

INVESTIGATION OF HYDROTHERMAL CLAYS AND SULFATES IN TYRRHENA TERRA MARTIAN CRATERS. L. M. Aaron¹ and K. D. Seelos², ¹Johns Hopkins University (laaron2@jhu.edu), ²Johns Hopkins University Applied Physics Laboratory.

Introduction: Mineralogical mapping of primary and secondary minerals is critical for understanding the formation and alteration history of planetary surfaces. Within Mars' oldest Noachian terrains, minerals are frequently associated with impact craters. While some of these minerals are exposed or excavated through the impact process, they may also form after impact due to weathering processes occurring at the time. This paper discusses how these hydrothermal processes produced the minerals detected within three craters in Tyrrhena Terra. This research was implemented by analyzing spectra of minerals in three craters on Mars, mapping mineral detection locations using confidence intervals, and interpreting these observations along with geomorphology to inform their formation process.

Methods: The Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) is an instrument onboard the Mars Reconnaissance Orbiter (MRO) ranging from 0.4 - 4.0 μm at a spatial resolution of 18 m/pixel and spectral sampling of 6.55 nm/channel [1]. Data used were Map-projected Targeted Reduced Data Records (MTRDRs) processed to spectrally correct for atmospheric gases and dust. Full-Resolution Target (FRT) images (FRT000148C1, FRT000147F9, and FRT000177E9) cover complex craters with diameters ranging from 11 to 25 km, all located within the Noachian southern highlands (**Fig 1**). Reflectance spectra were retrieved from 5x5 pixel regions of interest selected based on summary parameter browse products [2]. Scene endmember spectra were then compared to laboratory and CRISM reference spectra for dominant mineral identification. CTX and HiRISE imagery were juxtaposed with CRISM results to identify any morphologic features consistent with the mineralogy.

Results: The most common minerals detected in all three craters were polyhydrated sulfates, Mg/Fe-smectite, chlorite, and high- and low-calcium pyroxene (HCP and LCP, respectively), with distributions varying from widespread to local (**Fig 2-4**). Analcime, bassanite, and prehnite have also been detected, although not consistently between each crater. Also identified were small exposures of talc, gypsum, and Fe/Mg/Ca-carbonate.

Polyhydrated sulfates were either located on the crater floor near the central peak or along the bottom of the southern wall of the crater. Their 1.43 and 1.94- μm absorption features are due to the bending and stretching of water molecules. Cation-OH vibrations cause polyhydrated sulfate's diagnostic 2.43 μm feature. Weaker detections are closely associated with

finer-grained surfaces such as dunes and sediments, whereas stronger detections were located near larger-grained outcrops.

Mg/Fe-smectite were located either along the rims, as seen in FRT000148C1 and FRT000147E9, or around central peaks and walls of secondary craters in FRT000177F9. Mg/Fe-smectite also has absorptions features at 1.4 and 2.3 μm . The 2.3 μm feature is dependent on the proportion of Fe to Mg in its crystal structure. Fe-smectite has an additional feature at 2.5. This feature becomes more or less apparent when moving along the rim, which could indicate spectral mixing. Mg/Fe-smectite is primarily associated with large outcrops along the rim that contact a mixture of dark and light features. Below these are loose materials consistent with mass wasting and other physical weathering processes.

Chlorite was located in various locations within and around the craters, within proximity of Mg/Fe-smectite. Like Mg/Fe-smectite and polyhydrated sulfates, chlorite also contains a 1.4 μm and 1.9 μm feature. However, chlorite's 1.9 μm feature has a slight doublet at 1.9 μm and 2 μm , in addition to its 2.25 μm and 2.35 μm features. Similar to polyhydrated sulfates, features became weaker within finer grain dune-like regions and more apparent with more competent outcrops. Chlorite can sometimes be found stratigraphically beneath Mg/Fe-smectite outcrops, as seen in FRT000148C1 and FRT000147E9.

HCP and LCP were found along the walls and floors of craters and within ejecta. Each exhibits two broad absorptions: 0.91 and 1.95 for LCP and 0.99 and 2.16 for HCP. These features shift depending on Fe and Ca content. LCP has been located on the floors and walls of craters with weaker detections on finer-grained or weathered surfaces and stronger detections on more extensive outcrops. HCP is found mostly outside of the craters, except for one spectrally weak region on FRT000148C1's crater floor; it is commonly associated with more massive outcrops.

Analcime was located in FRT000148C1 and FRT000177E9 within the ejecta and around the central peak, respectively. Like the previously mentioned minerals, it also contains absorptions indicative of water molecule vibrations, in addition to its other features at 1.79 and 2.5 μm . They are often found with small outcrops closest to dunes. Bassanite was detected in FRT000177E9 around the central peak of the 25 km wide crater. Its absorption features are very similar to analcime. However, analcime's 1.9 μm band is

relatively sharp and strong, which can be distinctive. Lastly, prehnite was detected in FRT000147F9, exhibiting hydrated spectral features like the previously mentioned as well as two diagnostic features at 2.35 μm and 1.48 μm . This secondary mineral was located on a large outcrop along the crater walls and rim surrounded by chlorite.

Small outcrops of talc were detected only in FRT000148C1 along the Fe/Mg smectite rim of the crater. On Earth, talc lacks an H_2O interlayer, which is evident by its narrow 1.4 μm feature and relatively absent 1.9 μm feature. However, Martian talc can display a significant 1.9 μm feature due to mixing with other hydrated phases. Spectra may also be consistent with the talc being mixed with Fe/Mg smectite. Gypsum was located at the central peak of FRT000147E9, surrounded by polyhydrated sulfates and LCP; 1.44 μm , 1.95 μm , and a doublet 2.21 μm and 2.26 μm are due to combinations and overtones of H_2O vibrations and librations; the 2.4 μm drop-off is also a common characteristic of hydrated sulfates. Fe/Mg/Ca-Carbonate can be seen in all three craters at various levels of confidence. These small outcrops exhibit a 1.9 μm molecular H_2O overtone absorption and 2.3 μm and 2.5 μm features, which shift depending on the cation. Within FRT000148C1, these features are not as prominent. In all three craters, carbonate outcrops are associated with chlorite.

Discussion: Among the minerals observed in these three craters, most are not unusual in the Noachian southern highland terrain. Hydrated sulfates, however, are extremely rare and typically associated with younger, Hesperian-aged layered deposits or evaporites. Sulfates and clays could have formed together through volcanic or impact-induced hydrothermal processes between the late Noachian and early Hesperian. Early Hesperian volcanism can provide the temperate and chemical conditions necessary for hydrothermal processes to occur at the subsurface to create sulfates [3]. Impacts can also influence hydrothermal conditions with limitations [4]. These conditions are primarily associated with craters larger than 20 km in diameter; at this magnitude, pre-existing clays would likely be destroyed [5]. Quite possibly, large nearby impacts could contribute to initiating the hydrothermal process. Further research is necessary to understand the physical and geochemical conditions that resulted in each crater's mineral distribution. Studying these mechanisms can give insight into Mars' Noachian climate and environment.

References: [1] Murchie, S. et al (2007) *J. Geophys. Res.*, 112 [2] Viviano-Beck, C. E., et al. (2014) *J. Geophys. Res. Planets* [3] Zolotov, M. Yu., and Mironenko, M. V. (2016) *Icarus*, 275, 203–220. [4] Loizeau, D. et al (2012) *Icarus*, 219(1), 476–497.

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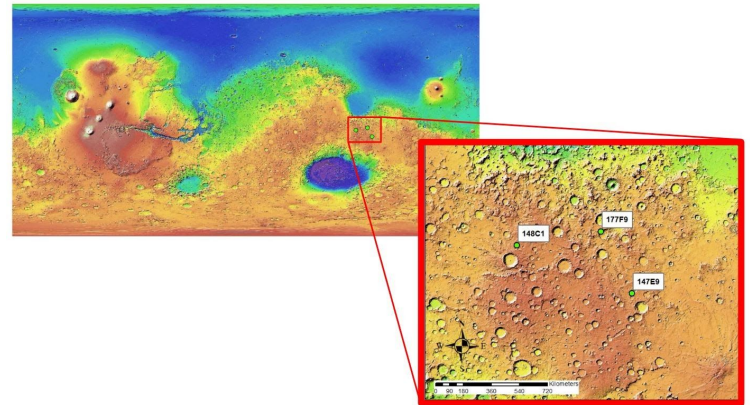
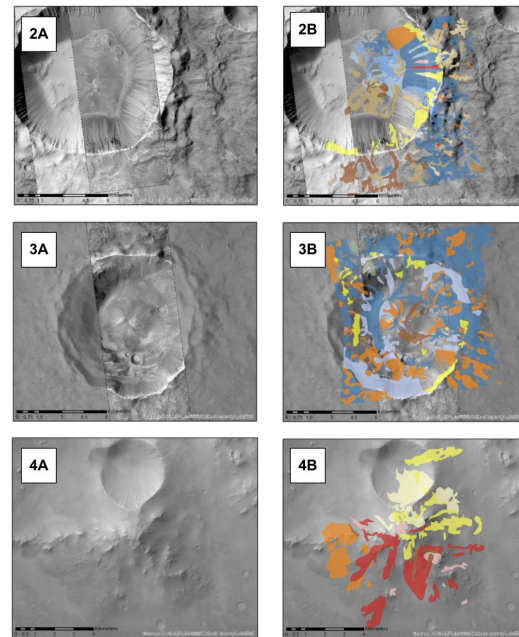


Figure 1. MOLA topography showing the locations of the three craters in Tyrrenia Terra.



	Confidence Intervals		
	High	Med	Low
Anatcline/Bassanite	Red	Light Red	White
HCP/LCP	Blue	Light Blue	White
Talc	Green	Light Green	White
Gypsum	Purple	Light Purple	White
Chlorite	Orange	Light Orange	White
Fe/Mg-smectite	Yellow	Light Yellow	White
Polyhydrated Sulfates	Brown	Light Brown	White
Fe/Mg/Ca-carbonate	Pink	Light Pink	White
Prehnite	Grey	Light Grey	White

Figures 2-4. For each crater studied: A) THEMIS daytime IR and CTX context with B) mineral map overlain. The legend applies to all maps and conveys identification confidence.