Allan Hills 84001 and Martian Organic Geochemistry

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The Martian meteorite ALH84001 is one of the most studied rocks in planetary science. More than 25 years after a 1996 paper reporting "possible relic biogenic activity" in this meteorite, we have unambiguously confirmed the presence of in situ Martian organic material in this meteorite [1]. Areas of organic carbon were detected and characterized in the matrix and carbonate globules of ALH84001 using high resolution Transmission Electron Microscopy (TEM) on Focused Ion Beam (FIB) sections of the meteorite cut from both thin section and across a carbonate globule from a fracture surface [2]. TEM observations revealed the presence of an iron-rich talc phase in the matrix of the meteorite, that only sometimes co-occurs with carbonate. Scanning-Transmission X-ray Microscopy (STXM) revealed the presence of organic material predominately of aromatic composition containing carbonyl and carboxyl functionality [2]. Similar organic material was found associated with amorphous silica and magnetite at carbonate / orthopyroxene (OPX) interfaces. These interfaces show the characteristic morphology of aqueous weathering of OPX. Hydrogen isotope measurements of the organic material reveal D/H ratios that are within the range of those measured previously in the meteorite and correspond to Martian values, thus confirming these organics as Martian. The provenance of the organic material in aqueously altered phases in the meteorite reveals that these organics were formed during serpentinization and carbonation reactions occurring between ~3.6 and 4 billion years ago on Mars, and reveal an inventory of the potential building blocks of life at that time. In recent years research into the presence, provenance and formation mechanisms of organic carbon on Mars has undergone a renaissance with measurements both on Mars and on Martian meteorites. This is revealing the existence and details of a Martian organic geochemical cycle [2,3,4]. Three separate synthesis reactions - electrochemical reduction of CO_2, serpentinization, and carbonation - have been described, illustrating that different pools of carbon and organic nitrogen, sulfur and chlorine species associated with these reactions are present [2-5]. While these meteorites sample a mainly igneous pool of rocks, organic material in NWA 7034 [6] and at the Cumberland unit of Mars (as measured by Curiosity) are present in a breccia and mudstone respectively. Understanding the provenance, alteration, movement and preservation of this organic carbon is key to unlocking the Martian organic geochemical cycle and the detection of possible life. [1] McKay et al., (1996), *Science*, **273**(5277); 924-930. [2] Steele, A., et al. (2022). *Science* **375**(6577): 172-177. [3] Steele, A., et al. (2016). *Meteoritics & Planetary Science* **51**(11): 2203-2225. [4] J. L. Eigenbrode et al., *Science* **360**, 1096–1101 (2018). [5] A. Steele et al., *Science Advances* **4**, eaat5118 (2018). [6] Agee C., et al., (2013). *Science* DOI:10.1126/science.1228858.