Observation and analysis of in situ carbonaceous matter in Nakhla: Part I

Conference or Workshop Item

OBSERVATION AND ANALYSIS OF *IN SITU* CARBONACEOUS MATTER IN NAKHLA: PART I.

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Introduction: We have made new surveys of thin sections of the martian meteorite Nakhla by petrographic microscope, laser Raman spectroscopy, NanoSims Ion Microprobe, and stepped combustion static mass spectroscopy. We have also applied a computer technique that produces three-dimensional anaglyphs from a series of down-through-focus images in a standard petrographic thin section. Here and in a companion abstract [1] we describe for the first time a new phase rich in carbon and also containing nitrogen. Nakhla thin sections always display secondary alteration consisting of corrosion of some minerals followed by partial or complete filling by indigenous secondary phases [2,3]. While olivine shows the greatest degree of corrosion and replacement, pyroxene and minor minerals such as apatitie and feldspar also exhibit corrosion and replacement. This new phase is closely associated with the iddingsite previously described as a major secondary replacement mineral in Nakhla [2,3].

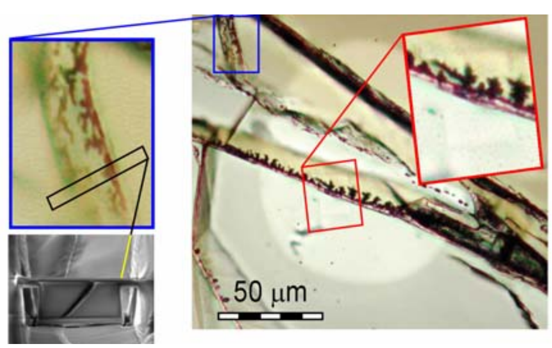
Results: Here, and in a companion paper [1] we report for the first time the presence of a carbon-rich indigenous phase in cracks and pores in Nakhla. The analyzed carbonaceous material occurs as vein fillings (Figs. 1-4) in at least 3 distinct, but related, morphologies. Most prominent is "massive" vein filling, which completely occupies narrow veins ranging in width from micrometers down to a fraction of a micrometer. The second type of occurrence is usually attached to the massive vein filling and consists of dendritic-like projections and tiny tubes usually attached on one side to the massive carbonaceous phase (Figs. 1-2). These tubes are sometimes found in hollowed-out corrosion cavities where they appear to line the walls. However, in 3d views, they are intimately interfingered with the host silicate near walls of cavities and cracks, and are not simply a coating; they appear to partially penetrate the silicate at the sub-nanometer level (Fig. 1c). The third occurrence consists of small (0.2-2 μm), mostly circular blebs of nearly opaque material. While this material closely resembles the analyzed carbonaceous veins and is spatially associated with it, we do not have direct analysis to confirm whether it is identical in composition.

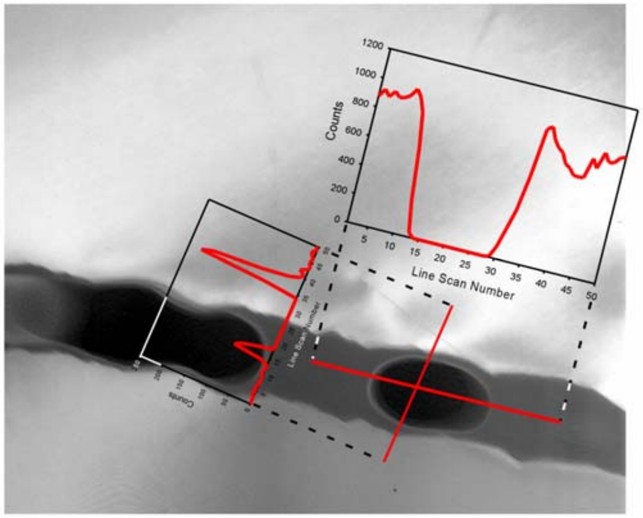
EDX analysis of a vein segment extracted from a thin section by FIB preparation is shown in Figs. 3 and 4. These data clearly show that the vein is rich in C with minor amounts of Cl and S; Si may be from adjacent pyroxene. The analyzed vein was taken from a region containing the dendritic material as well as the massive vein (Fig. 2), so the displayed composition likely includes the dendritic material as well.

Discussion: This carbonaceous material cannot be the epoxy used in thin section preparation. As shown in detail in [1], both NanoSIMS and laser Raman spectroscopy show distinct differences between the carbon/nitrogen ratio of the epoxy and of the carbonaceous vein; the laser Raman spectra of the vein is totally unlike that of the epoxy. In addition, [1] argue that the carbon isotopes strongly support an interpretation that this carbon is indigenous to Mars and is very unlikely to be a terrestrial contaminant. The carbon in this vein may be from infalling meteorites on Mars; recent work on carbonaceous chondrites show the presence of nano-sized carbonaceous particles containing both nitrogen and sulfur [4] but the close resemblance to the carbon found in subocean basaltic glass alteration veins [5-7] provides a plausible basis for a hypothesis that the Nakhla carbonaceous material is biogenic. We propose in this alternative hypothesis that organic acids from microbes (possibly in a polysaccharide biofilm) produced the corrosion [8], and the remains of the biofilm and the included microbes provide a kerogen-like carbonaceous material that fills the veins, provides the dendrites, fills the tiny tubes, and produces the small blebs. Additional support for a biogenic hypothesis comes from recent analysis of known microfossils in Proterozoic Bitter Springs chert by NanoSIMS that show a close association between fossil morphology and carbon, nitrogen, and sulfur abundances [9].

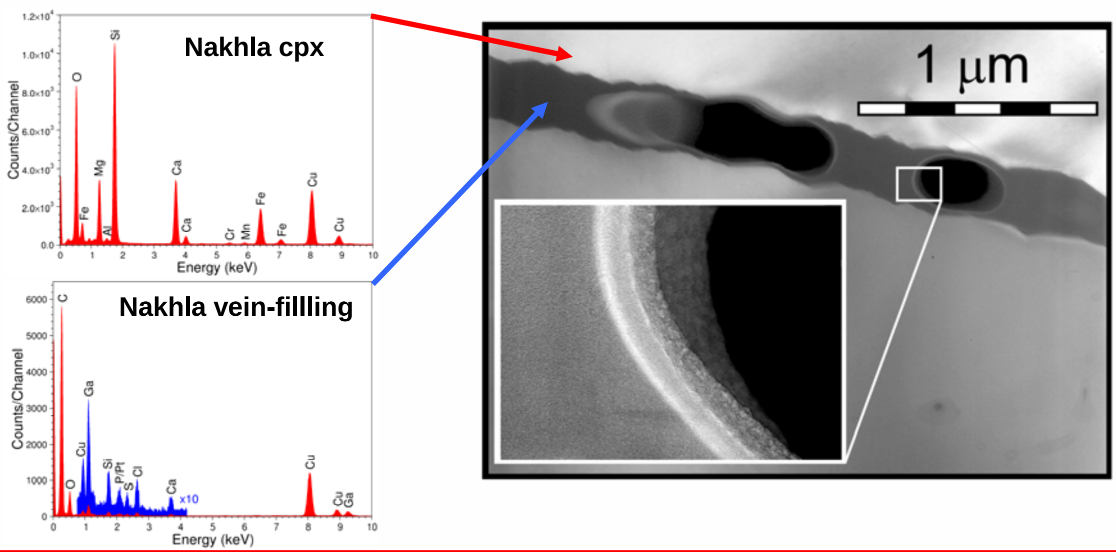
References: [1] Gibson et al. (2006) this vol.; [2] Gooding et al. (1991) *Meteoritics* 26, 135-143; [3] Wentworth et al. (2006) *Icarus* 174, 383-395; [4] Garvie & Buseck (2004) *EPSL* 224, 431-439; [5] Fisk et al. (2006) *AST* (in press); [6] Fisk et al (1998) *Science* 281, 978-980; [7] Thorseth et al. (1995) *Chem. Geol.* 126, 137-146; [8] Benzerara et al. (2005) *PNAS* 102, 979-982; [9] Oehler et al. (2006), this vol

Fig. 1. Optical views of polished section of Nakhla (right and left). Region in red box (right) is described in a complementary paper [1]. Region in blue box, (dark, dendritic) is morphologically identical to that located in the red box. A section of this region was extracted using FIB and analyzed using TEM and described herein. FIB section of vein-filled crack (lower left) imaged by FESEM.





Figures 2 (left) & 3 (below): TEM studies of dendritic vein filling. Element line scans (left) and EDX spectra (below) show that the vein-filling material is C-rich and contains minor S, Cl, P, and Si (Cu is from TEM grid; Ga and Pt from FIB section preparation). Nakhla cpx spectrum is shown for comparison. TEM diffraction (not shown here) demonstrates that this C-rich phase is amorphous.



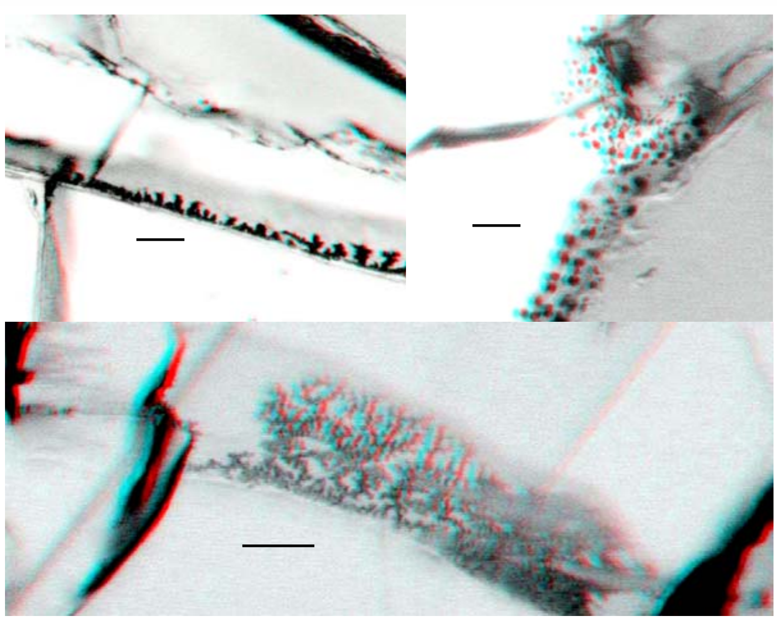


Figure 4: Anaglyph (stereo) optical images of Nakhla; all scale bars = 10 µm.
4A (left): Vein filled with carbonaceous material toward vein top, with dendritic branches at a deeper level.
4B (right): Blebs connected to more massive vein fillings.
4C (bottom): Intricate 3D network of dendritic and tube-shaped forms connected to more massive vein fillings (far left and far right).