

Comparison of Mineral Content in Cratered Areas on the Northern and Southern Hemisphere of Mars

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Abstract

The analysis of minerals on Mars may yield some clues to the geologic processes that formed its current surfaces. Two main theories exist to explain the dichotomy in terrains on Mars, a large impact to the Northern hemisphere, or the previous existence of an ocean in the Northern hemisphere. Impact craters in the Northern hemisphere unearth buried compounds, and may show a difference in mineral formation. Comparing these results to mineral detection in the Southern hemisphere may give some clues about the dichotomy formation. A spectral analysis of 18 impact craters, 9 from each hemisphere, was performed to detect high calcium pyroxenes (HCPs), low calcium pyroxenes (LCPs), olivine, nontronite, and gypsum. HCPs and LCPs could not be detected, but an unidentified mineral, referred to as mineral X, was found within some of the craters. The statistical analysis of mineral X, olivine, nontronite, and gypsum found that only mineral X and nontronite showed any preference for detection inside or outside of the crater. The results from this analysis make it difficult to conclude anything new about the dichotomy formation.

Introduction

There are many questions about the formation and geology of Mars. A key to understanding Mars past and possible future lies in its mineral composition. The Mars Express brought us much of the information needed to find out the answers to the mineralogical questions about Mars.

Mars Express was launched by the European Space Agency in 2003. On board the Mars Express is the sensor of interest in this study, Observatoire pour la Minéralogie, l'Eau, les Glaces et L'Activité (OMEGA). OMEGA is a visible and near-infrared mineralogical mapping spectrometer. The scientific mission of OMEGA is to "characterize the composition of the surface material and monitor atmospheric dust and aerosols" (1).

The objective of this project was to determine the mineral content of the Martian surface. The difference in mineral content between the inner and outer surfaces of impact craters, both in the northern and southern regions, was looked at. The minerals that were specifically focused on were the silicates olivine and nontronite, and the sulfate gypsum, as well as low calcium pyroxenes (LCP) and high calcium pyroxenes (HCP).

Olivine and pyroxene are iron rich minerals that have absorption bands in the visible and near infrared spectrums (2). Olivine $[(\text{Mg,Fe})_2\text{SiO}_4]$ is a greenish-colored silicate mineral commonly found in high density mafic igneous rocks. The olivine rocks get darker in color as they get a higher iron and magnesium content. Olivine can be detected as a broad, complex absorption peak centered near $1 \mu\text{m}$. As iron content increases, variations in width, position, and shape can be noted (3). Absorption features can vary between 0.8 and $1.5 \mu\text{m}$ as a result of Fe content changes (2).

Depending on the environment that they are formed in, pyroxenes detected on Mars may have high calcium content (HCP's) or low calcium content (LCP's). Due to the differences in calcium levels, HCP's and LCP's have similar absorption peaks, but are shifted to read at different wavelengths. Both minerals show the presence of two distinct absorption peaks centered near 1 and $2 \mu\text{m}$, where the band centers shift toward longer wavelengths with increasing calcium content. Because of this shift, the band centers for LCPs are at 0.9 and $1.8 \mu\text{m}$, while the band centers for HCPs are at 1.05 and $2.3 \mu\text{m}$ (4). The spectrum is shown in figure 1.

Nontronite is a mafic to ultra-mafic mineral of the clay group (5). These deposits are often found at the front of lava flows, volcanic vents, and other hydrothermally altered areas, such as mid-ocean ridges. Nontronite is a weathering product of basalts and other mafic to ultra-mafic minerals. OMEGA detects this mineral at $2.28 \mu\text{m}$ and shows absorption at 1.42 , 1.93 , 2.29 , and $2.4 \mu\text{m}$ (6) (see Figure 1).

Gypsum is a very common sulfate. The absorption spectrum for gypsum powder matches signals seen using OMEGA. Absorption features for gypsum are seen at 1.445 , 1.535 , 2.22 , 2.26 , and $2.42 \mu\text{m}$ (7), as seen in Figure 1. With the description of the absorption features of each of the minerals, the abundance of each mineral can be detected for further analysis.

Previous work with this data set shows that OMEGA can discriminate between HCP's and LCP's (6). Calcium levels in the surface minerals can be used as a way to determine the temperature in the geological systems that formed the Martian surface. High-calcium pyroxenes can only form in an environment where calcium is abundant, and will indicate hotter geological processes, such as volcanic activity and impact crater formation. Evaluating craters and the surrounding areas will show if there is any difference in the levels of HCP's between hemispheres, and may provide additional information about the mechanism that caused the relatively young surface in the northern hemisphere.

The Martian surface has two distinctive areas separated by the dichotomy boundary. The northern region is covered with lowland plains and the southern region is cratered highlands. The reason for the distinctive difference in the two regions of Mars is, as of yet, unknown. The current theories point to a huge impact crater, and tectonics and erosion (9).

According to one theory a massive impact occurred on the Martian surface. This impact caused huge volumes of basaltic magma to erupt and fill

the crater (10). This impact and the resulting magma lead to a resurfacing of the planet.

Another theory says the northern lowland area may have formed through plate tectonics. In this theory, the plains were thought to be the floor of a giant ocean. The magnetic stripes found in the southern hemisphere support the plate tectonic theory (10). If this is true the northern lowlands could have been formed through a series subduction events (9).

To find more conclusive evidence as to the origin of the Martian surface and the dichotomous boundary, mineral evidence will have to be thoroughly studied.

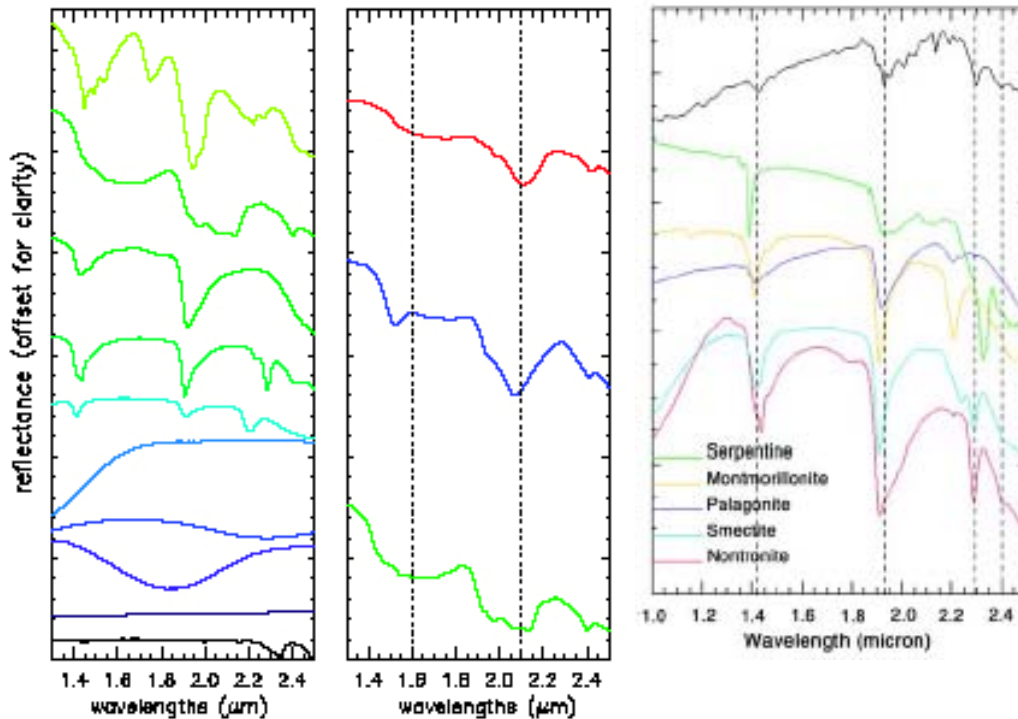


Figure 1: (far left) 3rd spectra from bottom is a high calcium pyroxene, 4th from bottom is the spectra for low calcium pyroxenes, 5th from the bottom is olivine, and 7th from bottom (4th from top) is the nontronite spectrum, top is the gypsum spectra (8); (far right) more detailed spectra of nontronite (6).

Study Area and Data Used

The data that used was acquired using the OMEGA instrument on the Mars Express satellite. The data used was from 5 satellites images.

OMEGA collects data over three channels, a visible band channel that collects spectra from 0.32 to 1.1 microns and two infrared channels that collects spectra from 1.0 to 5.2 microns. The spectra are collected with 352 contiguous bands (11). The visible channel works in a pushbroom mode. The field of view for the sensor is 8.8 degrees, but the instantaneous field of view is between 350 m and 10 km depending on the altitude of Mars Express. The infrared channels are a whiskbroom (1). The inclination of OMEGA is 86° (11).

The surfaces of the northern and southern regions of Mars are visually very different from each other. The dichotomy boundary of the planet runs through the northern hemisphere. The entire southern hemisphere and a small portion of the northern hemisphere of Mars are highlands and heavily cratered. The remaining part of the northern hemisphere has a lower elevation and few craters. The differences in the two regions caused samples to be taken from both of the two regions to see if there is a mineral composition difference in the craters of the north versus the craters of the south.

The data that was used for this study included five satellite images, numbered 171_3, 314_3, 329_4, 329_5, and 469_2. Between these satellite images eighteen craters were isolated to test. From image 469_2, in the southern highlands, six impact craters were tested. (This satellite image was much larger than the other images and had a large number of large craters for analysis.) From each of the remaining four images, three impact craters were analyzed. Images 171_1, 329_4, and 329_5 all cover the less cratered northern lowland area, nine craters were analyzed from this area. Images 314_3 and 469_2 cover the southern highland area of Mars, nine craters were analyzed from this region. (See Figure 2.)

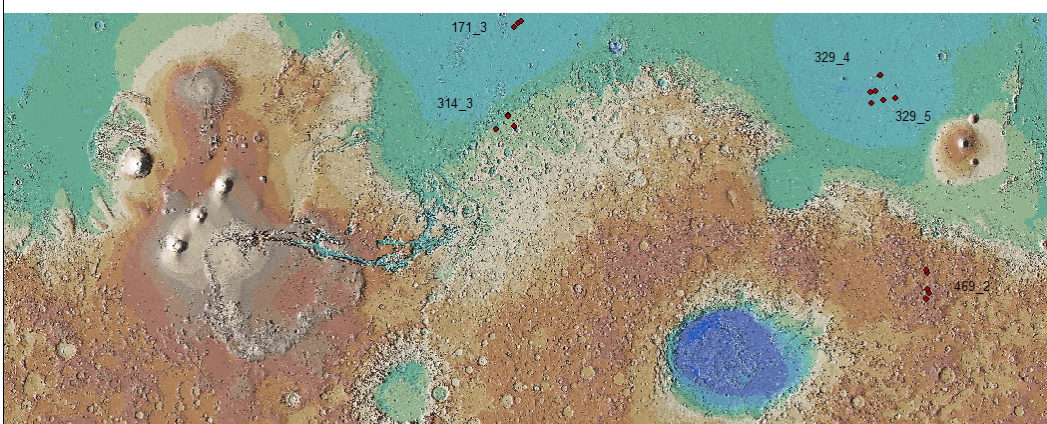


Figure 2: Mars surface showing the locations of the 18 impact craters analyzed for mineral content.

Methods

The first step utilized in analyzing the data was to set up a geographic information system map (GIS Map). In this map of Mars the potential satellite imagery was overlaid onto a topographic map using ArcMap 9. This process allowed the easy identification of impact craters versus other circular features. After choosing indentions, the craters were located on the satellite images using latitude and longitude coordinates. The craters tested were marked on the GISMap, as well as the satellite image locations.

The next part of the analysis process was to prepare the images for use in ENVI. Images from the OMEGA sensor were not initially compatible with ENVI software, and had to be processed for analysis to be possible. An IDL program was used to correct the chosen files for atmospheric interference and convert the data to radiance values. The IDL program also converted the files to a format that

could be opened with ENVI software. All 352 bands from the OMEGA sensor were translated into the ENVI compatible file, but since this project only called spectral analysis of the visible and near infrared wavelengths, the bands from 2.6 to 5.0 μm could be trimmed. The files were thus made as ENVI Standard files with only the visible and near infrared wavelengths intact. New header files were edited to include the wavelengths of the existing bands.

Processing of each of the ENVI Standard files began by linking it to its corresponding latitude, longitude, and altitude files. The cursor location feature could then be utilized to identify and classify each feature studied by its location and relative height. The z-axis profile was then enabled in order to review the absorption patterns of each pixel. The presence of each mineral was recorded as measurement location, inside or outside the crater, and hemisphere, northern or southern, that the crater resides in.

Determination of the spectra was done using the z-axis profile and known Martian spectra for the minerals gypsum, nontronite, and olivine. Analysis was performed pixel to pixel in the craters and around them. The analysis was performed by visually inspecting the resulting mineral spectra and comparing them to known spectrums. The known absorption features and the general shape characteristics of each mineral were compared to the unknown spectra.

For most images, three craters were chosen for spectral analysis. (Six craters were chosen for orbit 469_2, due to its large area and number of craters present.)

Results / Discussion

Gypsum, nontronite, and olivine were positively identified by the position of absorption peaks particular to their presence, as seen in Figure 3. A spectral pattern that could not be identified appeared when analyzing some of the pixels in the craters, and was determined to potentially be an unidentified mineral. That mineral will herein be referred to as mineral X.

In all of the spectra measured there was a noise peak that resulted from the atmospheric correction. This peak is seen in Figure 4.

Gypsum was detected in all measurements, regardless of location or hemisphere that the measurements were taken. Since no HCPs or LCPs were identified, they were not included in the statistical analysis. The remaining data were analyzed using ANOVA statistical techniques to see if there was any significant difference between measurements taken inside or outside the crater, and if there was any significant difference between craters from the Northern and Southern hemispheres. P-values were compared to a 0.05 significance level.

Results of the ANOVA analysis are shown in Table 1 below. The analysis showed there was no significant difference in olivine presence either in measurement location or in the hemisphere in which the crater resided. The presence of nontronite location was significant as well as the hemisphere. Further review of the data showed nontronite was detected preferentially outside the craters in the Northern Hemisphere, but was present both inside and outside of the craters in the Southern Hemisphere. The detection of an unknown compound or effect, referred to as mineral X, was seen to show significance in

location, but not in preferring one hemisphere. All data for mineral X was detected inside study craters, with no occurrences detected outside.

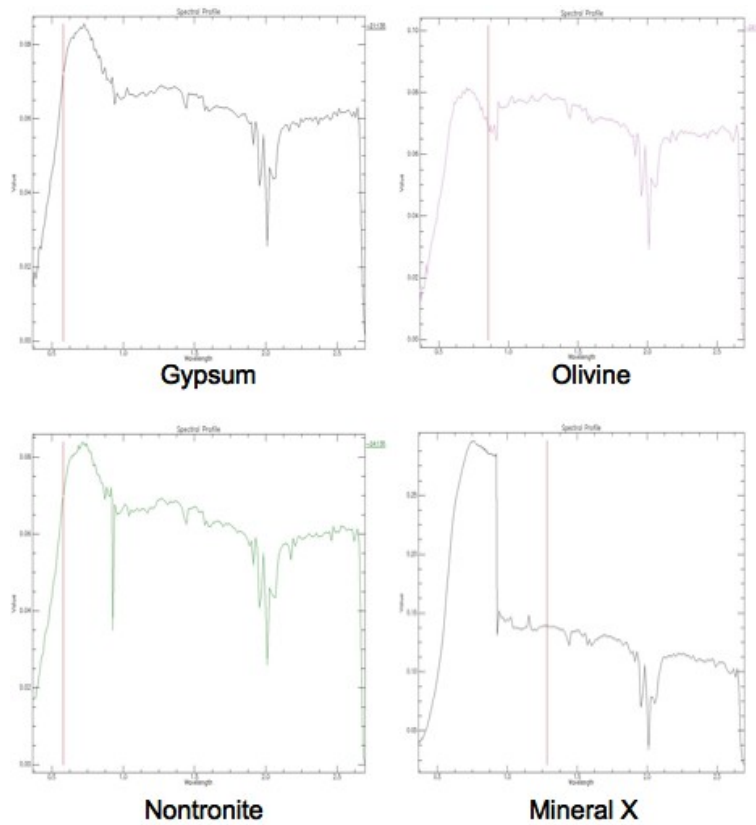


Figure 3 – Examples of spectra collected for gypsum, olivine, nontronite, and mineral x using ENVI software.

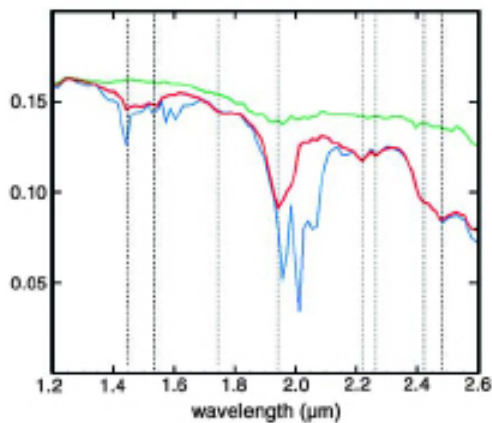


Figure 4- The blue line is the spectra residue resulting from the atmospheric correction (10).

Table 1 – Results of ANOVA analysis of mineral detection. Note that the significance in detecting a difference between groups is only seen in nontronite location, nontronite hemisphere, and mineral X location. ($\alpha = 0.05$)

Mineral	Variable	P-value
Olivine	Hemisphere	0.7654
Olivine	Location	0.4875
Nontronite	Hemisphere	<0.0001
Nontronite	Location	0.0076
Mineral X	Hemisphere	0.5205
Mineral X	Location	0.0003

Summary / Conclusion

The analysis performed on this data gave an overview of some of the minerals on the surface of Mars, but was difficult to interpret. HCPs and LCPs were not detectable by the method used because of the difficulty in reading the mineral spectra.

The statistical analysis of the minerals detected concluded olivine and gypsum do not show any pattern in location. In fact, gypsum was detected inside and outside of all study craters. Only mineral X and nontronite showed any preference for detection by location, with mineral X being detected only inside study craters, and nontronite being detected only outside the craters in the Northern hemisphere. The results from this analysis do not give any clues to the cause of the terrain in the Northern hemisphere, and make it difficult to conclude anything new about the dichotomy formation.

This project leaves many avenues open for future research. Using a spectral library and subtraction of the spectra would make it easier to interpret the minerals that are present in each location. This method may also be useful in helping to identify mineral X.

Acknowledgements

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