

**Archaean Cyanobacteria, Ghosts in the machine?** M. D. Brasier<sup>1</sup>, O. R. Green<sup>1</sup>, A. Steele<sup>2</sup>, M. Van Kranendonk<sup>3</sup>, A. P. Jephcoat<sup>1</sup>, A. K. Kleppe<sup>1</sup>, J. F. Lindsay<sup>4</sup>, & N. V. Grasseineau<sup>5</sup>. 1- Earth Sciences Department, University of Oxford, Parks Road, Oxford OX1 3PR, UK. 2- Carnegie Institution of Washington, Geophysical Laboratory, 5251 Broad Branch Rd, Washington DC. 3- Geological Survey of Western Australia, 100 Plain Street, East Perth, Western Australia, 6004, Australia. 4- Research School of Earth Sciences, Australian National University, Canberra ACT 0200, Australia. 5- Department of Geology, Royal Holloway, University of London, Egham Hill, Surrey, UK

Oxygenic photosynthesis may be very ancient indeed. But just how good is the evidence for it? Molecular evidence from bacterial rRNA sequencing, arguably confirms that cyanobacteria are likely to have evolved after the emergence of hyperthermophile methanogenic archaeobacteria but gives no evidence about timing. Arguments for the establishment of a diverse oxygenic, cyanobacterial micro-biota in the early Archaean depend mainly upon three kinds of data: biogeochemistry/biomarkers; stromatolites; and microfossils. Since oxygenic photosynthesis by rubisco results in isotopic discrimination against  $\delta C^{13}$ , comparison of  $\delta C^{13}$  ratios in organic matter and marine carbonates can be argued to provide an indirect proxy for its existence in rocks >3.7 Ga. But while such values are in broad agreement with values from modern cyanobacteria, they may also lie within the range of anaerobic methanogens. Biomarker evidence for cyanobacterial metabolism could provide support for oxygenic photosynthesis but there is, as yet, little evidence of this until the late Archaean at 2.7 Ga. Stromatolites have been described from various units in the Archaean but their cyanobacterial origin is hard to prove and even their biogenic origin is often controversial. Many so-called stromatolites of Archaean age could also have been formed abiogenically, for example by the rapid marine precipitation of aragonite or by hydrothermal precipitation of barite and chalcocite quartz. The description and interpretation of morphological remains in the form of microfossils preserved in sedimentary rocks must therefore play a crucial role in underpinning any claims for the early emergence of oxygenic photosynthesis. Relatively few such assemblages have been described to date, of which those from the c. 3.46 Ga old cherts of the Apex Basalt, Warrawoona Group in Western Australia hold a key position. Eleven reported species of microfossils (including cyanobacteria-like forms), were interpreted by Schopf (1993) to occur in water worn carbonate grains that had been transported a long distance before redeposition in a bedded grainstone conglomerate prior to silicification. Major aspects of preservation and the geological/biological context of this potentially important evolutionary benchmark have received little critical scrutiny.

We have examined and re-imaged the type thin sections of microfossil-bearing material deposited by Schopf (1993) at the Natural History Museum (NHM) in London, and compared them with samples collected

from the same horizon during recent field work (summer 2000). The new study involves light microscopy coupled to digital *Automontage* image analysis, SEM with microprobe and EDX, Raman spectroscopy,  $\delta C^{13}$  measurements and ToF-SIMS.

Detailed digital montage images of the figured material of purported microfossils (including all holotypes and paratypes) show that the filaments are sinuous and S-shaped but the majority are tightly C-, J- or L-shaped. Many of the filamentous structures are branched or formed in ways not revealed by the techniques used for the original descriptions and illustrations<sup>1,2</sup> because of the choice of focal depth and/or illustrated field of view. This is best illustrated in Figure 1 the holotype of *Eoleptonema apex*. From the original descriptions it is difficult to see that the proposed holotype is found to be part of a larger, sharply angular structure that we infer to have formed around rhombic crystal ghosts. The tiny thread-like holotype in *Archaeotrichion septatum* is seen to be part of a larger branched structure, deflected along polygonal planes between quartz crystals, in an area of pervasive iron staining. A further observation concerns maximum filament width, which was much greater (19.5 $\mu$ m) than seen in most other Precambrian microfossil assemblages<sup>2</sup>. Our studies extend this phenomenon, revealing branched pseudoseptate structures up to 36 $\mu$ m in diameter.

Of the eleven holotypes of prokaryotic 'microfossils' defined from these rocks<sup>3</sup>, we regard those of *E. apex* and *A. septatum* to be mineral rims that formed around crystal margins, while the other nine can be explained as arcuate, sinuous and branched mineral rims of spherulitic origin.

Most of these filamentous structures are claimed to preserve traces of septa which, in each filament, are thought to maintain a shape and size consistent with a biological origin<sup>3</sup>. Micro-raman and thin section petrography suggest that the septate appearance of the filaments is largely created by microcrystalline quartz grains (c. 1-10 $\mu$ m) interspersed with a darker amorphous graphite that makes up the bulk of each filament. The appearance of numerous thin septa appears to be caused by loosely packed plates of graphite alternating with thin fibres of quartz. The impression of bifurcated cells or cell pairs in the process of division can be explained by alternations of darker, platy graphite and paler quartz.

Energy Dispersive X-ray (EDX) analysis shows that barite ( $\text{BaSO}_4$ ) is common in both the vein and stratiform chert samples, occurring together with other hydrothermally-associated minerals including native metals, sulphides, chalcedonic quartz and megaquartz. Both the vein cherts and felsic tuff are characterised by grains of chromite ( $\text{FeCr}_2\text{O}_4$ ), iron oxide and  $\text{TiO}_2$  from hydrothermal leaching of adjacent mafic extrusives plus Al- and K-rich phyllosilicates from hydrothermally altered feldspars. Furthermore we find no evidence for surficial sedimentary structures or textures (e.g., sorting, rounded quartz) in the 'microfossiliferous' clasts and that neither Raman, ToF-SIMS or EDX imaging techniques revealed the presence of carbonate. This all points to a hydrothermal origin for the cherts and therefore incompatible with the postulated shallow marine environment. Indeed, samples analysed from 9 sites around the locale show that both the original collected material (by Schopf et al.) and the recollected material all came from an area that is probably a hydrothermal vent. (3). Carbon isotope analyses of sites moving down through this proposed hydrothermal vent begin to show  $\delta\text{C}^{13}$  values of  $-30\text{‰}$  for the reduced carbon. A value considered to be within the realms of methanogenic bacteria.

We therefore re-evaluate the apex chert as non-fossiliferous and extremely unlikely to show evidence of photosynthesis. Furthermore we postulate that the Apex chert may be the earliest example of a hydrothermal system containing the remnants of methanogenic archaea.

**Figure 1** shows a computer-generated digital automontage of the putative beegiatoan *Eoleptonema apex* Holotype, combining the most-sharply focussed images from successive focal planes; b, c, original manual photomontage and interpretative sketch<sup>2</sup> which omits lower structure; d, e, new single images showing continuity of original and newly imaged structures. f, topographic map showing computer-selected focal planes (plus  $\mu\text{m}$  scale) of Fig. 1a. Fig 1g is a computer-generated digital automontage of putative cyanobacterium *Archaeosclatoropsis disciformis* Holotype<sup>2</sup>; h, i, original manual photomontage and interpretative sketch which omits lower structure and side branch, arrows shows the presence of a rhombic crystal. Fig 1j, k, l, are single images showing the continuity of original and newly imaged structure. Images b, c, h and i published by permission of *Science*. Scale bar  $40\mu\text{m}$ .

#### References

1. Schopf et al., *Science* **237**, 70-73 (1987).
2. Schopf, J.W. *Science* **260**, 640-646 (1993).
3. Van Kranendonk, M.J. *Precambrian Res.* (in press).

Figure 1. (see text for details)

