Earth's geological record holds great potential for decoding the origin and evolution of life on our planet. However, the interpretation of this record is complex and often controversial because Earth's first life would have been very small, morphologically simple and likely only subtly different from co-occurring non-biological organic material.

Distinguishing between bona fide signs of life and abiotic artefacts requires analytical techniques with excellent spatial resolution in 2 and 3 dimensions, in order to accurately analyse key features of putative cells such as cell-wall ultrastructure, cell contents, and interaction of cells with the minerals that have fossilised them. We here show how TEM of FIB prepared samples and 3D-FIB-SEM reveal new details of fossilised cells at the nanometer to micrometer scale, providing new biosignatures for future studies on Earth or other planets.

Data are presented from three geological formations that play an important role in our understanding of the origin and evolution of life on Earth: 1, The 3,430 million-year-old Strelley Pool Formation of Western Australia, containing Earth's oldest well preserved cells [1]; 2, The 1900 million-year-old Gunflint Formation of Canada, containing an iconic suite of diverse microfossils used as a benchmark for high quality preservation of early life [2]; 3, The 3,460 million-year-old Apex chert of Western Australia that houses controversial microfossil-like artefacts [3]. Our data include EFTEM maps of the chemistry of the `microfossils` and their surrounding minerals, electron diffraction patterns to identify minerals and crystal orientation, plus serial SEM sections and 3D reconstructions (Figs. 1-2).

We find that the Strelley Pool and the Gunflint materials show many similarities in their style of fossilization and nano-scale morphology, and exhibit multiple features expected of bona fide fossilized organisms. In contrast, the Apex chert microstructures are shown to comprise complex clay mineral aggregates onto which carbon later adsorbed; these show no biological morphology at the nano-scale.


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Fig. 1: 3D reconstruction (A) and orthogonal x-y-z slice view (B) of a cellular microfossil from the 3,430 million-year-old Strelley Pool Formation. Each FIB-SEM slice was approximately 10 μm x 10 μm and the step size between slices was 200 nm. This clearly demonstrates the spherical to elliptical nature of the microfossil.

Fig. 2: 3D reconstruction of carbonaceous (A-B) and pyritic (C) filamentous microfossils from the 1,900 Ma Gunflint Formation. Note that preservation appears better for the pyritic examples with extra details such as putative heterotrophic bacteria (orange spheres) and exopolymers (pale yellow) visible.