

EVIDENCE FOR WIDESPREAD SHALLOW CHLORITE IN TYRRHENA TERRA, MARS. L. E. Sacks^{1,2}, L. L. Tornabene^{1,2}, C. E. Viviano³, J. R. C. Voigt⁴, J. L. Bishop⁵, M. D. Lane⁶, D. Loizeau⁷, D. Tirsch⁸. ¹Institute for Earth and Space Exploration, University of Western Ontario (London, Canada; lsacks4@uwo.ca) ²Department of Earth Sciences, University of Western Ontario (London, Canada), ³Johns Hopkins University Applied Physics Lab, ⁴University of Arizona Lunar and Planetary Laboratory, ⁵SETI Institute, ⁶Fibernetics LLC, ⁷Institut d'Astrophysique Spatiale, ⁸German Aerospace Center (DLR)

Introduction: Tyrrhena Terra is a large area of Mars bounded by the Libya Montes and the Isidis Basin to the north and the Hellas Basin to the south. Mapping of CRISM data covering the area shows multiple smectite and chlorite spectral signatures correlating with impact craters (ex. [1]). These signatures suggest the possibility of an extensive phyllosilicate unit or units exposed by the impactors, with chlorites indicating elevated temperatures. Viviano and Phillips [2] examined the possibilities of three potential formation theories for deposits throughout the area: 1. "Isidis-induced metamorphism", 2. "Pre-Isidis burial diagenesis," and 3. "Post-Isidis burial diagenesis." Their results support either the first or third theory after evaluating the *deepest* depths that each of the phyllosilicate signatures identified in the area could be excavating. To further constrain the history of the area, this study aims to examine the extent of *shallow* chlorite-bearing units in Tyrrhena Terra (examples in Fig. 1). The study area (Figs. 2 & 3) is hereafter abbreviated as LM-TT (Libya Montes – Tyrrhena Terra).

Methods: We examined a database of chlorite signatures identified in the LM-TT area [2] and documented the landforms and morphology related to the chlorite detections, the majority of which are primarily associated with crater deposits. For analysis, we created a subset database containing all chlorite signatures that correlated with ejecta or other crater-related features. As this study intentionally focuses on constraining the extent of chlorite in the shallow subsurface, we eliminated all large craters in the database with radius greater than 6 km ($D > 12$ km) (e.g. [3, 4]). The usage of smaller craters also reduces the probability that chlorite was directly generated by these small craters (e.g., [5]), and thereby excavation depth scaling of these smaller craters would reflect the local depth to the chlorite-bearing layer. This does not, however, preclude the formation of chlorites due to other impact-related alteration.

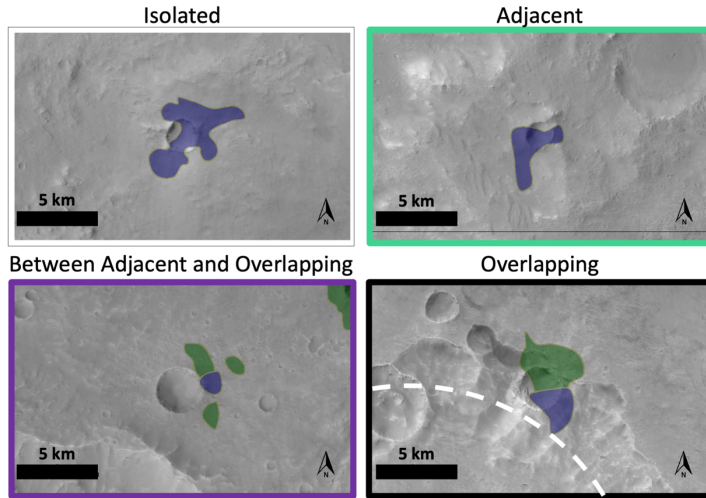
We then identified those craters least likely to be influenced by alternative sources of chlorite (such as chlorites generated by other impacts), and show exclusively excavation of shallow chlorites. The database of simple ($D < 12$ km) chlorite-associated craters was sorted into three possible categories, allowing for placement in multiple categories to best

describe the crater. The categories were "isolated," "overlapping other craters or crater ejecta," and "adjacent to other crater features or signatures." Examples of each type of crater are shown in Fig. 1.

Results: The full database of craters in the LM-TT area bearing chlorite signatures with $R < 6$ km contains 137 craters. Of those craters, 29 were identified as solely "isolated" craters, while 35 were identified as "adjacent" to other crater features. The small chlorite-bearing craters of all categories are mapped in Figs. 2 & 3.

Discussion and Conclusions: When mapped onto topographic and geologic maps, the "isolated" and "adjacent" craters are observed to occur primarily atop or bordering older terrain (Figs. 2 & 3), specifically areas that are topographically complex and mapped as early Noachian terrain [6]. These older Noachian-aged units that appear to be the source of the chlorite are noted to be embayed or superposed by younger units. Small, simple craters expose only material at shallower depths, suggesting that the chlorite unit is relatively shallow in the old terrains impacted by these craters. While not all craters in Tyrrhena Terra were examined, the simple craters in this study all expose a chlorite unit, indicating widespread, shallow chlorite deposits stretching across the Tyrrhena Terra area. Those craters that impact younger units bordering the Noachian terrains are likely still sourcing the older units through thin areas of the younger terrain.

In conjunction with the results of Viviano and Phillips [2], there are possible implications for the formation of these deposits from the extent of the chlorites observed in this study. Of the two primary viable formation mechanisms for the chlorites observed in that study, both the "Isidis-induced metamorphism" and "post-Isidis burial diagenesis" hypotheses would have allowed for formation of chlorites across the region. However, "post-Isidis burial diagenesis" is the mechanism that would best allow for extensive outcrops across Tyrrhena Terra (see [2]). It should be noted that similar hypotheses should be considered relating to Hellas Basin as well. Induced metamorphism would likely have spatial constraints tying the chlorites to specific locations related to Isidis or Hellas, while burial diagenesis allows for a widespread distribution. The observed chlorite deposits could be subsequently buried



Noachian smectite clays transformed to chlorites. The results of this study would also allow for similar formation of chlorites from burial of smectites under ejecta from both Isidis and Hellas basins, as alluded to by researchers such as Tornabene et al. [5], as well as other possible origins for chlorites.

References: [1] Tirsch et al. (2021) 52nd LPSC p. 1193 [2] Viviano and Phillips (2019) 9th Conference on Mars, 2089, p.6359. [3] Boyce and Garbeil (2007) *Geophysical Research Letters*, v. 34, L16201 [4] Tornabene et al. (2018) *Icarus*, v. 299, p.68-83 [5] Tornabene et al. (2013) *JGR Planets* v. 118, p. 994-1012 [6] Tanaka et al. (2014) *USGS Scientific Investigations Map*

Fig. 1 Examples of categorized craters (<6 km radius) with associated chlorite signatures (blue transparent layers, green are smectite detections). White dashed line represents a pre-existing crater. Colored panel outlines correlate with mapped craters on maps in Figures 2 and 3.

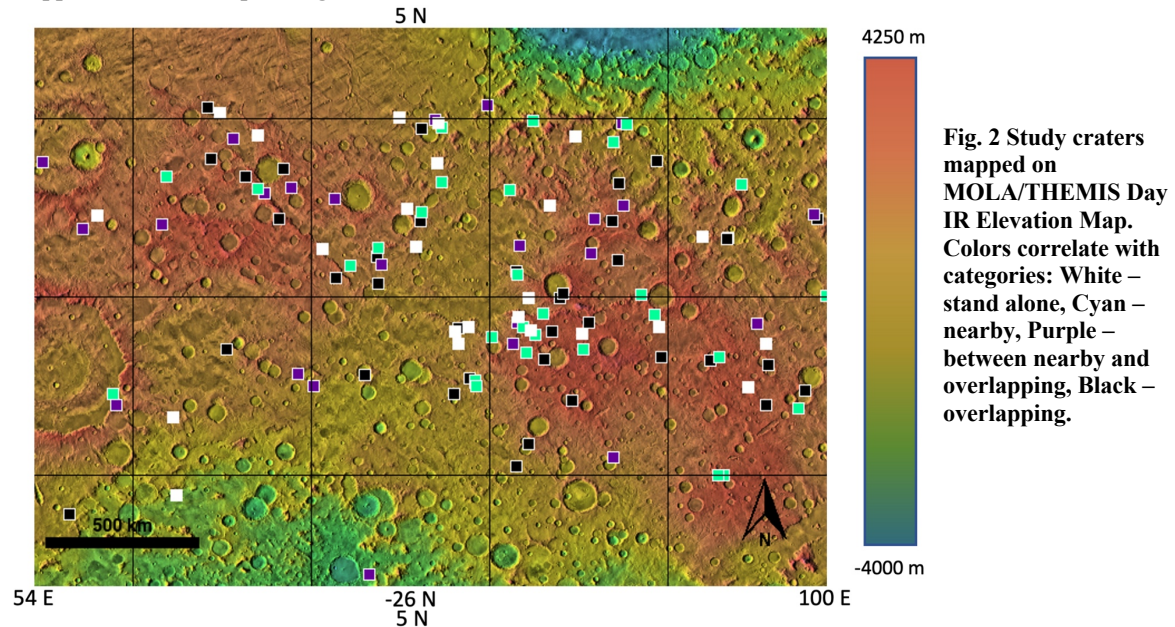


Fig. 2 Study craters mapped on MOLA/THEMIS Day IR Elevation Map. Colors correlate with categories: White – stand alone, Cyan – nearby, Purple – between nearby and overlapping, Black – overlapping.

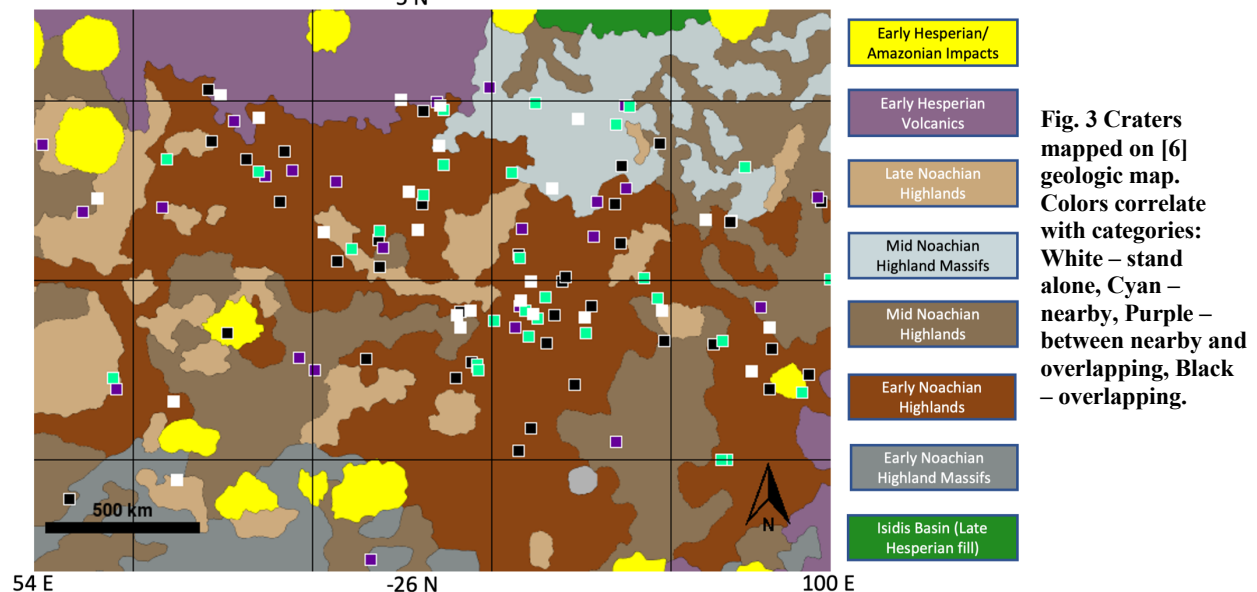


Fig. 3 Craters mapped on [6] geologic map. Colors correlate with categories: White – stand alone, Cyan – nearby, Purple – between nearby and overlapping, Black – overlapping.

- Early Hesperian/Amazonian Impacts
- Early Hesperian Volcanics
- Late Noachian Highlands
- Mid Noachian Highland Massifs
- Mid Noachian Highlands
- Early Noachian Highlands
- Early Noachian Highland Massifs
- Isidis Basin (Late Hesperian fill)