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Remarkably preserved tephra from the 3430 Ma Strelley Pool Formation, Western Australia: Implications for the interpretation of Precambrian microfossils

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ABSTRACT

The ~3430 Ma Strelley Pool Formation (SPF), Pilbara, Western Australia contains some of the most diverse microfossil evidence for early life on Earth. Here we report an assemblage of tephra (scoria, tubular pumice, plus vesicular and non-vesicular volcanic glass shards) from two stratigraphic levels in the SPF, including morphotypes that closely resemble previously described microfossils from this unit and elsewhere.

Clasts of scoria are characterised by numerous spheroidal vesicles, with subordinate eye- and lens-shaped morphotypes, commonly lined with anatase (TiO_2) and small amounts of organic material. Their diameters range from 5–180 µm with 80% in the 10–50 µm range. Fragments of tubular pumice are also lined with anatase +/− carbon and have tube diameters of 5–15 µm. Other volcanic ejecta particles include a multitude of sub-angular shard particles with or without vesicles, plus more rounded vase-shaped, eye-shaped, and hair-like morphologies; once again, most of these are coated by anatase +/− carbon and are several tens of micrometres in size. Many of the tephra fragments are now entirely silicified with no compositional difference between the former volcanic glass, the vesicle infill and the clast matrix. However, some examples retain a partial aluminosilicate composition, either as a vesicle infilling phase or as isolated lath-like grains within the formerly glassy groundmass.

Isolated occurrences of some of these tephra morphotypes strongly resemble simple microbial morphologies including pairs and clusters of cells (cf. scoria), filamentous microbes (cf. tubular pumice) and larger sheaths/cysts (cf. sub-rounded glass shards). Furthermore, some tephra-containing clasts occur in a SPF sandstone unit that hosts previously described microfossils, while others are interbedded with chert layers from which microfossils have also been described. In light of our new volcanogenic data, we evaluate the robustness of previous microfossil evidence from the SPF in the East Strelley greenstone belt. We find that the majority of previously illustrated microfossils from this greenstone belt possess multiple features that are consistent with a biological interpretation and are unlikely to be volcanogenic, but at least one previously illustrated specimen is here reinterpreted as volcanic in origin.

The importance of this work is that it serves to highlight the common occurrence of volcanogenic microstructures resembling biological fossils (i.e. pseudo-fossils) in Archean environments that are habitable for life. Such structures have until now been largely overlooked in the assessment of putative Precambrian microfossils. Our data show that tephra-derived microstructures should be considered as a null hypothesis in future evaluations of potential signs of life on the early Earth, or on other planets.

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1. Introduction

The ~3430 Ma Strelley Pool Formation (SPF) has emerged as one of the most important rock units in the study of early life on Earth. It occurs over about 30,000 km^2 in 11 greenstone belts across the East Pilbara granite greenstone terrane, marking a regional hiatus in volcanic activity of up to 75 Ma (Hickman, 2008). Several biosignatures have been reported from the SPF, including carbonaceous microfossils (Sugitani et al., 2010, 2013, 2015a, 2015b; Wacey et al., 2011a, 2012; Lepot et al., 2013; Brasier et al., 2015), stromatolites (Hofmann et al., 1999; Allwood et al., 2006, 2007, 2009; Wacey, 2010; Van Kranendonk, 2011), and other potential biofilms and biominerals (Wacey et al., 2010a, 2011b), some of which arguably represent the most robust indicators of early Archean life.

In a recent paper (Wacey et al., 2018) we reported spheroidal to lenticular volcanogenic microstructures from the ~3480 Ma Dresser Formation, Pilbara, Western Australia, some of which closely resemble previously reported putative Archean microfossils from the SPF and other stratigraphic units (e.g., Walsh, 1992; Sugitani et al., 2007). Here we extend this work to report a much more diverse suite of volcanogenic microstructures from the SPF, several of which have microfossil-like morphologies.

Our study samples come from the East Strelley greenstone belt (ESGB) of the SPF close to the type locality of Strelley Pool (Lowe, 1983; Wacey et al., 2010b). Sample 1 (SPZ 1) comes from the eastern portion of Strelley Ridge, approximately 80 m east of Strelley Pool (Fig. 1a and c; GR 0722362E 7664053N). It was obtained from the basal sandstone unit of the SPF (Fig. 1e), just below the transition to laminated grey chert (that hosts stromatolites in places), and some 3–4 m stratigraphically above the level from which microfossils and trace fossils were reported in Wacey et al. (2011a, 2011b). Sample 2 (SPC 2) comes from the central portion of Strelley Ridge, approximately 1.2 km west of Strelley Pool (Fig. 1b and d; GR 0721110E 7663764N). It was obtained from a conglomeratic unit near the top of the SPF (note that the contact between the SPF and the overlying Euro Basalt is not exposed here but is no more than ~10 m above SPC 2), some 18 m stratigraphically above Sample 1 (Fig. 1e). The conglomerate clasts are diverse and include both angular and sub-rounded grey chert, green chert and banded black and white chert, all heavily silicified and cemented by clear silica (Fig. 1d). The clasts are interpreted to be mostly locally reworked fragments of units lower of the SPF stratigraphy, but older pre-SPF lithologies are also represented.

2. Methods

2.1. Optical microscopy

Petrographic analysis was carried out on uncovered polished geological thin sections (30 μm and 100 μm thick) using a *Leica DM2500M* microscope, with 5×, 10×, 20×, and 50× objective lenses (plus 10× eyepieces), located within the Centre for Microscopy Characterisation and Analysis (CMCA) at The University of Western Australia (UWA). Images were captured using a digital camera and *Toupview* imaging software. Clasts of interest were mapped in transmitted and reflected light in order to gain an understanding of the distribution of volcanic shards and scoria-like vesicles, measure their dimensions, and select the most appropriate targets for higher resolution study.

2.2. Laser Raman microspectroscopy

Confocal laser Raman microspectroscopy was performed using a *WITec alpha 300RA+* instrument with a *Toptica Photonics Xtra II* 785 nm laser source at CMCA, UWA. The laser was focused through either a 20×/0.4, or 100×/0.9 objective, the latter obtaining a spot size of smaller than 1 μm, and the laser excitation intensity at the sample surface was in the 1–5 mW range. Spectral acquisitions were obtained with a 600 l/mm grating and a peltier-cooled (−60 °C) 1024 × 128 pixel CCD detector. Laser centering and spectral calibration were performed daily on a silicon chip with characteristic Si Raman band of 520.4 cm^{-1}. Count rates were optimised prior to point spectra acquisition or hyperspectral mapping using the dominant quartz Raman band of 465 cm^{-1}. Spectra were collected in the 100–1800 rel. cm^{-1} region in order that both 1st order mineral vibration modes and 1st order carbonaceous vibration modes could be examined simultaneously. Raman maps were acquired with the spectral centre of the detector adjusted to 944 cm^{-1}, with a motorised stage allowing XYZ displacement with precision of better than 1 μm. Spectral decomposition and subsequent image processing were performed using WITec Project FOUR software, with baseline subtraction using a 3rd or 4th order polynomial. Carbon maps were created by integrating over the ~1600 cm^{-1} 'carbon G' Raman band, quartz maps using the ~465 cm^{-1} Raman quartz band and anatase maps using the ~145 cm^{-1} Raman anatase band. Anatase can be distinguished from other common TiO phases such as rutile and brookite by characteristic strong Raman bands (in order of intensity) at ~145 cm^{-1}, ~400 cm^{-1} and ~515 cm^{-1}, plus a minor band at ~640 cm^{-1}. All analyses were conducted on material embedded below the surface of the thin section to avoid artefacts in the Raman spectra resulting from polishing and/or surface contamination. Spectra were monitored for any potential contamination from epoxy resin/glue; these results were negative.

2.3. Focused ion beam (FIB) preparation of TEM samples

A dual-beam FIB system (*FEI Nova NanoLab*) at the Electron Microscopy Unit, University of New South Wales was used to prepare TEM wafers from the thin sections described above, coated with ~30 nm of gold. Electron beam imaging within the dual beam FIB was used to identify microstructures of interest in the thin sections allowing site-specific TEM samples to be prepared. The TEM sections were prepared by a series of steps involving different ion beam energies and currents (see Wacey et al., 2012 for details), resulting in ultrathin wafers of c. 100–150 nm thickness. These TEM wafers were extracted using an *ex-situ* micromanipulator and deposited on continuous-carbon copper TEM grids. FIB preparation of TEM sections allows features below the surface of the thin sections to be targeted, thus eliminating the risk of surface contamination producing artefacts.

2.4. TEM analysis of FIB-milled wafers

TEM data were obtained using a *FEI Titan G2* 80-200 TEM/STEM with *ChemiSTEM Technology* operating at 200 kV, located in CMCA at UWA. Data obtained included bright-field TEM images, HAADF (high angle annular dark-field) STEM images, and EDS (*ChemiSTEM*) maps.

2.5. SEM-EDS

Semi-quantitative elemental analysis of thin sections was performed on a *FEI Helios Nanolab G3 CX* instrument equipped with an *Oxford Instruments X-Max 80* EDS system and *Oxford Instruments AZtec 3.0* nano-analysis software, located in CMCA, UWA. Analyses were performed on FIB-milled faces below the surface of the thin section to avoid potential surface contamination.