INDIGENOUS ORGANIC MATTER ASSOCIATED WITH UNUSUAL LOW TEMPERATURE AQUEOUS SECONDARY PHASES IN THE MARS METEORITE NAKHLA

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Introduction: The Martian meteorite Nakhla provides demonstrates evidence of mineral-water interactions that occurred in the Martian regolith within the last 1 Ga, as well as the presence of trace indigenous organic matter. The aim of our research is threefold: [1] provide a context in which to interpret alteration features; [2] determine the physical and chemical environment during alteration; and, [3] investigate the hypothesis that the formation of alteration phases was intimately involved in the accumulation and/or preservation of organic matter. In freshly fractured chips of the Mars meteorite Nakhla, we found carbonaceous matter intimately associated with secondary aqueous alteration phases interpreted to have formed through the low temperature, mineral–water dissolution of the host Martian basalt. We have characterized the nature of carbonaceous matter and spatially associated secondary phases within Nakhla using a multidisciplinary suite of analytical instrumentation. Our goals are to provide a context to interpret the formation of secondary alteration assemblages within the Mars meteorite Nakhla and determine whether, and if so the extent to which, these phases participated in the accumulation and preservation of Martian organic matter [1].

Results: *Secondary Phases*. Preserved secondary mineral phases are best described as 'juvenile' hydrated amorphous silica, with embedded nanophase ferrihydrite, which formed when water interacted with Mars mafic rocks. On Earth amorphous silica is typically a transient phase that rarely persists through geologic time due to its propensity to transform into other phases, *e.g*., microcrystalline opal-CT and eventually quartz. Hence the the lack of maturation of amorphous silica in Nakhla infers these phases formed in a limited water environment by low temperature, circumneutral pH fluids stabilized by the presence of coexisting amorphous silica. This interpretation is further strengthened by the identification of the ferrous hydroxycarbonate mineral chukanovite ($Fe_2(OH)_2CO_3$), a transient precursor mineral in the formation of siderite, within some of the secondary silica-mineral aggregates studied.

Organic Matter. Arguably indigenous carbonaceous matter in Nakhla is present both in condensed phases and in a dispersed state that is spatially associated with secondary alteration phases. In the former, discrete micron to submicron sized refractory assemblages were identified and interpreted as macromolecular in nature. In several cases these are spatially aqssociated with F and, in one case, significant N. While organofluorine species have yet to be detected on Mars, the identification of organic N within one of the carbonaceous phases is considered a prerequisite for Martian astrobiological potential.

Discussion and Summary: Neither the intimate association of carbonaceous matter with secondary aqueous alteration phases, nor the identification of chukanovite have been previously reported in any of the Martian meteorites. Although the term iddingsite is now often used as a generic descriptor for aqueous alteration assemblages in the Nakhlites, we found little evidence for it in any of our Nakhla samples. Rather the term *silicate "rust*," adopted in the earliest analyses of secondary alteration features in Nakhla [2], is more apt. Although the condensed organic phases were refractory, we found no evidence for graphite or graphitization. Additionally, the observation that some of this organic matter was N-rich has significant implications for the biogenic potential of ancient Mars because formation of organo-N species from N_2 is kinetically inhibited under ambient Martian conditions.

We propose the aqueous alteration features observed in the Nakhla samples studied formed through the action of briny aqueous fluids at circumneutral pH, under pressure and temperature conditions closer to those of the Martian ambient surface regolith than to a hydrothermal system. There were at least two and possibly more temporarily distinct episodes associated with alteration. The alteration fluid brought with it dissolved mineral and organic species implying local alteration did not occur in isolation, but rather was a component in a larger alteration system. The nature of the alteration fluid was not static but evolved over time due to both endogenous and exogenous factors. Based on observed alteration phases and dissolution features, the temperature of the alteration fluid was likely far cooler than previously estimated, suggesting such alteration is widespread in the near surface regolith.

A variety of habitability-related metastable solid-phase, oxidation-reduction, and organic-molecular sample attributes in Nakhla formed hundreds of millions of years ago near Mars' surface; these alteration products persisted on Mars until very recently and resemble the amorphous materials observed at Gale crater by Mars Science Laboratory Curiosity Rover [3]. Similar phases may be expected to occur elsewhere on Mars (*e.g*., Jezero crater).

References: [1] Thomas-Keprta K.L. *et al.* (2022) *Geochimica et Cosmochimica Acta* **320**, 41-78 (online). [2] Gooding J.L. (1986) *Geochimica et Cosmochimica Acta* **50**, 2115-2223. [3] Rampe E. B. *et al.* (2020) *Geochemistry* **80**, 125605.