

**INDIGENOUS CARBONACEOUS MATTER IN THE NAKHLA MARS METEORITE.** S. J. Clemett<sup>1</sup>, K. L. Thomas-Keprta<sup>1</sup>, Z. Rahman<sup>1</sup>, L. Le<sup>1</sup>, S. J. Wentworth<sup>1</sup>, E. K. Gibson<sup>2</sup>, D. S. McKay<sup>3</sup>; <sup>1</sup>Jacobs JETS Contract, NASA/JSC, Houston, TX 77058 (simon.j.clemett@nasa.gov); <sup>2</sup>ARES, NASA/JSC, Houston, TX 77058; <sup>3</sup>Deceased, formerly ARES, NASA/JSC, Houston, TX 77058.

**Introduction:** Detailed microanalysis of the Martian meteorite Nakhla has shown there are morphologically distinct carbonaceous features spatially associated with low-T aqueous alteration phases including salts and iddingsite. A comprehensive suite of analytical instrumentation including optical microscopy, field emission scanning electron microscopy (FESEM), energy dispersive X-ray (EDX) spectroscopy, focused ion beam (FIB) microscopy, transmission electron microscopy (TEM), two-step laser mass spectrometry ( $\mu$ -L<sup>2</sup>MS), laser  $\mu$ -Raman spectroscopy, Fourier transform infrared spectroscopy (FTIR), and nanoscale secondary ion mass spectrometry (NanoSIMS) are being used to characterize the carbonaceous matter and host mineralogy.

The search for carbonaceous matter on Mars has proved challenging. Viking Landers failed to unambiguously detect simple organics at either of the two landing sites although the Martian surface is estimated to have acquired at least  $10^{15}$  kg of C as a consequence of meteoritic accretion over the last several Ga [1]. The dearth of organics at the Martian surface has been attributed to various oxidative processes including UV photolysis and peroxide activity [2-4]. Consequently, investigations of Martian organics need to be focused on the sub-surface regolith where such surface processes are either severely attenuated or absent. Fortunately since Martian meteorites are derived from buried regolith materials they provide a unique opportunity to study Martian organic geochemistry.

An extensive body of work has shown that organic matter in Martian meteorites is not simply terrestrial contamination. Indigenous organics have been identified by their isotopic signatures [e.g., 5], distinctive molecular distributions [e.g., 6], and by textural observations [7, 8] such as specific mineral associations.

**Methods:** The Nakhla samples used in this work were acquired from the British Museum of Natural History. Chips from Nakhla, 15 were fractured under clean conditions and freshly fractured surfaces were analyzed. Samples were optically imaged before being lightly coated with Pt and characterized using FESEM/EDX. FIB microscopy was used to extract two  $10 \times 20 \mu\text{m}$  sections,  $\sim 2.5 \mu\text{m}$  in thickness. One section was investigated by  $\mu$ -Raman to provide an initial overview of carbonaceous phases (e.g., degree of aromaticity & domain size). Results from  $\mu$ -L<sup>2</sup>MS, FTIR, TEM and NanoSIMS will be presented.

**Results:** Fig. 1A shows an SEM/BSE image of one of the Nakhla chips studied, oriented to show the freshly

exposed fracture surface partially covered with iddingsite clay and containing alteration/etch pits and evaporate salts. These are typical of a mineral surface exposed to aqueous fluid phases. The highlighted region in Fig. 1A shows a refractory C-rich region of interest (ROI), which sustained no visible beam damage at 15 kV. High resolution FESEM imaging (Fig. 1B) combined with EDX mapping & spectra (Fig. 1B lower right & Fig. 1C, resp.) reveal a C-rich feature,  $\sim 20 \mu\text{m}^2$  in size. EDX analysis shows this feature is composed of major C and O with minor N, Na, Cl & S, while the underlying mineral phase is rich in O, Si, Mg, Al, Ca, & Fe. A FIB section was extracted from the region indicated by the yellow box in Fig. 1B. FESEM analysis of the FIB section shows a carbonaceous band that formed part of a thin surface mantle ( $\sim 0.8 \mu\text{m}$  thick) of C-rich material overlying the mineral alteration surface. EDX mapping (Fig. 1D) and point spectra (Fig. 1E) show composition of the C-rich vein is consistent with that of the bulk analysis. The presence of C, N and O along with the stability to  $e^-$ -beam irradiation indicates a complex/ macromolecular organic assemblage.  $\mu$ -Raman spectra (Fig. 1F) demonstrate characteristic D- and G-band structures with Raman shifts of  $\sim 1375$  and  $1561 \text{ cm}^{-1}$ ; this indicates aromatic moieties and infers the C-ROI is not graphitic. We estimate an aromatic domain size ( $L_a$ ) of  $\sim 1.20$  [9], consistent with poorly-ordered carbonaceous matter.

**Summary:** We have identified an indigenous, morphologically discrete, organic-rich feature on a freshly exposed surface from the Mars meteorite Nakhla. This observation further supports McKay et al. [7] who previously reported organic matter associated with low T alteration phases in a separate sample of Nakhla. In both cases, discrete carbonaceous assemblages are associated with, and in some cases partially embedded within, low-T mineral phases produced by aqueous alteration that occurred in the Martian regolith. These observations have important implications for the habitability and biogenic potential of Mars.

**References:** [1] Flynn, G.J. *et al.* (2004) *Adv. Space Res* 33, 57-66. [2] Becker, L. *et al.* (1999) *EPSL* 167, 71. [3] Mathew, K.F. *et al.* (2003) *EPSL* 214, 27-42. [4] Jakosky, B.M. & Phillips, R.J. (2001) *Nature* 412, 237-244. [5] Jull, T.J. *et al.* (2000) *GCA* 64, 3763-3772. [6] Clemett, S.J. *et al.* (1998) *Faraday Discuss.* 109, 417-436. [7] McKay, D.S. *et al.* (2011) *LPSC* 42, Abst. #2673. [8] White, L. *et al.* (2014) *Astrobiology* 14, 170-181. [9] Munoz Caro, G.M. *et al.* (2006) *A&A* 459, 147-159.

