THE STRATIGRAPHY OF THE NORTHERN PLAINS INFERRED FROM MINERALOGY OF IMPACT CRATERS.

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Introduction: A record of Mars' global volcanism and aqueous activity lies in the stratigraphy of the northern plains of Mars, including the heavily cratered Noachian basement [1], Hesperian outflow channel and/or possible ocean deposits [2,3], and widespread lava flows [4], as well as Amazonian surface sedimentary/volcanic geomorphic structures (cones, knobs, polygons, etc. [5-7]). The mineralogy of excavated buried bedrock thus provides a key tracer for understanding the geologic and climate history of Mars. Building on previous studies [8-11], the mineralogy is diverse, including different mafic minerals and hydrated minerals detected in association with different sized craters. Here we report the complete results of a survey of impact craters in the northern plains of Mars using data from the Compact Reconnaissance Imaging Spectrometer on Mars (CRISM). The results indicate widespread mafic mineral detections that are relatively insensitive to crater size, while hydrated mineral detections are strongly associated with the largest craters, with some geographic heterogeneities.

Survey Methods: Using a noise reduction algorithm developed to enhance spectral mineral identification [10-11], 886 CRISM images have been examined for >1-km-diameter craters in the northern plains of Mars (excluding polar regions above 60°N where spectral properties are dominated by a dust-rich-mantle [12]). In the global survey, CRISM images taken up to 13 November 2015 that cover any part of the crater wall, crater central peak, crater floor and the ejecta blanket have been investigated. The surveyed images cover 431 craters with diameters ranging from 2.8 km to 220.3 km.

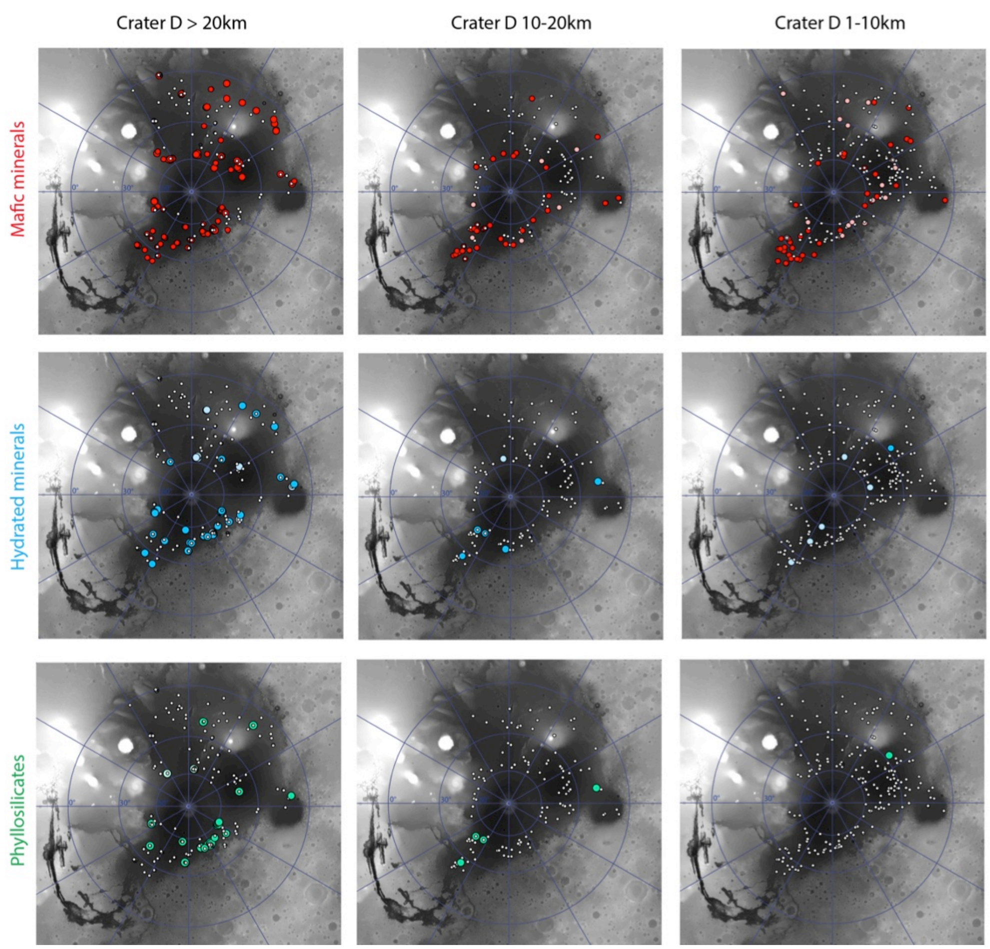

Figure 1. Global distribution in the northern plains of Mars for mafic, hydrated minerals and phyllosilicates for different crater size bins. (Lighter colored dots indicate images where absorption features are found that may represent mineral detections but are less clear)

Results: By identifying electronic absorptions due to Fe around 1μm and 2μm, mafic minerals (olivine and pyroxene) have been detected in 161 craters in 340 CRISM images (Figure 1). Those associated only with aeolian deposits rather than bedrock, e.g., detections over sand dunes, are excluded in this dataset. The percentage of craters with mafic mineral detections is ~70% for large craters (diameter, D>30km); ~40% for craters with D=20-30km; and ~20% for small craters with D=1-20km (histograms in Figure 2). Mafic minerals can be detected over the entire northern plains; however, the detections are concentrated mainly in the dust-free regions in the northern plains, especially for smaller craters (D<20km). The absorption features are also more pronounced in Acidalia and Elysium Planitia compared to Arcadia Planitia, Utopia Planitia and Isidis Basin, due to the effect of dust cover (Figure 1).

Various hydrous silicates have been identified in the northern plains of Mars including Fe/Mg phyllosilicates, hydrated silica, chlorite/prehnite and Al-phyllosilicates [8, 10-11]. In this survey, the spectral class with clear 1.9-μm absorption features due to H_2O combination modes is also included as "hydrated mineral" even though absorptions at longer wavelengths are not clear enough to support better phase discrimination. Hydrated minerals have been detected in 130 CRISM images covering 45 impact craters, in which 83 images over 23 craters have confirmed phyllosilicate minerals (Figure 1). The distribution of hydrated minerals is widespread in all the major basins in the northern plains for craters larger than 20km, but the percentage of craters with hydrated mineral detections decreases dramatically from ~30% for all craters larger than 20 km to less than 5% for smaller ones (Figure 2).

Major Findings: Overall, both mafic minerals and hydrated minerals are widespread in the subsurface of the northern plains, even though they are not readily detectable on the surface of the plains [13]. However, phyllosilicates and other hydrated minerals are mostly detected in large craters (D > 20km) while the mafic detections are found in craters of all sizes (D >1km) in the northern plains. High-resolution investigations of some impact sites show phyllosilicate-bearing layered blocks in central peaks [11] indicating formation by crater excavation instead of post-impact alteration. However, for detections with less clear geologic context the possibility of alteration after crater formation cannot be completely ruled out.

Assuming an excavation origin of these minerals, we can put constraints on the original depth of the minerals in the northern plains stratigraphy using different-sized craters (Figure 2) [10, 13]. Across the northern plains of Mars, the hydrated minerals are mostly observed in craters larger than 20 km corresponding to a maximum excavation depth of ~1.5 km. 5 craters with diameter smaller than 20 km (in 318 craters) are found with hydrated minerals (Figure 1), which could be related to variations in local stratigraphy or impact ejecta. Mafic minerals are found in small craters as well as large ones, indicating that they are present over a range of depths for at least 1-2 kilometers. In large craters, minerals are commonly detected on central peaks/rings, where the minimum

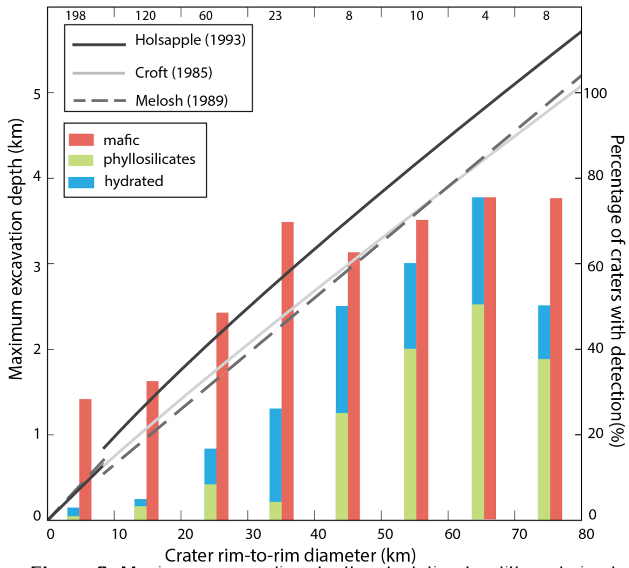

Figure 2: Maximum excavation depth calculation for different sized craters. Color bars show the percentage of craters with mineral detections. Numbers on the top of the chart indicate the number of craters in each sized bin [14-16].

depth of origin should be deeper than the maximum extent of the melt zone [17]. Therefore, it can be inferred that both hydrated and mafic minerals exist at depths of at least 2-4 kilometers in the northern plains. The emerging stratigraphy indicates that phyllosilicates and many other hydrated phases are widespread in the northern plains at depths greater than 1.5 km, while olivine and pyroxene are present from close to the surface to several kilometers deep. From further morphologic study of the detections of impact sites and statistical analysis of crater size and distribution, we will identify local variations in stratigraphy in the northern plains, infer the possible scenarios of hydrated mineral alteration and put constraints on the volume of sediments/volcanic deposits buried in depth. This will greatly improve our understanding on the resurfacing of the northern plains as well as the evolving global climate and volcanic activity for Mars.

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