Implications of unsupported radiogenic Pb in ancient zircon

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The complexity of zircon U-Th-Pb systematics from strongly layered early-Archean ortho- and paragneisses at Mount Sones and Gage Ridge (Napier Complex, Antarctica) was reported in some of the earliest SIMS zircon studies [1,2]. We report here new SIMS analyses untaken to further investigate this complexity. Notably brown/black coloured, non-cathodo-luminescent, relatively low-U (few 100's ppm) zircons from orthogneisses show a wide range in isotopic composition and exhibit a characteristic reverse discordance pattern. Analyses are distributed broadly along a discordia line (lower intercept ca. 2.5 Ga) that crosses concordia at ca. 3.3 Ga and extends to strongly reverse discordant compositions. As also noted in previous studies [1,2], inspection of the internal peak-hopping signal traces reveal spikes in Pb without corresponding spikes in U. The relatively low U content of the analysed grains as well as the distribution along a well-defined discordia line argues against operation of the well-documented matrix effect seen in SIMS analysis of high U zircon. Instead this effect appears to be related to redistribution of radiogenic Pb within the zircon, with both Pb-loss and Pb-gain (U migration is a less likely mechanism).

To further investigate and constrain the processes responsible for this phenomenon, we have undertaken two types of multicollector Pb isotope analysis in the same grains. Spot analyses exhibit a strong within-run correlation between the Pb count rate and the $^{207}Pb/^{206}Pb$ ratio/age, demonstrating Pb components (sometimes more than one in the same analysis) up to ca. 3.9 Ga. Scanning ion image analysis with a 2 μm spot size rastered over 70 x 70 μm reveal patchy variations of Pb within the zircon (Fig. 1) and in many cases "hot-spots" with $^{207}Pb/^{206}Pb$ ratio/ages up to ~4.2 Ga. These data are consistent with previous suggestions of radiogenic Pb redistribution and suggest that geochronology of ancient zircons such as the ≤ 4.4 Ga Jack Hills detrital zircon suite, which primarily utilises $^{207}Pb/^{206}Pb$ ages, may need to be treated with caution.

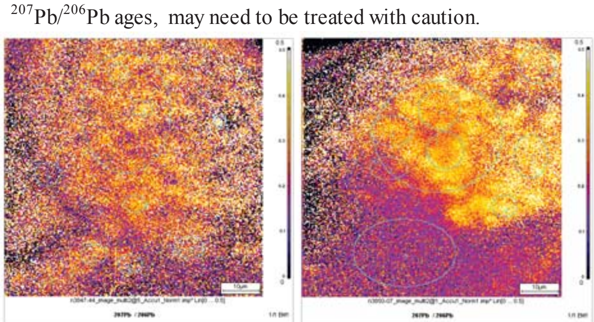

Figure 1: Scanning ion image of the $^{207}Pb/^{206}Pb$ ratio in zircons from Mt Sones and Gage Ridge.

What can zircon really tell us about Earth's earliest crustal evolution?

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High-spatial resolution studies of ancient (<4.4 Ga) detrital zircon from the Jack Hills, Western Australia, have yielded invaluable geochemical and isotopic data that are relevant to the evolution of the Earth's earliest crust. While zircon does indeed provide a unique "time capsule" from this period, its use in isolation can however lead to models for early crustal evolution that are at odds with other constraints.

Several lines of evidence from the Jack Hills detrital zircon suite appear to support the existence of modern-style plate tectonics, subduction and well-developed continental (-type) crust on the Earth as early as 4.4 - 4.5 Ga. These include: (1) stable isotope evidence for transfer of surface material to zircon crystallisation depths [1, 2]; (2) inclusion assemblages suggesting relatively high P-T conditions [3]; (3) Ti-in-zircon temperature and REE signatures suggesting crystallisation from evolved melts [4].

In contrast, observations both from zircon and post-Hadean isotopic reservoirs require several 100 Ma isolation of Hadean "proto-crust" and are therefore inconsistent with modern-style plate tectonics. These include: (1) Lu-Hf systematics of the Jack Hills zircons which show no significant input of juvenile material into their source region [5]; (2) unusually radiogenic initial Pb-isotope compositions of some early Archaean rocks requiring long-term high-μ source isolation [6]; (3) solar-like isotopic compositions of rare gases in modern plumes requiring ancient, long-term surface regolith accumulation and subsequent transfer to deep mantle [7]; (4) Th/Nb systematics of post-Hadean mantle-derived rocks recording progressive development of the crust-mantle system [8]; (5) graphite and diamond inclusions in some Jack Hills zircons which are inconsistent with a granite source [9]. These observations have been used to propose an alternative view of the Hadean Earth characterised by a less differentiated basaltic crust (or "stable lid") and the absence of modern style plate tectonics [10].

This apparent dichotomy of evidence needs to be addressed in formulating fully consistent models of the Hadean Earth. Specifically, proponents of plate-tectonic models need to explain the long term isolation of Hadean crust while proponents of models that exclude plate tectonics need to propose mechanisms that can deliver surface-derived materials to middle- lower-low crustal levels.

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