flat, HREE-depleted profiles that suggest growth in the presence of garnet (Fig. 4b).
* **D_{REE}** (Zrc/Grt) values indicate that zircon rims are MREE-depleted relative to garnet, and therefore out of equilibrium (Fig. 4d).
* Zircon rims most likely grew during post-UHT garnet-breakdown - their age does not record peak metamorphism.









Zircon growth during UHT & HT metamorphism

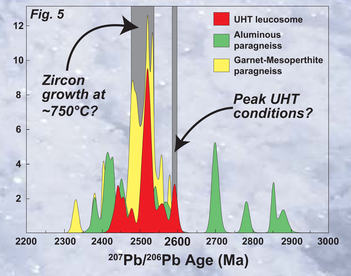
* Although bulk of reported ages for 'metamorphic' zircon in the Napier Complex are ~2510 - 2480 Ma (Fig. 5), **D_{REE}** (Zrc/Grt) data indicate:

  1) peak of UHT conditions >2590 Ma

  2) equilibration of zircon and garnet occurred at high temperature conditions between 2550-2500 Ma

  3) zircon growth and recrystallisation occurred at ~2500 Ma duing post-peak garnet breakdown

* *Suggests that most zircon growth and recrystallisation in the Napier Complex occurred much later than the peak of UHT metamorphism.*



Conclusions

* These data suggest that **D_{REE}** (Zrc/Grt) relationships are useful for assessing the timing and significance of ages from metamorphic zircon.
* In the Napier Complex example, we suggest that most zircon growth occurred at some time following peak UHT conditions, and that the bulk of metamorphic zircon in high-grade terranes may also grow due to a post-peak process.
* Better understanding of **D_{REE}** (Zrc/Grt) relationships, including the effects of pressure, temperature, fO2 and mineral composition is required to place more confidence in the interpretation of such information in natural systems.

Ongoing research

* Integrated experimental & empirical study of **D_{REE}** between zircon-garnet-melt:

1) Distribution experiments will be carried out at P-T conditions of 5 and 10 kbar, and 900 and 1000°C, and appropriate water activities. Experiments will involve production and equilibration of garnet and melts with compostions appropriate to typical pelites, and zircon with typical Hf, REE and Y contents.

2) Empirical study of distribution of REE between zircon and garnet in HT/UHT granulite facies migmatites, leucosomes and leucogranites. Natural samples are being targeted on the basis of: mineralogical and textural simplicity, simple geological evolution and well defined *P-T-t* histories.

References

Black et al. (1986). Contrib Mineral Petrol 94: 427-437; Carson et al. (2002). Precambrian Res 116: 237-263; Grew & Manton (1979). Science 206: 443-445; Harley et al. (2001) 4th International Archaean Symposium, Extended Abstract Volume, AGSO Geoscience Australia Record 2001/37, 511-513; Harley (1998), Memoir Nat Inst Polar Res, Special Issue 53: 49-73; Harley & Black (1997), Antarctic Sci 9: 74-91; Hokada (2003). Precambrian Res 127: 215-228; Kelly & Harley (*in press*). Contrib. Mineral. Petrol.; Rubatto (2002), Chem Geol, 184, 123-138; Whitehouse & Platt (2002), Contrib Mineral Petrol 145: 61-7.

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