THE TERRANECHRON® APPROACH TO CRUSTAL EVOLUTION STUDIES AND IMPLICATIONS FOR CONTINENTAL GROWTH

E.A. Belousova[1], W.L. Griffin[1], G. Begg[1,2] & S.Y. O'Reilly[1]

[1]*GEMOC, National Key Centre, Department of Earth and Planetary Sciences, NSW 2109, Australia*
[2]*Minerals Targeting International., West Perth WA, 6005, Australia*

Introduction

To understand the genesis of a block of crust and the nature of crust-mantle interaction, we need to know not only the age distribution of the magmatic rocks but also the nature (juvenile/mantle or ancient/crustal) of the magmatic protoliths. TerraneChron® is a specifically developed methodology to study the evolution and growth of the continental crust through time. It allows the evaluation of how much new crust was formed, and how much older crust was recycled, thus providing essential information on the rate at which the continental crust has grown at different stages of Earth's history. This approach is based on the integrated in situ analysis of zircons for U-Pb and Hf isotopic composition using laser-ablation microprobe techniques. The methodology is typically applied to zircons from drainage samples judiciously collected within defined catchments that sample areas of the crust formed in different tectonic settings, but also uses separated zircons from host rocks for groundtruthing.

Application to crustal evolution studies and mineral exploration

Most mineral exploration models require an understanding of the geological evolution of the crust in the area of interest; critical information includes the timing of magmatic events and the types and sources of the magmas. Acquiring this type of information in unmapped regions, or even checking the reliability of existing data, can be very costly in both time and money. However, TerraneChron® has provided a rapid and cost-effective solution to this problem.

Sampling Strategy

The methodology can be applied to zircons separated from single rocks or to zircons from drainage samples collected within a defined catchment (on scales of 10 - 1000 km, depending on the objective). The use of drainage samples has many advantages: nature has separated and concentrated a statistically more meaningful sample than is achievable by conventional single rock sampling and methods, and this can provide a more comprehensive coverage of rock types from the drainage area (Griffin et al., 2006; Belousova et al., 2009). These sediment samples also may provide zircons from source rocks that no longer outcrop, or even exist as intact rock units; these grains carry valuable information on crustal history.

Analytical Techniques

The U-Pb analyses are done by LAM-ICPMS techniques, which provide rapid and cost-effective age determinations with precision equivalent to the ion microprobe (e.g. Jackson et al., 2004). The Hf-isotope data are collected by LAM-multicollector (MC)-ICPMS (e.g. Griffin et al., 2000). Hf isotopes provide information on the source of the magmatic rock from which each zircon crystallised; they tell whether the magmatism involved a juvenile source (e.g. melting of young mantle-derived magmas, if only pre-existing crust was involved (i.e. crustal reworking), or a combination of these processes. The analysis of trace elements provides information about the composition of the magmatic rock that precipitated the zircon (e.g. Belousova et al., 2002). Thus the TerraneChron® approach provides more layers of information than the conventional approach based on U-Pb age spectra.

Event Signatures and Terrane Correlation

The comparison of large volumes of data on the ages and Hf-isotope compositions of zircons can be simplified by reducing the data to 'Event Signature' curves that show the main features of crustal evolution (Griffin et al., 2006; O'Reilly et al., 2008). Figure 1 illustrates the principle; the mean crustal residence time of the magma sources involved at each stage of the area's evolution is given by the difference between the mean crystallisation age of the magmas (the U/Pb age of the zircons) and the mean T_{DM} model age of those zircons. In this plot (Figure 1), reworking of older crust produces a downward trend with decreasing age, while juvenile inputs (leading to a lower mean source age) produce rising trends with decreasing age. Trends of intermediate slope imply contributions from both juvenile and pre-existing crustal sources.

Event Signatures reveal the timing and geochemical patterns of mantle magmatic events and crustal orogenesis that have affected each terrane sampled. Figure 1 compares the curve for the Gawler Craton with those for the Mount Isa Inlier, the Broken Hill area and the Georgetown Inlier. Although all these areas have strong evidence for Archean basement, the Broken Hill curve is significantly different from the other three curves before ca. 1800 Ma. The near-parallelism of curves for the Gawler Craton, the Mount Isa Block and the Georgetown Inlier implies a similarity in their early evolution (e.g. before ca. 1800 Ma). After ca. 1800, the Mount Isa and Broken Hill areas show remarkably parallel development (Figure 1): both underwent melting of the older crust from ca. 1800-1750 Ma, then experienced a major juvenile addition around 1650 Ma.

Testing models for Continental crustal growth

A worldwide database of 12,375 TerraneChron® analyses of zircon (Belousova et al., unpubl.), largely from detrital sources, has been generated at GEMOC since 2000. To this dataset we have added U-Pb and Hf-isotope data available from a number of recent publications (4,070 analyses from rock samples and sediments). This large volume of data (n=16,445) makes it feasible to examine processes of crustal evolution on a global scale, and to test existing models for the growth of continental crust through time.

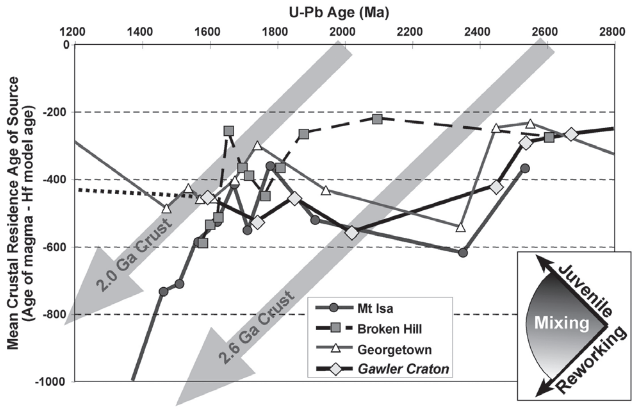

Figure 1. Comparison of 'Event Signatures' for the Gawler Craton with the Curnamona Craton, Mount Isa Block, and Georgetown Inlier (Belousova et al., 2009).

Figure 2 shows the distribution of U-Pb ages in the GEMOC TerraneChron® database (blue line) compared to the data from other studies. Previous studies (e.g. Iizuka et al., 2005) have shown that the distribution of zircon ages in a large sample from the Mississippi River accurately reflected the relative areas of the igneous provinces in the drain-age area. The data of Campbell & Allen (2008) are shown separately as a green line; these represent detrital zircons collected from the mouths of 40 of the world's largest rivers and thus provide a broad global picture of the age distribution, but unfortunately they are not accompanied by Hf-isotope data. A good correlation between the major peaks in the TerraneChron® and Campbell & Allen (2008) datasets indicates that the TerraneChron® dataset is broadly representative of the worldwide distribution of crustal age provinces.

To understand the growth rate of the continental crust it is critical to evaluate the proportion of juvenile material added to the crust at each point during its evolution. The amount of juvenile material produced at any given time is commonly underestimated, because some of that material was later reworked, and the record of the original juvenile material is lost during subsequent crustal evolution. The approach proposed in this study attempts to offset this effect, and "restore" an indication of the true juvenile input using the integrated dataset.

The age data alone would support an Episodic Growth model, but the Hf-isotope data (Figure3) reveal that most of the magmatic rocks represented in the major "episodes" were derived by the recycling of pre-existing crust, especially after ca. 2.5 Ga; the juvenile contribution represents a small proportion of most magmatic episodes. Modelling of the ages of the recycled components emphasises the repeated reworking of Archean components, supporting an Early Growth model.

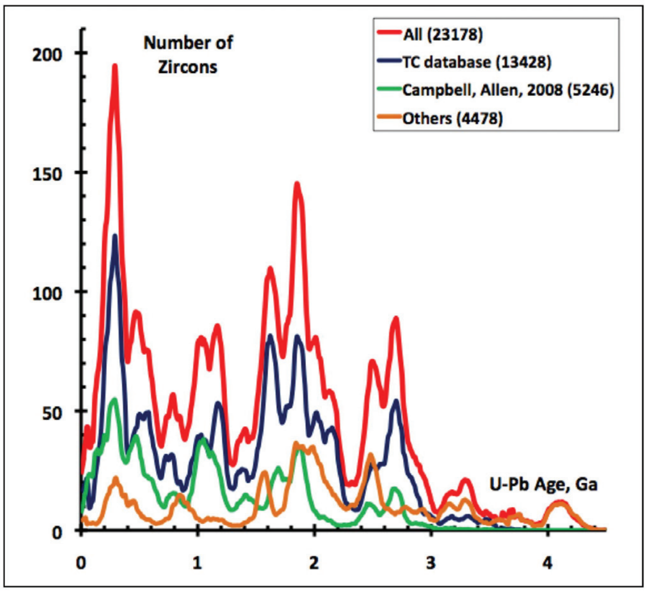

Figure 2. Comparison of zircon U-Pb age distributions for data collected from different sources. The red curve shows distribution of ages in a worldwide data set including grains with ages but no Hf-isotope data. The TerraneChron® (TC) database (blue curve) is from GEMOC; data of Campbell & Allen (2008; green curve) are detrital zircons from the mouths of 40 of large rivers.

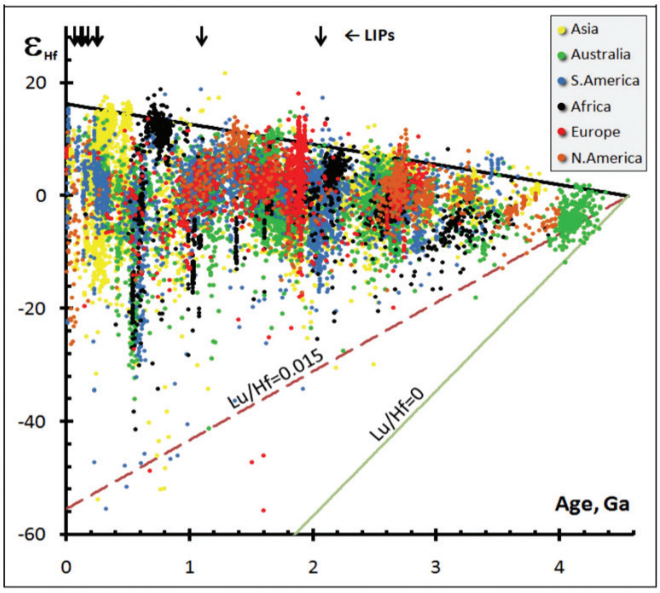

Figure 3. Plot of εHf vs. age showing data plotted by continent (Belousova et al., unpubl.).

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