EVALUATING MODELS OF CRUSTAL COOLING USING CRISM OBSERVATIONS OF IMPACT CRATERS IN TERRA TYRRHENA AND NOACHIS TERRA.

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Introduction: The persistence of lithospheric thickness variations from its earliest era provides constraints on the thermal evolution of Mars [1,2]. Under these constraints, plausible thermal evolution models require cooling of the crust that could be accomplished by either hydrothermal cooling in a fractured portion of the upper crust or the existence of a stable stratified mantle where heat-producing elements are sequestered in a deeper portion of the mantle [2].

CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) [3] and OMEGA (Observatoire pour la Mineralogy, l'Eau, les Glaces et l'Activité) [4,5] observations of phyllosilicate minerals excavated from depths of 4-5km have been proposed as evidence in support of the deep crustal hydrothermal cooling model [6]. The most prevalent of these phyllosilicates appear to be Fe/Mg smectites, which typically form at moderate temperature (<200°C) and pressure conditions expected in a hydrothermal geotherm.

Here, we use CRISM data to further evaluate models of crustal cooling. In stratified mantle cooling, the geothermal gradient shows an approximately linear increase in temperature with depth, creating a correlation between mineralogy and depth. This model predicts higher temperature mineral phases with depth. In a hydrothermal circulation environment, however, the crustal temperature stays relatively constant with depth to the base of the hydrothermal layer. This system would not produce noticeable changes in mineralogy as a function of depth, though it could generate regional mineralogic variations reflecting regions of cool water downwelling and warmer water upwelling [6].

Impact craters provide a window to the interior where larger craters expose rocks from deeper sections of the crust. Here we systematically analyze the mineralogy in central peaks, rims, and ejecta of craters across Noachian/Phyllosian-age terrains to assess if there is any systematic variation in mineralogy exposed by impact.

Data Sets: CRISM is a visible to near infrared imaging spectrometer onboard the Mars Reconnaissance Orbiter. CRISM can acquire high resolution targeted images that have a spatial resolution of 18-35m/pixel and cover 544 wavelengths from 0.362-3.92 μm [7]. Photometric and atmospheric corrections are applied to images to account for variations in observation geometry and atmospheric gas absorptions respectively [3].

We analyzed a subset of spectral data from 1.0 – 2.6 μm in corrected FRT (Full Resolution Targeted) and HRL (Half Resolution Long Targeted) CRISM images. Spectral parameters were used to highlight regions of a CRISM observation that expressed characteristic mineralogical features [8]. We collected spectra from areas with strong spectral parameter values and ratioed these to spectrally neutral areas in the same image columns. These ratio spectra were then compared to standard laboratory spectra. We examined CRISM observations of 137 craters in Terra Tyrrhena and Noachis Terra, two areas of Mars that are comprised of mostly Noachian/Phyllosian-aged terrains (Fig. 1).

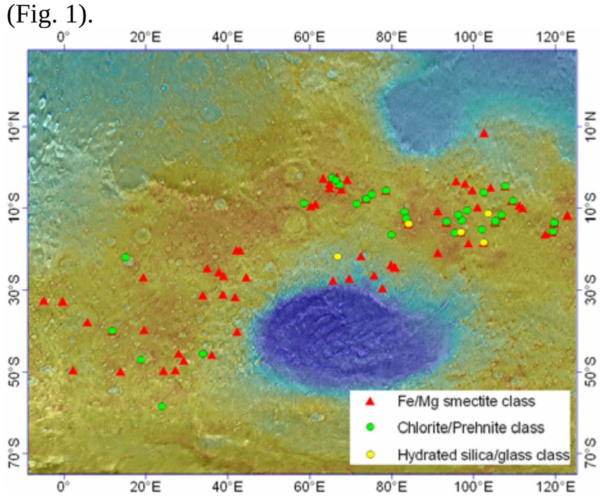

Fig. 1: Distribution of most prevalent non-mafic mineral classes

Results. *Spectral Diversity and Classifications.* The observed spectra from Terra Tyrrhena and Noachis Terra can be grouped into eight unique spectral classes based on their absorption features, representing mafic minerals (pyroxene, olivine), phyllosilicates (Fe/Mg smectite, chlorite/prehnite, illite/muscovite, and kaolin group), hydrated silica/glass, and zeolites.

Distribution and morphologic setting: Pyroxene was the most frequently detected mineral class, occurring in 94 of the 137 crater observations. Fig. 1 shows the geographic distributions of the most prevalent non-mafic mineral class detections. Fe/Mg smectite class minerals are found throughout the study area. In Terra Tyrrhena, the chlorite/prehnite class is common between about 3˚S and 18˚S, but no chlorite/prehnite class spectra were found in the southern portion of Terra Tyrrhena. Chlorite/prehnite and smectites are both observed in Noachis Terra but without any pattern in distribution. Many of the less frequently detected classes in Terra Tyrrhena, such a illite/muscovite and zeolite, were not detected in the Noachis Terra region. The hydrated silica/glass, illite/muscovite, and kaolin family classes occurred in only a few locations and thus there are not enough occurrences to determine if they have a systematic regional distribution.

Minerals of the chlorite/prehnite and smectite classes were found associated with structures and deposits of the craters, including ejecta, exposed crater walls and rims, small knobs on the crater floor, and in the central peak/pit material. In many images, spectra from these classes were also detected in mobile material (talus, scree, eolian) that appears to be eroding from exposures in the rims and central peaks. Hydrated silica/glass was found in ejecta, central peak material and in mobile material around the central peak that potentially eroded from the material in the central peak. Zeolite class minerals were detected in crater ejecta and in a small outcrop in the center of a crater (though not in a crater central peak complex). Kaolin family minerals and muscovite/illite were found in central peak material and in small outcrops on the crater floor. That these hydrated silicate detections occur in multiple types of crater structures and deposits is in agreement with previous work [3,5,9]. The occurrence of hydrated silicates in ejecta and upper wall rock indicates that they were, in many instances, present prior to the impact events rather than formed during the impact process or in subsequent alteration. On Earth, minerals formed by hydrothermal systems subsequent to or during crater formation are typically found both along small valley networks on the rims and central uplifts of impact craters, in vertical fractures and cavity fillings, and beneath impact melt deposits, conditions not observed in CRISM images [10, 11].

Depth Relationships. Crater scaling relationships can be used to provide approximations for the pre-impact depth of materials in a crater's central peak, rim, and ejecta [12-14]. To first order, all of these relationships show an approximately linear correlation between current crater diameter and depth of excavation with a ratio of 10:1 of diameter to depth. The approximate diameter of each crater was measured from the Viking Mars Digital Image Mosaic (MDIM). Fig. 2 shows the prevalence of mineral class detections in the central peak materials in Noachis and Terra Tyrrhena.

Discussion: The apparent lack of any strong correlation between mineralogy and depth supports a hydrothermal cooling hypothesis. A weak positive correlation may exist between smectite and depth, while a weak negative correlation may exist between chlorite/prehnite and depth. However, these apparent correlations are likely due to small number statistics and are opposite to what we would expect. Prehnite and chlorite are generally higher temperature minerals than smectite and thus should be found in larger, deeper craters. In addition, other possible high-temperature minerals, such as muscovite/illite, are only found from the shallowest depths. Future observations will help to clarify these relationships.

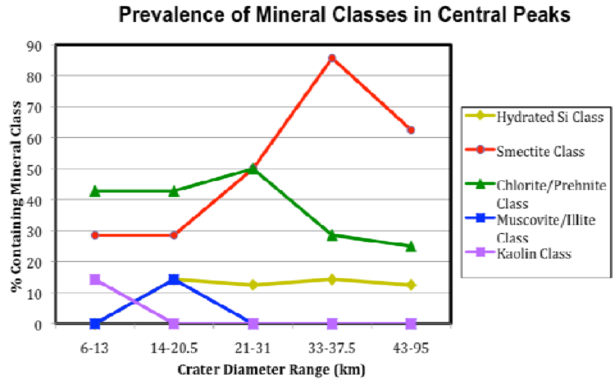

Fig. 2: Craters are binned into groups based on their present day diameter and graphed as a function of percentage of observations in each group containing the mineral. In order of increasing diameter, groups contain 7, 8, 8, 8, and 9 total observations.

Our region of study is located between two large impact basins, Isidis and Hellas, and it is also possible that we are looking at material derived from basin impact ejecta rather than from the original crust. High resolution imaging shows that mega-breccia is quite common in Noachian-aged rocks [15]. If we are studying well-mixed ejecta, homogenized by several generations of impacts, it will be impossible to determine whether any correlation between mineralogy and depth originally existed. However, the crust under Isidis is very thin, so in this case we would at least expect that the basin would have excavated minerals from depths at the base of the lithosphere to the surface [1]. In the case of the stratified mantle cooling scenario, minerals at the base of the lithospehere would be formed at significantly higher temperatures than minerals in a hydrothermal circulation scenario. The lack of very high temperature minerals found in our observations also suggests that the hydrothermal circulation scenario is a more likely to means to explain the cooling of early Mars' crust.

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