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Micro- to nano-scale mapping and characterization of low-temperature metamorphism in Archean subseafloor metabasalts with implications for early life

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In modern oceanic environments, the low-temperature alteration of subseafloor basaltic glass provides potential chemical energy argued to sustain deep microbial ecosystems. By analogy, it has been argued that early Archean subseafloor pillow lava sequences may provide an environment in which to seek evidence for the earliest traces of microbial life on Earth, and possibly on Mars. Microtextures in metavolcanic pillow lavas from the ca. 3.55 – 3.10 billion-year-old Barberton greenstone belt of South Africa have been argued to represent the remains of microbes that tunneled into Archean subseafloor volcanic glass [1]. The filamentous titanite microtextures occurring in a quartz-chlorite-epidote matrix have been argued to represent Earth's oldest trace fossil. However, distinguishing abiotic hydrothermal processes from candidate geochemical and micro-textural biosignatures preserved in early Archean rocks has proven to be a major scientific challenge. Also, very few PT-constraints on ocean-floor metamorphism are available in this greenstone belt. This quest for the earliest traces of life relies upon the ongoing development of in-situ analytical techniques in terms of instrument sensitivity and spatial resolution.

Here we employ a wide-range of novel petrological tools and metamorphic thermodynamic modelling techniques to test the biogenicity of microtextures, provide the first constraints on metamorphic conditions on the host metabasalts, and contribute to the search for robust traces of life in the early Archean. This includes in-situ mapping of the microtextures by laser Raman confocal spectroscopy, high-spatial-resolution elemental (C, N, P) mapping and in-situ isotopic measurements by NanoSIMS (nanoscale secondary ion microprobe) to evaluate the candidate biosignatures [2]. We have also developed and applied a new quantitative microscale mapping technique combined with thermodynamic modelling to map out metamorphic conditions surrounding the candidate biosignatures [3]. In-situ U-Pb dating of the titanite microtextures by laser-ablation multi-collector ICP-MS has been combined with the microscale metamorphic temperature mapping to test their syngenicity and biogenicity [4]. On-going work includes high-resolution nano-scale investigation of the mineral interfaces between titanite, chlorite and carbonate by FIB-TEM (Focussed ion beam – transmission electron microscopy). Our current results indicate that the filamentous titanite microtextures are not reliable biosignatures [4], but that microscopic sulphides may preserve sulphur isotope evidence for early Archean subseafloor microbial sulphate reduction. The search for earliest traces of life has not only contributed to developing state-of-the art analytical techniques, but has also led to development of new biogenicity criteria for subseafloor life. We propose that these new criteria and analytical mapping techniques may prove useful also in the search for microbial life in extra-terrestrial metabasalts and altered ultramafics from Mars, and/or meteorites [3].

[1]. Furnes et al., (2004), Science, 304 (5670) 578-581.
[2]. McLoughlin et al., (2012) Geology, 40(11), 1031-1034.
[3]. Grosch et al., (2014) Astrobiology, 14, 216-228.
[4]. Grosch & McLoughlin, (2014) Proceedings of the National Academy of Sciences, 111, 8380 - 8385.