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A High Resolution Study of Micro-alteration and Organic Carbon in Yamato 000593: Exploring Subsurface Impact Processes on Mars

McLoughlin, N.[1,2], Grosch, E.[1], Vullum, P.E.[3], Guagliardo, P.[4] and Wacey, D.[4,5]

[1]Department of Geology, Rhodes University, South Africa; Email: nicolamcloughlin@hotmail.com
[2]Centre for Excellence in Paleosciences, University of Witwatersrand, South Africa
[3]SINTEF Materials and Chemistry, Trondheim, Norway
[4]The University of Western Australia, Perth WA 6009, Australia
[5]University of Bristol, Bristol BS8 1TQ, UK

Here we report high-resolution characterization of alteration textures in the meteorite Yamato 000593, an ultramafic rock from the subsurface of Mars [1]. The 1.31 Ga Yamato meteorite comprises coarse-grained augitic pyroxene and olivine with accessory opaques. The meteorite shows strong evidence for low-temperature aqueous alteration, with iddingsite veins that are truncated by the fusion crust indicating subsurface hydrothermal alteration on Mars. A study by White et al. [2] described micro-alteration textures as microtubular features emanating from the iddingsite veins into the surrounding olivines, plus indigenous organics in the vein fill. Here we further characterize the Yamato alteration features in three dimensions using FIB-TEM (focused ion beam transmission electron microscopy) combined with elemental mapping targeting the organics using TEM and nanoSIMS (nanoscale secondary ion mass spectrometry). These data will be used to explore low-temperature subsurface processes on Mars.

The micro-alteration textures are typically 2-3 µm long and less than 0.5 µm wide, commonly occur at high angles to the veins and many taper strongly. The three dimensional information collected from combining FIB and TEM reveals that the microtextures are not tubes as previously reported, but rather the angular interface between fractured olivine crystals and amorphous vein filling phases. The host olivine crystals show high strain with micro-fractured and brecciated margins indented by triangular and elongate alteration fronts. There are two amorphous vein filling phases: an outer phase that is Si depleted leached olivine, and an inner iddingsite phase which is relatively Fe-depleted, but Si (and potentially Mg) enriched. Elemental mapping by X-ray energy dispersive spectroscopy (EDS) and electron energy loss spectroscopy (EELS) by TEM and nanoSIMS confirms the presence of organic carbon that occurs in fine veins and irregular patches, particularly near the interface of the two vein filling phases as well as within iddingsite. In addition, comparison of the nanoSIMS sulphur, carbon and nitrogen (measured as CN^-) maps suggests the presence of organic bound sulfur.

In summary, the high-resolution textural observations suggest that micro-alteration of the Yamato olivines post-dates impact-induced brecciation and microfracturing. Our compositional mapping suggests that post-impact hydrothermal processes and progressive alteration of the olivines records organic synthesis in the Martian subsurface.

References:

[1] Imae, N. et al. (2003). Antarctic Meteorite Research 16:13-33
[2] White, L.M. et al. (2014) Astrobiology 14: 170-181