Spectroscopic Reflectance In Theophilus Crater

Boulder Fields, Regolith Covered Rocks, or Shocked Rock?

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Research Problem

Data from M³ can be analyzed and mapped to reveal a unique distribution of mineral diagnostic absorptions at the 1, 1.25, and 2 micron wavelengths in the vicinity of Theophilus Crater.

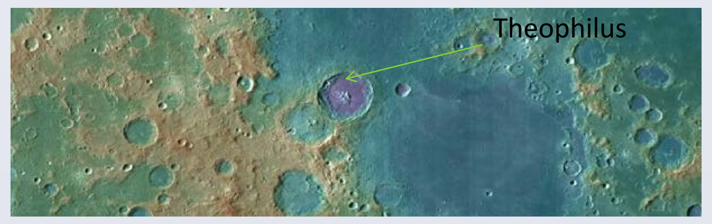
What do these reflectance patterns mean in terms of geologic features? Are they associated with bedrock outcrops, ejecta rocks, crater rims, or well-developed soil?

Can the patterns of spectroscopic absorption observed in Theophilus Crater be linked to a pattern of observed ground features: especially boulders, boulder fields, and fresh rock?

Only since the launch of the Lunar Reconnaissance Orbiter in 2009 has it been possible to research a question requiring numerous high resolution meter-scale images of large areas of the lunar surface which also contain precision location data. The readily accessible LROC Narrow Angle Camera does just that.

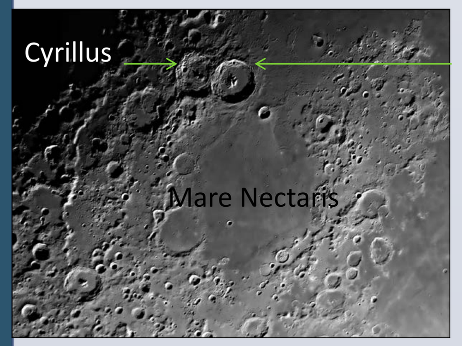
Can a systematic search of the NAC highest resolution images be used to establish the source of the observed reflectance patterns at Theophilus?

Area of Study : Theophilus Crater

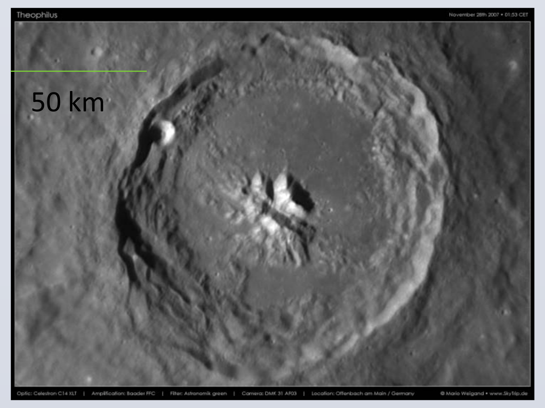


Near Side of Moon showing Theophilus region

Theophilus is a large complex crater nestled on the east side of the Nectaris Basin. The crater has a set of central peaks rising about 1500 meters , a smooth crater floor due to filling with its own impact melt and is surrounded on the inside by faulted and slipped terraces. (NASA Apollo Archive). Theophilus is 100 to 110 km across and 3-4 km (14,000 ft) deep. Due to this crater's large size and implied huge impact energies, ejecta was spread over the surrounding surface of the moon, hundreds possibly even thousands of kilometers away. Samples of ejecta from Theophilus were collected at the Apollo 11 & 16 landing sites , both about 300 km away. Theophilus is considered young by lunar standards. Its location on top of Nectaris Basin deposits and the neighboring Cyrillus crater signals its relative youth, about 1-3 billion years ago. Its young age implies less ejecta cover from neighboring impacts.

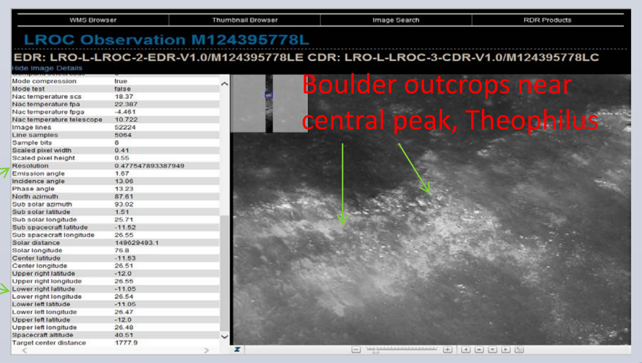


Theophilus Crater on north edge of Mare Nectaris



Methods

- One outcome of this study was to develop a method to employ many student observers to examine the numerous LROC NAC images available for our study area.
- 25 students examined over 100 LROC NAC strips in the Theophilus region searching for specific features: fields of broken rock, isolated boulder piles, areas without any boulders, ejecta blanket layers on boulders, rolling boulders, and areas of high and low visual reflectance.
- The student observations were reviewed and linked to specific longitude and latitude locations which were then mapped in conjunction with the spectral absorption data.



Example of LROC image used in this study showing data side panel which provides scale and locational data

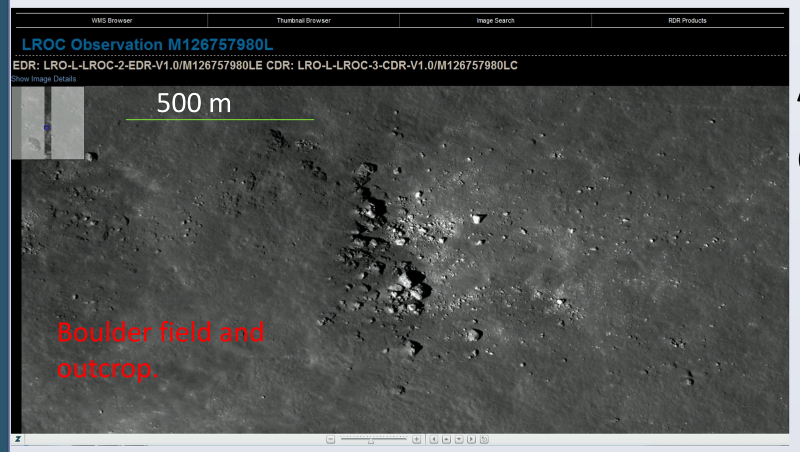
Summary of Research

The reflectance of light from the lunar surface can be interpreted to indicate the presence of specific mineral types. Data from the Moon Mineralogy Mapper (M³) can be used to show the spatial distribution of infrared absorption at specific, diagnostic wavelengths. Strong absorption is seen at the 1, 1.25, and 2 micron wavelengths and is presumed to be generated by rocks containing plagioclase, pyroxene, spinel, and olivine.

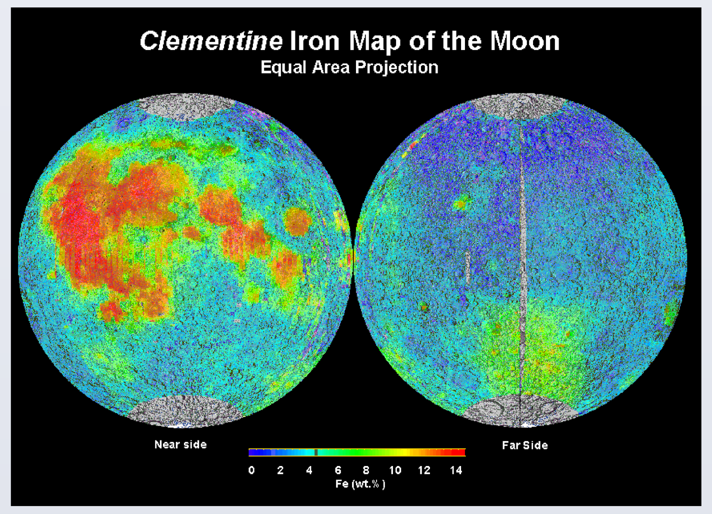
What exact surface features are absorbing and reflecting light at these wavelengths? Imagery from the Lunar Reconnaissance Orbiter Camera (LROC) is of sufficient resolution to show the ground features that might be the source of the observed absorption. Surveying approximately 100 LROC Narrow Angle Camera (NAC) images from the central and north part of Theophilus crater for clear exposures of rocks revealed numerous apparent "bedrock" outcrops, scattered boulders, fields of boulders, buried boulders, fresh craters, and areas of bright reflective material. The spatial distribution of most of these features **do not** correlate with the spatial distribution of the M³ absorption data. Some individual outcrops or boulder fields are seen in areas of M³ 1, 1.25, and 2 micron absorption, but numerous surface features showing apparent "bare" or "fresh" rock surfaces occur outside the M³ maps of diagnostic mineral absorptions.

We conclude that the rocky materials observed in the LROC images either: (1) experience shock metamorphism during the impact of Theophilus and surrounding more recent craters and/or (2) that much of the rock in and around Theophilus is covered with a veneer of ejecta dust and/or regolith, blocking its true reflectance properties. Close examination of many of the surface boulders do show apparent "bare" or "fresh" rock, suggesting that the distribution plotted of our observational data is, in part, a distribution of shocked materials

Further work will need to be done assessing the amount of ejecta debris and/or regolith on lunar boulders in this and other locations and determining if the high resolution LROC imagery is sufficient to identify thin veneers of ejecta that could alter or block its reflectance properties.



Are these features creating the observed reflectance patterns?



Clementine Iron Map of the Moon: using reflectance to establish mineral distributions

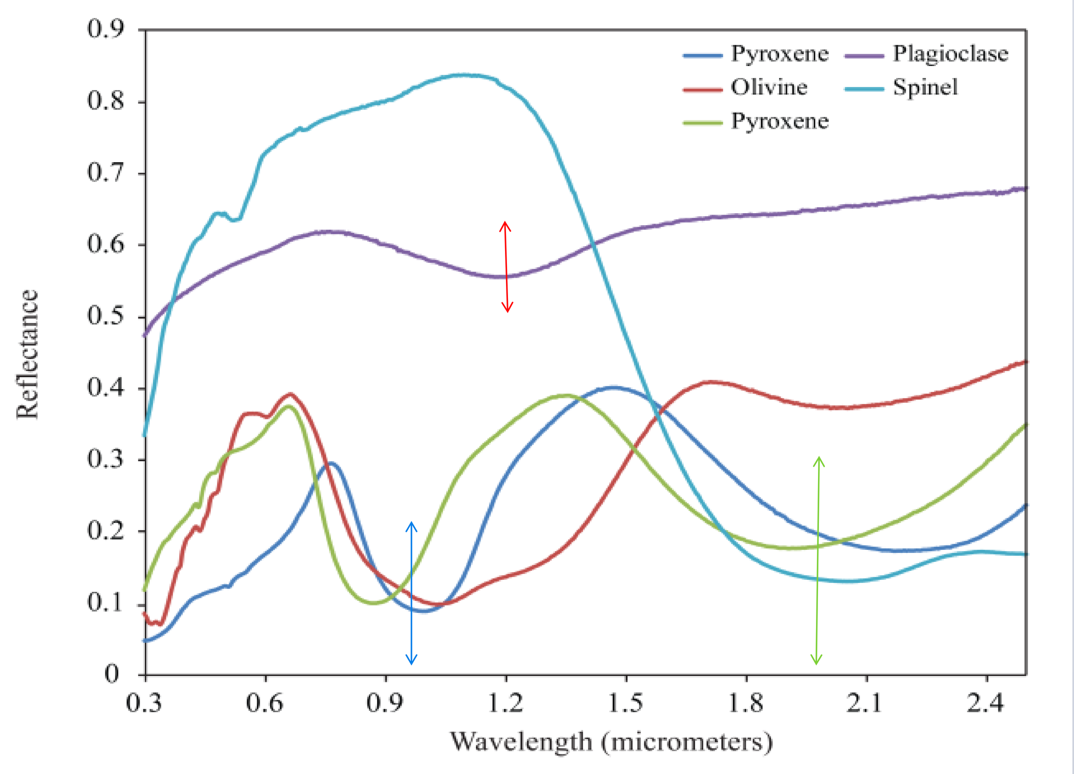
Reflectance

It is well known from Earth and space observations that the Moon's surface, in fact any surface, reflects light differentially. Lunar rocks, like many Earth rocks absorb certain wavelengths well, and readily reflects others. This method of lunar study came into its own in the 1990s with the results of the Clementine satellite showing clearly that the nearside mare lava surfaces contain more iron than the surrounding highlands. The spectral resolution of these data put limitations on their use. Since then the Moon Mineralogy Mapper (M³) has generated higher spatial and spectral resolution data. These new data allow for spectral parameter maps, used to highlight areas rich in specific Fe-bearing minerals, to be made. Maps of 1, 1.25, and 2 micron integrated band depths were provided by Kerri Donaldson Hanna, Brown University and used to correlate to our observations of rocky materials.

Reflectance is especially unique in the visible- to near-infrared region and has been studied with great precision in laboratory settings. As seen in Graph 1, laboratory reflectance spectra show definite absorptions near 1 and 2 microns for pyroxene, olivine, and spinel and at 1.25 microns for plagioclase. These diagnostic absorptions should be capable of revealing the exact nature and distribution of surface materials on the Moon. Using the high resolution imagery from LROC it should be possible to identify the sources of the observed reflectance patterns.

It is possible that the reflectance alone will not link specifically to exact lunar features (boulder fields, outcrops, crater sides) due to the presence of regolith and/or fine ejecta material covering most objects and/or the presence of shocked rock. Neither would have the diagnostic absorption patterns of Graph1.

Graph 1 showing 1, 1.25, 2 micron absorption



Source: NASA RELAB (Brown Univ.)

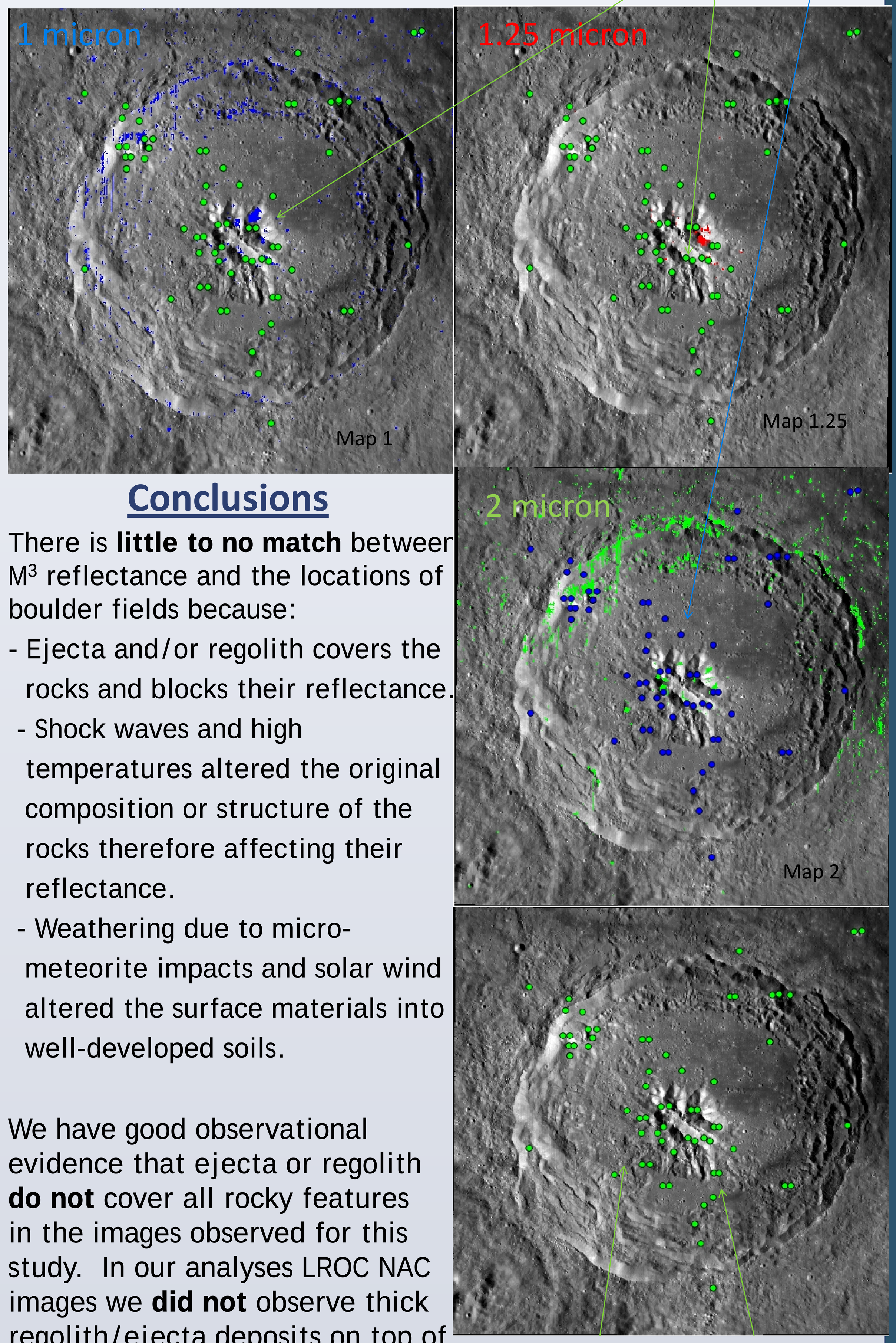
Results

The spatial distribution of the M³ diagnostic mineral absorptions are mapped against the observed locations of rocky outcrops and boulder fields showing <u>very little association</u> between any of the diagnostic absorptions and rocks on the ground.

Maps of rocks vs. reflection

1,1.25, 2 micron Absorption

Boulders = green or blue



Possible distribution of shocked rocks in Theophilus

Conclusions

There is **little to no match** between M³ reflectance and the locations of boulder fields because:

- Ejecta and/or regolith covers the rocks and blocks their reflectance.
- Shock waves and high temperatures altered the original composition or structure of the rocks therefore affecting their reflectance.
- Weathering due to micro-meteorite impacts and solar wind altered the surface materials into well-developed soils.

We have good observational evidence that ejecta or regolith **do not** cover all rocky features in the images observed for this study. In our analyses LROC NAC images we **did not** observe thick regolith/ejecta deposits on top of all rocky materials.

The likely conclusion is that the distributions of these features are **shocked materials** from the intense impact energies of Theophilus and nearby craters.

Seacrest School Moon Team, April 2013,jfuller@seacrest.org

References

Numerous detailed and informative personal communications from our mentor: **Kerri Davidson Hanna**, Geology Department, Brown University. Thanks Kerri!

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