POOLING OF WATER AND THE FORMATION OF EVAPORITE MINERALS IN THE MARTIAN SUB-SURFACE.

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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. Halite is one of a range of such secondary minerals that includes clays, carbonates, sulphates, oxides, and iron oxy-hydroxides [1,2] 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.

We present here the results of a combined computed tomography and electron microscopy investigation focusing on the formation of halite in the Nakhla meteorite.

Samples and methods: A Metris X-Tek HMX ST 225 System was used to scan a 0.3g sample of Nakhla, measuring 6mm x 5mm x 3mm. These analyses provided a resolution of ~5µm per voxel, producing several thousand computed tomography (CT) 'slices', subsequently reconstructed to provide 3D representations of the sample. Assigning CT (grey) values to voxels of different linear attenuation coefficients (i.e. density) permits different mineral phases, and fractures, to be identified. However, the CT data alone cannot unambiguously resolve halite from other mineral phases. To investigate the occurrence and distribution of halite it is necessary to identify halite by electron microscopy and subsequently compare this with CT data to understand the relationship between halite and other mineral phases and rock fractures.

Following CT analyses the chip of Nakhla was physically split into several slices. To preserve fragile mineral phases such as halite one of these slices was split using only a dry scalpel blade; no polishing agents or water were used on this slice. High-resolution back-scatter electron imaging and electron dispersive X-ray mapping were then used to identify halite. These analyses were performed using a FEI Quanta 200 dual beam instrument. This instrument was also used to perform focused ion beam (FIB) milling and lift-outs of 100nm to 5um thick sections for more detailed investigation.

Results and discussion: Fifteen occurrences of halite were found across the ~20mm^2 surface area of the unpolished section. Two of the larger (200-400um) occurrences (locations 7 and 9) were within 500um of each other, but otherwise no systematic relationship was found between size and distribution across the sample. Halite is always associated with fractures in the rock, and is clearly post-magmatic. The inter-connectivity of the cracks in Nakhla was demonstrated previously [3] and the same applies here. The CT data reveal cracks leading to location 7 from several directions, including connecting halite location 7 to the other large occurrence nearby (location 9). Halite 7 and 9, and most likely all halite occurrences in Nakhla, may therefore have formed from the same water source at the same time.

Cracks are critical for the flow of fluid, and an absence of cracks (coupled with a suitable orientation relative to gravity) can allow fluids to pool in topographic depressions.

The largest occurrence (halite 7) was found between a large pyroxene phenocryst and interstitial feldspar. From SEM/EDS images the halite appears to mantle the pyroxene phenocryst. Single phenocrysts, and unfractured groups of crystals, provide ideal conditions to restrict fluid flow, allowing sufficient time and space for fluids to pool and evaporate to produce minerals like halite. If topographic depressions are the usual hosts for halite, and if halite is also typically associated with the (relatively) Na-rich interstitial areas, then it is clear that primary mineralogy is an important control on secondary mineralisation in the rock sequence from which the nakhlite meteorites were excavated.

The lack of significant alteration of pyroxene in the nakhlites demonstrates that liquid water was not present for long periods of time. This does not, however, mean that significant amounts of water were not present on the surface and in the near sub-surface of Mars. In fact, water flowed ubiquitously through the network of cracks in Nakhla suggesting that large volumes of water must have been present in the nakhlite source region. In the same way that halite has been preserved only in sub-millimetre topographic depressions, the majority of the water which passed through Nakhla must have stopped and pooled elsewhere in the Martian sub-surface, perhaps evaporating slowly, freezing to form a permafrost layer, or becoming incorporated into clays and other secondary minerals. Large pools of water could have existed below the surface of Mars at different times through it's history.

In the absence of sedimentary rocks from Mars (in the form of either meteorites or sample return missions) the rare occurrences of secondary minerals in igneous meteorites remain one of our most important sources of information on the history of water on Mars. However, the record of water may be biased depending on the secondary minerals present, which in turn may depend on features of the host rock, such as small topographic depressions and variations in primary mineralogy (e.g. differences in interstitial material between Nakhla and MIL 03346), rather than being controlled solely by temperature and chemistry of the fluids. While great care therefore needs to be exercised when drawing planetary-scale conclusions from studies of these minerals we will continue to gain deeper understanding of the history of water on Mars by integrating novel CT analyses with high precision chemical and isotopic analyses.

References: [1] Gooding. J. L. et al. (1991) *Meteoritics*, 26, [2] Bridges. J. C and Grady. M. M. (2000) *EPSL*, 176 [3] Needham A. W., Tomkinson T., Abel R. L., Franchi I. A., Grady M. M. (2010) *MAPS* abstract #5336