Interpretation of ion-probe U-Pb dates from early Archaean zircons - implications for the age of the earliest life on Earth

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The age of the proposed earliest life on Earth, preserved as C-isotope anomalies in the Akilia supracrustal rocks of SW Greenland, has been constrained to $\geqslant$ 3.87 Ga by ion-microprobe data on zircons from enclosing orthogneisses (Nutman *et al.*, 1997). These zircons have clearly experienced ancient Pb-loss, yielding a broad range of ages from *c.* 3.6–3.9 Ga, of which the oldest have been assumed to represent the intrusion age. Using new ion-microprobe analyses coupled with detailed imaging of zircon grains, we demonstrate that there are at least two magmatic events represented by zircons in these grey gneisses, the youngest of which, at *c.* 3.65 Ga provides the true minimum age constraint upon the Akilia sequence, and hence the Earth's earliest life.

Introduction

Ion-microprobe U-Pb dating of zircons from early Archaean rocks is potentially a very powerful technique combining high spatial resolution (typically < 30 mm) with a precision generally better than a few Ma on $^{207}Pb/^{206}Pb$ ages. Unfortunately, the corresponding precision of $^{206}Pb/^{238}U$ ages is limited to several tens of Ma by the technique of calibration against a standard reference zircon. This means that individual ages are commonly 'concordant' within analytical error, even though they might have experienced varying degrees of ancient Pb-loss subsequent to crystallisation. In the case of simple zircon populations, where there is no evidence for more than a single episode of zircon growth, the technique of successively rejecting analyses with the lowest $^{207}Pb/^{206}Pb$ ages until the remaining ones yield a statistically acceptable mean is a reasonable and valid approach. However, there will be considerable problems for interpretation when there are closely spaced (less than a few 100 Ma) episodes of zircon growth, particularly if analyses are performed without detailed structural control. Previous ion-microprobe U-Pb dating of key quartz-diorite gneiss samples that have been used to suggest a $\geqslant$ 3.87 Ga minimum age for the early-life-bearing supracrustal rocks of Akilia Island, south-west Greenland (Nutman *et al.*, 1997) rely upon the microscopic observation that 'structurally older inherited cores were not discerned in the photomicrographs of the analysed zircons', apparently validating the rejection technique outlined above. Our present study was initiated because claims for a $\geqslant$ 3.87 Ga age for these quartz-diorite gneisses are in conflict both with Pb-isotopic evidence that they cannot be older than *c.* 3.65 Ga (Kamber and Moorbath, this volume) and direct dating of Akilia supracrustal rocks (Moorbath *et al.*, this volume).

Zircon complexities revealed by cathodoluminescence imaging

Ion-microprobe U-Pb dating of zircons is essentially a surface analytical technique which is therefore best supported by surface imaging techniques such as cathodoluminescence (CL) or back-scattered electron microscopy (BSE). The potential of these techniques to reveal the polyphase nature of zircons is well documented, and is greatly superior to optical microscopy which can yield confusing, or worse, no information about complex internal structures. In this study, CL-imaging of each grain prior to ion-microprobe analysis reveals highly complex internal structures in grains which show no evidence of this in transmitted light. These images facilitate an in-depth analysis of each sample's evolution and suggest a substantially different geochronological history from that proposed by Nutman *et al.*, 1997).

Sample SM/GR/97/2 comes from the southern contact of the Akilia enclave with its host Amîtsoq gneiss, the same locality as sample G88-66 for which

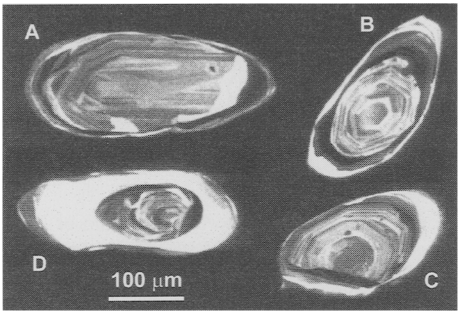

FIG. 1. CL images of four typical grains from SM/GR/97/2.

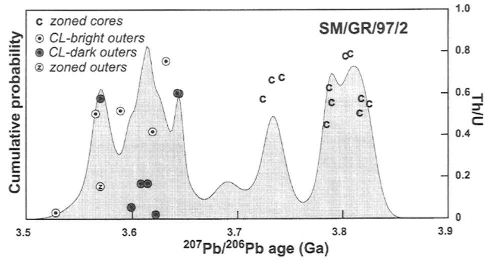

FIG. 2. Combined plots of cumulative age probability and Th/U ratios for zircons from SM/GR/97/2.

Nutman *et al.* (1997) claim an age of *c.* 3.87 Ga. It contains relatively low-U zircons which show minimal effects of radiation damage and yield clear and spectacular CL images (Fig. 1). All grains show evidence for at least two phases of zircon growth, the earliest of which ('core') is characterised by strong oscillatory zoning typical of crystallisation from a felsic magma (it is possible that some of these zoned regions contain an even older 'inner core', although this is too small to analyse with a 30 mm ion beam). These zoned cores also contain locally abundant inclusions of various minerals (e.g. apatite). $^{207}Pb/^{206}Pb$ ages range 3.83–3.69 Ga with Th/U 0.4–0.8, i.e. typically igneous (Fig. 2). We interpret the spread in ages of these cores to reflect post-3.69 Ga Pb-loss from what may be a single age ($\geqslant$ 3.83 Ga) zircon population, although the possibility remains that more than one age is represented if these zoned cores are xenocrystic in a younger magmatic event, as discussed below. Paradoxically the youngest age in this group is that of the only inner core analysed which also has very low (metamorphic?) Th/U.

The zoned cores are mantled in most crystals by successive CL-dark and CL-bright outer phases whose total thickness (a few mm's to *c.* 100 mm) and relative proportion vary widely (Fig. 1). In some cases, these outer phases are clearly developed upon zoned cores which have been broken (irregularly truncated zoning, Fig. 1A,C), consistent with their incorporation as xenocrysts into a younger magma. Furthermore, no inclusions are seen in these phases. Faint oscillatory zoning is present in some of the CL dark phases, while the CL bright phases appear structureless. $^{207}Pb/^{206}Pb$ ages for the CL-dark phases range from 3.65–3.57 Ga, with Th/U varying over a large range from 0.02–0.8 (Fig. 2); corresponding ranges for the CL-bright phases are 3.63–3.53 Ga and Th/U from 0.4–0.8 (with one analysis at 0.03; Fig. 2). In a single case, we analysed a late-Archaean (2.75 Ga), low Th/U tip on one of the polyphase grains.

Interpretation of ion-probe U-Pb ages

The key question concerning the minimum age of the Akilia succession, assuming that field relationships are correct (and this is not in dispute), hinges upon the interpretation of the age spectrum in Fig. 2 and similar spectra presented by Nutman *et al.* (1997). These authors interpret some of their younger, low Th/U grains to represent post 3.65 Ga metamorphic growth, while much of the spread of ages from 3.7–3.9 Ga is attributed to 'selective' ancient Pb-loss. We also believe that the spread of ages above 3.7 Ga in our own population probably results from ancient Pb-loss in $\geqslant$ 3.83 Ga zircons. In the light of the CL images presented here however, we have more difficulty simply attributing post 3.65 Ga ages to metamorphism. In particular, the observations of (1) obvious rim-core relationships in most crystals; (2) breakage of original $\geqslant$ 3.83 Ga zoned zircon crystals; (3) absence of inclusions outside of the zoned cores; and (4) variable, but not consistently low, Th/U ratios (cf. Nutman *et al.*, 1997; Fig. 2), are considered here to be more compatible with involvement of $\geqslant$ 3.83 Ga zircons in a magmatic cycle at $\leqslant$ 3.65 Ga. The occurrence of such a magmatic cycle renders the suggested $\geqslant$ 3.87 Ga age for the Akilia enclave untenable, but is entirely compatible with Pb-isotope data (Kamber and Moorbath, this volume) and independent estimates for the age of the Akilia enclaves (Moorbath *et al.*, this volume).

Conclusions

Ion microprobe data from the host gneisses of the Akilia supracrustal enclave, combined with CL-imaging of zircon growth phases, suggests that at least two magmatic events are represented. The oldest, at $\geqslant$ 3.83 Ga, is preserved in zircon cores which are mantled by zircon grown during a $\leqslant$ 3.65 Ga magmatic event. The later magmatic event implies a minimum age for the Akilia sequence and hence, the age of the earliest life on Earth.