How old is the earliest life on Earth? Re-appraisal of evidence from the early Archaean of West Greenland

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In two recent papers, Mojzsis *et al.* (1996) and Nutman *et al.* (1997) claimed the discovery of evidence for life on Earth extending back to >3.85 Ga. This lower age limit for the existence of life overlaps the period at which massive, destructive impacts were occurring on the moon (terminating at *c.* 3.8 Ga), and by implication, on the earth (Wilhelms, 1987). The claims of Mojzsis *et al.* (1996) and Nutman *et al.* (1997) are in conflict with the view that quiescent conditions were a pre-requisite for the establishment of life (Sleep *et al.*, 1989) or with the generally held assumption that the Earth had a similar bombardment history to its moon. Based on our new isotope data obtained from the critical rock samples and a discussion of all available evidence we conclude that the oldest rocks of possibly biological significance are some 150–200 Ma younger than claimed in the cited papers. By this time cataclysmic impacts had terminated and quiescent conditions for earliest life had probably been established.

Introduction

On Akilia Island, southern West Greenland, a package of metasedimentary and mafic rocks (a so-called Akilia-association enclave) is enclosed by tonalitic gneiss, which is demonstrably younger than the inclusion. Mojzsis *et al.* (1996) discovered isotopically light carbon in graphite occurring as mineral inclusions in apatite of a banded iron-formation. This light carbon isotope signature was interpreted as biogenic in origin. The critical question is how old is this early life? Dating the enclosing tonalitic gneisses would provide a lower age limit, whilst dating of metasediments and associated mafic Akilia inclusions themselves would provide a direct age limit. Here we discuss published evidence and provide new indirect and direct age constraints for the Akilia inclusions.

Indirect age constraints

The bulk of the predominantly tonalitic Amîtsoq orthogneisses of southern West Greenland are generally regarded as having been emplaced at *c.* 3.65 Ga, thus providing a lower age limit for the Akilia inclusions. However, based on ion-probe U-Pb zircon dating, Nutman and co-workers (e.g. 1997 and references therein) have claimed the discovery of substantially older tonalitic gneisses. Of particular importance for the age of earliest life is that such age claims have been made for some of the tonalitic gneisses on Akilia Island. The contact between the tonalitic gneisses and the Akilia inclusions is discordant and was interpreted to be intrusive by Nutman *et al.* (1997). Although we note that there is a possibility for these contacts to be tectonic (i.e. re-worked during later orogenies), we agree with Nutman *et al.* (1997) that the age of these tonalitic gneisses places a lower limit for the age of the Akilia inclusions. Nutman *et al.* (1997) dated zircons from two tonalitic samples from Akilia Island and from one sample from a nearby island with the U-Pb ion-probe method. All samples yielded similarly complex age distribution patterns, ranging from 2.7 to 3.9 Ga. Using arguments based on Th/U ratios, grain shape, degree of discordance and a statistical analysis, they concluded that the oldest age cluster at 3.86 Ga was the most likely crystallisation age of the tonalites, thereby placing a lower limit for the Akilia inclusions and hence the origin of life. Their interpretation of the zircon age spectra relies on the microscopic observation that "structurally older inherited cores were not discerned in the photomicrographs of the analysed zircons" and it was stated that "... it cannot be argued that the zircon population of G93-05 [sample of the cross-cutting tonalite] is rich in inherited zircon mantled by magmatic zircon" (Nutman *et al.*, 1997, p. 2478). We note, however, that optical microscopy is not the most appropriate tool for the analysis of internal structure of zircon. In our own study of zircons from these tonalites (re-sampled during 1997) cathodoluminescence imaging has revealed a very complex internal structure of all zircons. These structures include abundant low-luminescence cores (some with magmatic zones), which are usually partly resorbed and mantled by complex rims (both magmatic and metamorphic) and typically overgrown at their tips by yet another generation of zircon. Cathodoluminescence analysis therefore shows that the basic assumption of Nutman *et al.* (1997) in their interpretation of the complex age distribution patterns is questionable. Indeed, detailed U-Pb ion-probe dating of the zones as defined by cathodoluminescence has revealed very complex age patterns which are reported elsewhere in this volume by Whitehouse *et al.* Based on this new evidence, it appears at least equally likely (and indeed far more probable) that the age of intrusion is dated by the 3.65 Ga main magmatic zircon mantles and not by the partly resorbed, structurally older cores with dates approaching 3.8–3.9 Ga.

To test further the likelihood of a 3.65 Ga intrusion age (as opposed to 3.86 Ga) we performed Pb-isotope analyses on leached feldspars from these rocks and other Am'tsoq samples with age claims of >3.8 Ga. The common Pb isotope compositions of these rocks plot exactly onto the array of all other Am'tsoq gneisses, which can only be interpreted as reflecting differentiation from a mantle-like source at 3.65 Ga (see Kamber and Moorbath, this volume).

In brief, a dating approach combining the cathodoluminescence-based U-Pb ion-probe technique with determination of initial Pb-isotope characteristics shows beyond doubt that the age of Am'tsoq gneisses which enclose and probably cross-cut the Akilia inclusions on Akilia island is 3.65 Ga. This age is also found in all age spectra reported by Nutman *et al.* (1997). In contrast to those authors, however, we argue that the older dates represent inherited cores (albeit magmatic themselves).

Direct age constraints

The above indirect age constraint shifts the lower age limit for earliest life on Earth downwards by some 200 Ma to 3.65 Ga. Direct age constraints on the Akilia inclusions provide additional evidence for a much younger age of the inclusions themselves. If one plots the Sm-Nd data of Bennett *et al.* (1993) for a suite of four gabbroic Akilia association enclaves from the crucial localities of Akilia Island and nearby (12 km to the south) Innersuartuut Island, they yield a perfect Sm-Nd isochron (MSWD<1) with an age of 3677 ± 37 Ma. It is probable that this is a close estimate for the age of not only the gabbroic enclaves on these islands, but also for the closely associated metamorphosed banded iron-formation enclaves. An age of 3.68 Ga for the Akilia association itself is compatible with our new lower age limit of 3.65 Ga, but in obvious conflict with Nutman *et al.*'s (1997) minimum age of 3.86 Ga. To further test the possibility of a 3.86 Ga lower age limit, we determined the initial Pb-isotope ratios of these gabbros (using leached plagioclase). They plotted between 3.6 to 3.7 Ga relative to terrestrial Pb evolution curves and showed no evidence for an age approaching 3.86 Ga. U-Pb ion-probe dating of the crucial Akilia banded iron-formation enclaves has exclusively yielded late Archaean metamorphic ages (Nutman *et al.*, 1997). The only other ion-probe U-Pb data so far measured directly on an Akilia association inclusion, namely a schist from Innersuartuut Island, was reported by Schi¿tte and Compston (1990). They obtained a fairly complex age pattern, but favoured 3685 ± 8 Ma as representing the original age of this part of the Akilia association. They found no zircons approaching values of up to 3.86 Ga such as those obtained by Nutman *et al.* (1997) for discordant gneiss sheets on Akilia Island.

Conclusion

The revised direct and indirect age constraints presented here for Akilia association enclaves of significance for the study of earliest life are nearly 200 Ma younger than the minimum age of 3.86 Ga proposed by Nutman *et al.* (1997). If our re-interpretation is correct, the question of overlap of earliest life with a lunar-type impact scenario >3.80 Ga becomes irrelevant.

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