

HYDROTHERMAL FORMATION OF CLAY-CARBONATE ALTERATION ASSEMBLAGES IN THE NILI FOSSAE REGION OF MARS. A.J. Brown¹, S.J. Hook², A.M. Baldridge², J.F. Crowley³, N.T. Bridges², B.J. Thomson⁴, G.M. Marion⁵, C.R. de Souza Filho⁶ and J.L. Bishop¹. ¹SETI Institute, 515 N. Whisman Rd Mountain View, CA 94043, abrown@seti.org, ²Jet Propulsion Laboratory, 4800 Oak Grove Dr, CA 91109, USA, ³USGS 12201 Sunrise Valley Dr, Reston, VA, 20192, USA, ⁴Johns Hopkins University Applied Physics Laboratory, Laurel, MD, 20723, USA ⁵Desert Research Institute, 2215 Raggio Pkwy, Reno, NV 89512, USA ⁶Universidade Estadual de Campinas, Campinas, São Paulo, Brasil. Author website: <http://abrown.seti.org>

Introduction: We report here on a formation hypothesis for carbonates detected in the Nili Fossae Region near Syrtis Major. The Nili Fossae region contains large amounts of olivine [1,2] apparently in volcanic basalt [3]. The Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) has returned observations of the Nili Fossae region indicating the presence of Mg-carbonate in small (<10km sq²), relatively bright rock in commonly fractured units [4].

In order to form the observed Mg-carbonate unit and a stratigraphically lower Mg-phylosilicate (talc)-bearing unit, we propose that the carbonate-bearing units have undergone hydrothermal alteration in a circum-neutral (6-8) pH environment, similar to regions of the basaltic mafic/ultramafic Warrawoona Group (Figure 1) in Western Australia [5].

CRISM Carbonate detections: Mg-carbonate has been inferred in Nili Fossae by recognition of bands at 2.30 and 2.50 μm , accompanied by weak 3.4 and 3.9 μm bands [4]. A 1.9 μm H₂O absorption band is also present which is probably due to a second, hydrated mineral (eg. hydrous carbonate [4] or phyllosilicate).

Absorption band maps: We have applied an absorption band mapping technique [6] to several CRISM scenes of Nili Fossae containing Mg-carbonate spectra. We used a threshold method to map the pres-

ence of carbonates. We required that the 2.3 and 2.5 μm bands be present and that the 2.3 μm band had a depth > 0.1 and lay between 2.285 and 2.335 and the 2.5 μm band had a depth > 0.1 and lay between 2.46 and 2.54 μm . Figure 1 shows maps of the 2.5 μm absorption band strength. No atmospheric correction was applied, however a noise detection algorithm was used to eliminate spectra with spikes before processing.

Talc vs. Saponite (Mg-phylosilicate): In addition to the Mg-carbonate found at Nili Fossae, [7] has discovered a stratigraphically lower Mg-phylosilicate-bearing unit in many locations throughout Nili Fossae. The Mg-phylosilicate has been associated with the mineral saponite, a plausible spectral match to the 2.315 and weak 2.39 μm bands (Figure 2). On the basis of experience working with clay-carbonate alteration in the Pilbara region, we have found from HyMap airborne observations that a prominent 2.31 and 2.39 μm are most often associated with talc, which is easy to detect from airborne observations, even when mixed with other minerals [5]. Figure 2 shows example spectra from FRT 28BA and USGS library spectra of talc and saponite. Spectrally, at the resolution of the CRISM observations, it is not possible at this time in our judgement to discriminate between the two Mg-phylosilicates saponite and talc, however on the basis

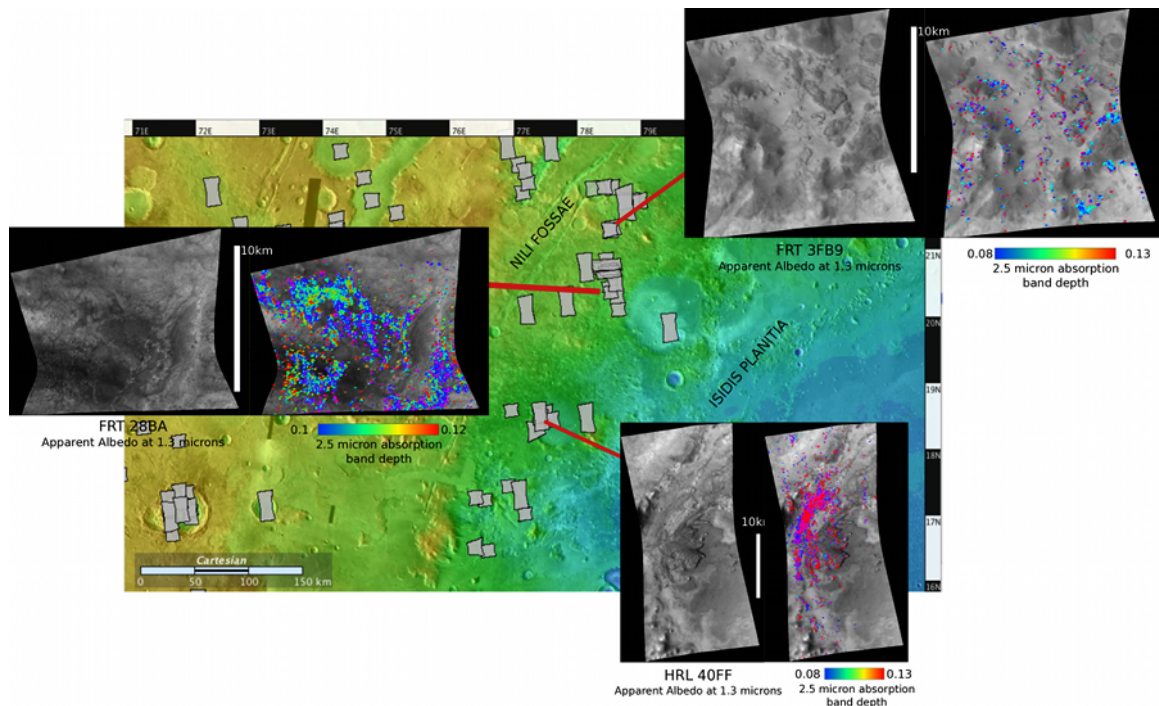


Figure 1. Absorption band maps from CRISM scenes in Nili Fossae showing depth of 2.5 μm absorption band. (top) FRT 3FB9 of a localized olivine deposit near Nili Fossae (Center lat, long: 21.33, 78.55 taken on 24 Jan 2007). (middle) FRT 28BA of an olivine bearing site near Nili Fossae (Center lat, long: 20.46, 78.50 taken on 04 Oct 2006). (bottom) HRL 40FF of a deposition fan near Nili Fossae (Center lat, long: 18.50, 77.42 taken on 29 Jan 2007).

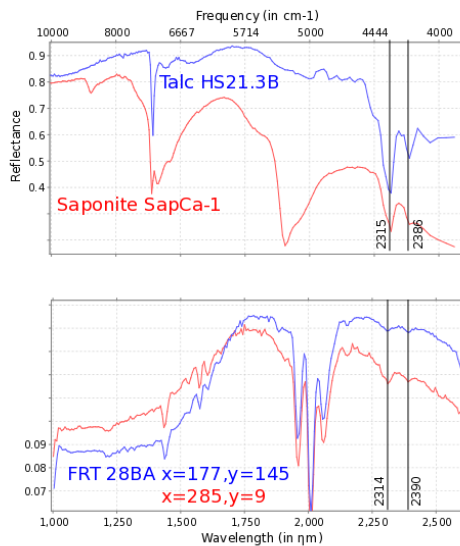


Figure 2. (top) USGS library spectra of talc and saponite. (bottom) Example spectra from FRT 28BA (Nili Fossae). Spectra are 5x5 averages centered at x,y locations (in instrument coordinates) shown. Note bands at ~2.315/2.390μm. The small differences in band center can be explained by ~0.007μm gap between CRISM bands at full resolution.

of Earth analog field observations, we favor talc, particularly as a typical alteration product of olivine rich rock units.

Stratigraphy: The carbonate-bearing units of Nili Fossae are relatively reflective in the visible part of the spectrum, commonly fractured, and are capped by an unaltered mafic cap unit [4]. Below the carbonate-bearing unit, there is a regionally extensive, Fe-Mg smectite-bearing (or talc-bearing, as suggested above) stratigraphic rock unit [8]. Above the carbonate unit, an Al-phylosilicate unit is sometimes observed, always stratigraphically higher than the carbonate unit. Ehlmann et al. [4] pointed out that the carbonate unit also appears stratigraphically coincident with olivine-bearing units observed by Mustard [9].

Formation scenarios: Ehlmann et al. [4] proffered four potential formation scenarios – 1.) *groundwater* percolating through fractures altering olivine to Mg-carbonate at slightly elevated temperatures, 2.) olivine-rich material, heated by impact or volcanic processes, was deposited on top of water-bearing phyllosilicate rich unit and initiated *hydrothermal alteration* along the contact, 3.) olivine-rich rocks were *weathered to carbonate at surface* (cold) temperatures in a manner similar to olivine weathering of meteorites in Antarctica, and 4.) the carbonate precipitated from shallow *ephemeral lakes*.

Our clay-carbonate alteration formation hypothesis: We offer here a slightly modified version of Ehlmann’s [4] hydrothermal emplacement hypothesis (#2). We propose that the phyllosilicate (probably talc) and overlying carbonate bearing unit was formed at the same time by a single hydrothermal event. The phyllosilicate (argillic) and carbonate

losilicate (argillic) and carbonate (propylitic) zones would thereby reflect the temperatures to which those zones were heated during hydrothermal alteration.

Talc-carbonate propylitic zone alteration reactions: A two-step representative alteration reaction leading to the propylitic style of mineral assemblage is shown in Table 1. This reaction is often associated with the outermost, lower temperature (<150°C) propylitic zone of hydrothermal systems [10]. In many locations (e.g. CRISM spectra in Figure 2 from FRT 28BA) a deep and wide 1 μm band is present in the pixel with talc or carbonate bands. This suggests olivine is co-located with the talc-carbonate layers. The presence of olivine and its alteration product within the same ~18m pixel suggests that insufficient heat and water were available for the alteration reaction to run to completion. This contrasts with the situation in the 3.5 Ga Warrawoona group mafic/ultramafics, where olivine signatures are no longer visible from airborne observations and olivine phenocrysts have usually been totally replaced when viewed under a microscope [5].

The formation of carbonate such as magnesite is enhanced by high dissolved CO₂ (>10%) in the metasomatic fluids and higher magnesian ultramafics – conditions more likely to be met in neutral to basic alteration conditions. This suggests circum-neutral, low temperature (<150°C) and short-lived hydration conditions existed in order to form the Nili Fossae clay-carbonate unit.

Acknowledgements: Our thanks to Bethany Ehlmann for helpful discussions and to Scott Murchie and the CRISM science operations team at APL.

References: [1] Hoefen, T. et al. (2003) *Science* **302** 627. [2] Mustard, J. et al. (2005) *Science* **307** 1594 [3] Hamilton, V. and Christensen, P. *Geology* **33** 433 [4] Ehlmann, B. et al. *Science* **322** 1828 [5] Brown, A. et al. (2005) *AJES* **52** 353 [6] Brown A.J. (2006) *TGARS* **44** 1601 [7] Ehlmann et al. (2009) *JGR* **114**, doi://10.1029/2009JE003339 [8] Mangold et al. (2007) *JGR* **112** doi:10.1029/2006JE002835 [9] Mustard (2008) *Nature* **454** 305 [10] Lowell, R. and Rona, P. (1985) *JGR* **90** 8769

Basalt Clay-Carbonate Two-step Alteration Reaction	
Mg-rich precursor	Step 1 $3 \text{Mg}_2\text{SiO}_4 + \text{SiO}_2 + 2\text{H}_2\text{O} \Rightarrow 2\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$ <i>forsterite aqueous silica serpentine</i>
	Alt. Step 1a $18\text{Mg}_2\text{SiO}_4 + 6 \text{Fe}_2\text{SiO}_4 + \text{CO}_2 + 26\text{H}_2\text{O} \Rightarrow 2\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4 + 12\text{Fe}_3\text{O}_4 + \text{CH}_4$ <i>forsterite fayalite serpentine magnetite</i>
	Step 2 $2\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4 + 3\text{CO}_2 \Rightarrow \text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4 + \text{H}_2\text{O} + 3\text{MgCO}_3$ <i>serpentine talc magnesite</i>
Fe-rich precursor	$\text{Fe}_2\text{SiO}_4 + 2\text{H}_2\text{CO}_3 \Rightarrow \text{SiO}_2 + 2\text{FeCO}_3 + 2\text{H}_2\text{O}$ <i>fayalite carbonic acid silica siderite</i>
Alternative one step reaction	
High Mg conditions with CO ₂	$\text{Mg}_2\text{SiO}_4 + \text{nH}_2\text{O} + \text{CO}_2 \rightarrow \text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4 + \text{Fe}_3\text{O}_4 + \text{MgCO}_3 + \text{SiO}_2$ <i>forsterite serpentine magnetite magnesite</i>

Table 1. Two step clay-carbonate reaction series to arrive at carbonates from an Mg-rich ultramafic precursor. Fe-rich precursors (from fayalite) may also be applicable on Mars, although siderite has not yet been detected by CRISM. Alternate Step 1a shows it is possible in the presence of CO₂ to form methane as part of the serpentinisation process.