MARTIAN SUBSURFACE FLUID PATHWAYS REVEALED BY 3D MINERALOGY OF THE NAKHLA METEORITE

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Introduction: Fluids in a near-surface environment on Mars were responsible for the formation and alteration of many minerals in the nakhlite meteorites. These secondary minerals include complex mixtures of clays, carbonates, sulphates, oxides and iron oxy-hydroxides [1-3] which may have formed at different times, under different fluid flow regimes (groundwater, hydrothermal, crater lake), experiencing a range of water-rock ratios, evaporative histories, and varying degrees of interaction with the atmosphere and bedrock [2,3].

As part of a continuing investigation of this aqueous activity we have performed a comprehensive suite of 2D and 3D chemical, physical and structural analyses of these secondary minerals within Nakhla.

Samples and methods: To characterize the 3D mineralogy of Nakhla – thereby providing a deeper understanding of fluid pathways – a Metris X-Tek HMX ST 225 System was used to scan two small (~1.1g total) sections of Nakhla. These analyses provided a resolution of ~5µm per voxel, producing several thousand computed tomography (CT) 'slices', subsequently reconstructed to provide 3D representations of the samples. Assigning CT (grey) values to voxels of different linear attenuation coefficients (i.e. density) permits different mineral phases, and fractures, to be identified. After CT scanning several sites of interest were identified and one of the samples was physically cut into several slices for high-precision and high-resolution imaging and analyses by electron microscopy (back-scattered and EDX), and FTIR and Raman spectroscopic analyses.

Results: Fluid pathways and modal mineralogy: By combining the 2D and 3D techniques it is possible to reconstruct a reliable and quantitative model of the location and relationships of primary and secondary minerals, alteration veins produced by fluid flow, as well as later and unrelated fracturing (e.g. during impact events). The combination of techniques also provides a highly representative modal mineralogy, avoiding bias introduced by 2D analyses alone. For example, individual CT 'slices' – equivalent to traditional petrologic thin sections – reveal abundances of olivine varying from a minimum of 1.98 vol% to a maximum of 19.62 vol%.

Conclusions: The present study of Nakhla will serve as a unique demonstration of the potential benefits of combining high-precision 2D mineralogical, chemical and structural analyses with 3D sample characterisation. These results provide a truly representative modal mineralogy of the sample and also give us a much clearer picture of the aqueous processes and fluid pathways on the surface and subsurface of Mars.

References: [1] Gooding. J. L. et al. (1991) *Meteoritics*, 26, 135-143. [2] Bridges. J. C and Grady. M. M. (2000) *EPSL*, 176, 267-279. [3] Grady M. M. et al. (2007) *LPSC XXXVI*II, 1826