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Assessment of spectral properties of Apollo 12 landing site

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ABSTRACT

The geology and mineralogy of the Apollo 12 landing site has been the subject of recent studies that this research attempts to complement from a remote sensing point of view using the Moon Mineralogy Mapper (M^3) sensor data, onboard the Chandrayaan-1 lunar orbiter. It is a higher spatial-spectral resolution sensor than the Clementine UVVis sensor and gives the opportunity to study the lunar surface with a comparatively more detailed spectral resolution. We used ISIS and GRASS GIS to study the M^3 data.

The M^3 signatures are showing a monotonic featureless increment, with very low reflectance, suggesting a mature regolith. The regolith maturity is splitting the landing site in a younger Northwest and older Southeast. The mineral identification using the lunar sample spectra from within the Relab database found some similarity to a basaltic rock/glass mix. The spectrum features of clinopyroxene have been found in the Copernican rays and at the landing site. Lateral mixing increases FeO content away from the central part of the ray. The presence of clinopyroxene in the pigeonite basalt in the stratigraphy of the landing site brings forth some complexity in differentiating the Copernican ray's clinopyroxene from the local source, as the spectra are twins but for their vertical shift in reflectance, reducing away from the central part of the ray.

Spatial variations in mineralogy were not found mostly because of the pixel size compared to the landing site area. The contribution to stratigraphy is limited to the topmost layer which is a clinopyroxene-dominated basalt belonging to the most remote tip of a Copernican ray and its resulting local regolith mix.

Keywords: Apollo12, Moon, Chandrayaan-1, Hyperspectral, remote sensing, clino-pyroxene, Copernicus, ejecta, GRASS GIS, ISIS

BACKGROUND

This research's focus is the landing site of Apollo 12, with standard geographical coordinates of 03^o 12'S, 23^o 23'W. In planetary coordinates, these coordinates translate into 03^o 12'S, 336^o 37E (3.2S,336.62E). The region surrounding the landing site is best described by its four oversized landmarks, Mare Cognitum in the South, Fra Mauro formation (including the Apollo 14 landing

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site) in the East, Oceanus Procellarum in the West-Northwest, and finally the superlative Copernicus crater in the North.

The Lunar Geologic GIS Renovation 2013 (astrogeology.usgs.gov) completed the digital renovation of the 1:5,000,000 lunar geological maps series, enhanced with Lunar Orbiter Laser Altimeter - Lunar Reconnaissance Orbiter (LOLA-LRO) information in March 2013 (Fortezzo and Hare, 2013). In this classification, Apollo 12 landing site sits in an Erastothenian system with an age ranging from 1.1 to 3.2 Ga.

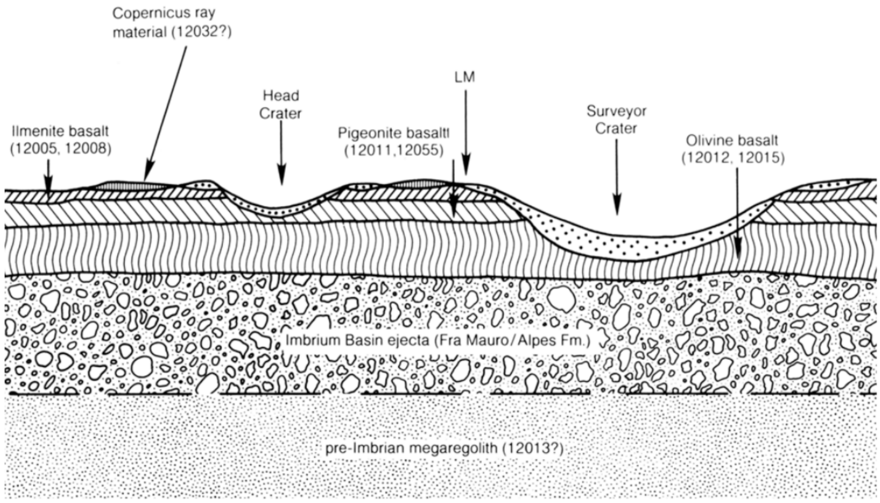

Figure 1. Apollo 12 Landing site cross-section (Harland, 2008)

Looking further into the Apollo 12 landing site, Harland (2008) summarised the earlier work of both Rhodes (1977) and Wilhelms (1984) in Figure 1. Korotev et al. (2011) reviewed the lunar research done until recently, with a special interest in the Apollo 12 landing site and its vicinity (Figure 2).

Among the information newly deducted, are a geological context of Apollo 12 landing site interpretive cross-section (Snape et al., 2014) also provide an interpretive cross-section of the landing site in Figure 3.

Clearly, Snape et al. (2014) are listing three potential basalt types: olivine, pigeonite and ilmenite, from older to younger, in close proximity to the Lunar Module. They also imply in Figure 3 that the Middle Crescent crater's bottom is reaching the olivine basalt, the Surveyor crater's bottom is reaching the pigeonite basalt and that the Head crater's bottom is made of ilmenite basalt. These three types of locations corresponding to three types of basalt are going to be extracted from Chandrayaan-1 Moon Mineralogy Mapper (M^3) and spectral analysis will try to contribute to their work. Additional information about the Copernicus ray material layer appearing in Figure 2 will also be investigated by the same imagery.

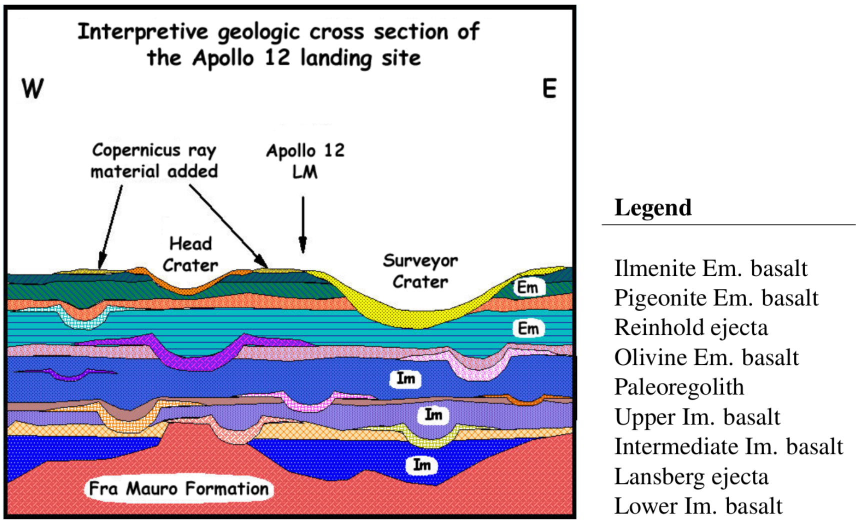

Figure 2. Geological cross-section at Apollo 12 Landing Site (Korotev et al., 2011)

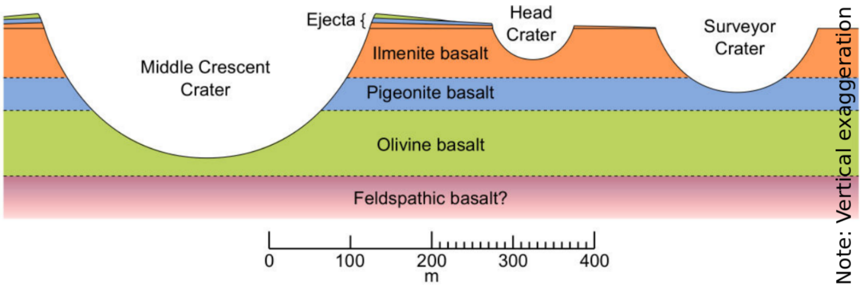

Figure 3. Apollo 12 Landing site mineralogical cross-section (Snape et al., 2014)

CHANDRAYAAN-1 M^3 IMPORT IN GRASS GIS

Chandrayaan M^3 tile M3G20090111T013904 V01 RFL.IMG was downloaded from PDS [pds-imaging.jpl.nasa.gov] and imported in GRASS GIS, resulting in 85 bands. The M^3 data strip M3G20090111T013904 V01 RFL from the PDS archive was inputted to ISIS-GRASS (Frigeri et al., 2011) and converted into a multi-band binary file following the ENVI format. The M^3 bands number 1 and 2 where empty, thus generating a problem in the analysis by introducing a bias, they were removed prior to use, resulting in an hyperspectral cube with 83 bands.

The official lunar nomenclature has given a total of 9 named locations pertaining to the Apollo 12 human exploration. This study has removed one (Snowman) as it is within the same M^3 pixel (150x150m) as another crater: Surveyor. The spectral signal found a consistent difference across the M^3 channels for two groups, the first one consisting of Head,Surveyor, Bench & Halo, with a small difference of reflectance on the lower side (Figure 4).

ANALYSIS AND RESULTS

By performing a standard object-oriented classification (Momsen and Metz, 2012) of the M^3 image cube (Figure 5) one can find natural boundaries in the form of a map. Two main geographical areas are found, green and yellow. Three minor areas are also found, blue, red and grey (below the wind rose). The red area might be related to an old crater now barely visible.

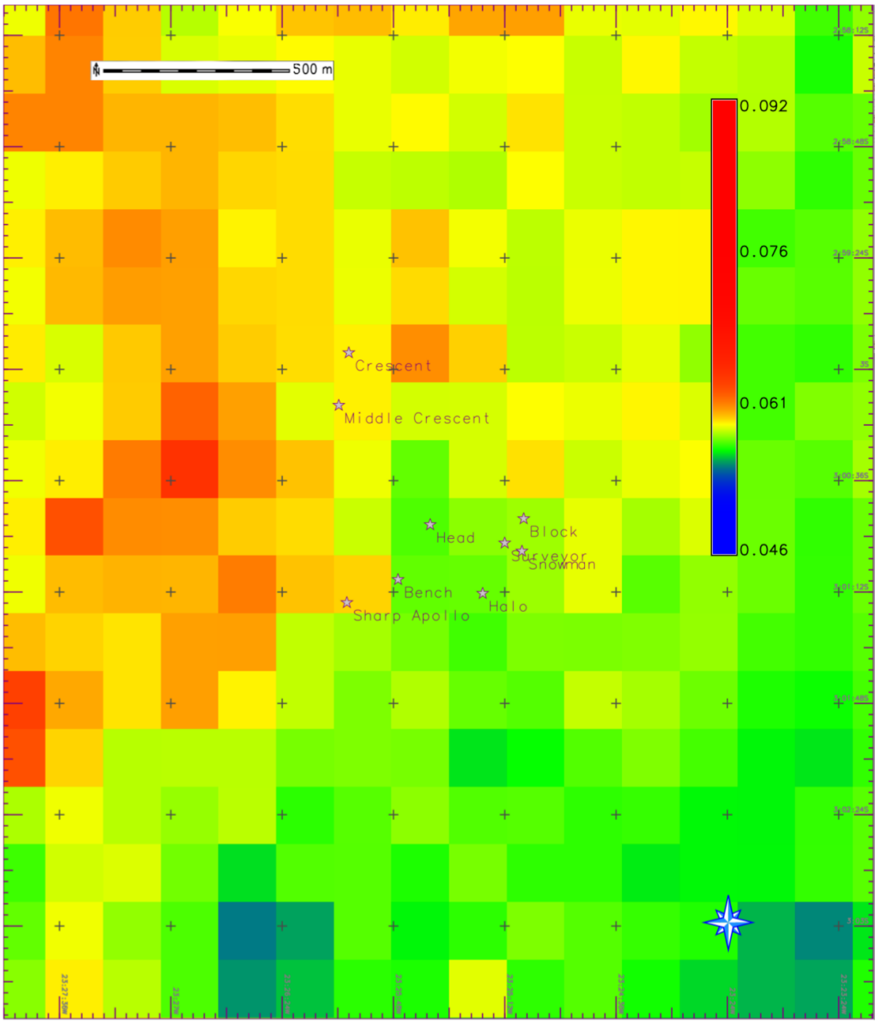

Figure 4. Crater location map (M^3 band 19, reflectance @ 950nm)

Though the spectra are similar in shape, they show a subtle difference. This small change delineates two spectra groups. In turn, this generates a division of the A12 site with a boundary from NNE to SSW. The change in the reflectance is not much, and if it could be attributed to "maturation" of the regolith by the combined effects of "space weather & gardening", then this would depict two age groups of the regolith. The northwest zone (green colour) would then have a comparatively higher reflectance and could then be given a "younger" age compared to the southeast area (yellow colour). This is is most probably related to the Copernicus ray, known to cross the landing site.

After closely and individually looking at all the Apollo 12 signatures from the Relab database, only very few exhibit a close shape from the signatures from M^3. This set of signatures comes from a rock/glass mix belonging to LRS 12063 [Warner, 1971], specific sub-sample codes are: "12063,79IS" "12063,79MV" "12063,79NT". The most similarity in shape is found in "12063,79NT" where the proportion of glass is higher than the proportion of rock (47% rock, 53% glass). If we extrapolate this observation while keeping in mind the reduction of reflectance with glass percentage increase, we could think of a glass percentage of about 60-65%.

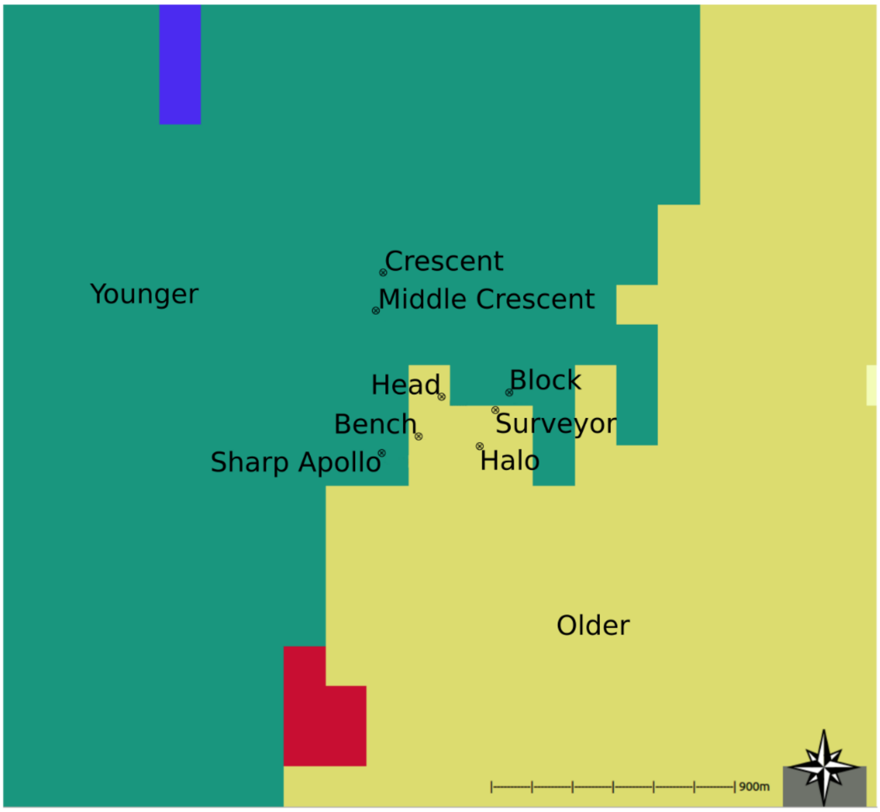

Figure 5. M^3 image segmentation in close proximity of the landing site

However the absorption feature at 1000nm and the reflection feature at 750nm are still there, maybe adding ilmenite will lower the reflectance. An additional question would be if the space weathering actually reduces the features and linearise spectra. In that case we could postulate that the study area is covered by an old glass/basalt mix, given the constraint of the viewing resolution of M3 (about 22,500 m^2). In the perspective to compare Relab class 309 (47% Rock, 57% Glass) with one of the M^3 pixels (in this case IntrepidSurveyor), a detrending procedure should be done. Initially, a linear regression is done for both spectra. Eventually, the distance to the trendline is computed as shown in Figure 6. It can be observed that there is a common "peak" at 770nm, a common absorption at 1000nm and a common "mixed positive" zone in the 1100-1700nm range.

Regarding the absorption area in the range of 1800 to about 2300+ nm, it is hard to say if any commonality is found. The M^3 broad absorption feature centered in 2200nm seem to be similar to

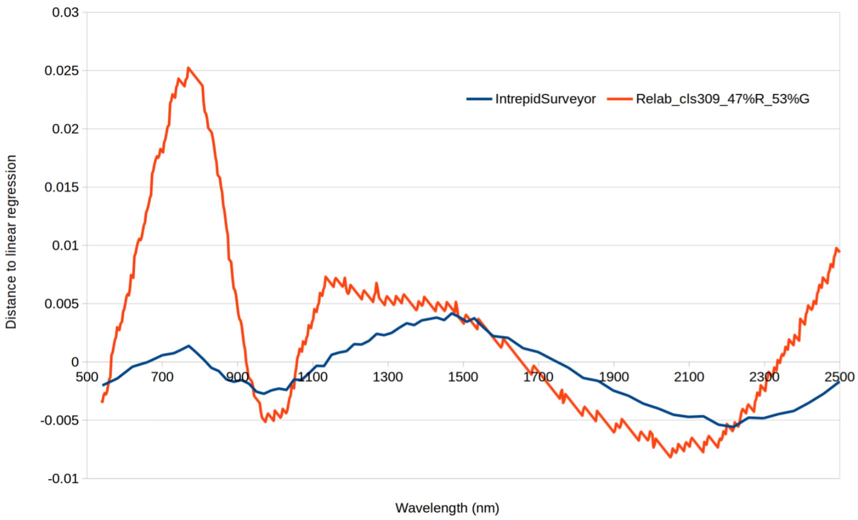

Figure 6. M^3 detrended comparison to Relab class 309 (Lunar Sample 12063,79NT)

the clinopyroxene.

A last attempt was made by spectral angle mapping (Kruse et al., 1993) and unmixing (Neteler, 1999), which is highly dependent on exhaustive signatures, a weakness in this case for the A12 spectra as expanded earlier in the difference in observed matured regolith from the M3 signal compared with the Relab class 309. Even using all the A12 spectra from the lunar samples, the mapping was uncertain. Unmixing attempts brought another level of difficulty, where Relab signals were nearly all correlated to many others linearly, thus requiring to do a set of pre-selection of the most representative end-members in the A12 Relab database, which was not done. Adding to this, the fact that unmixing requires an optimisation system to converge spectra to M3 ones. This was found not to converge due to confusion in spectra possibilities due to co-linearity in between many of them.

CONCLUSIONS

Analysis found the presence of clinopyroxene in the spectral information at the A12 landing site, suggesting a clinopyroxene-dominated basalt, e.g. pigeonite-rich basalt. There is an increasing wt%Feo from the central Copernican ray towards the Southeastern direction, suggesting a lateral mixing rate away from the Copernican ray. The observations enhance previous information about local layers of Ilmenite and and pigeonite-rich basalts. It is probable that the presence of clinopyroxene-dominated basalt, not only is found all across the Copernican ejecta blanket, but also in the Apollo 12 site pigeonite layer. Within the Copernican ray, less wt%FeO brings about clinopyroxene that maybe in pigeonite/augite with trends towards (En)Diopside composition. Going away from the Copernican ray, the clinopyroxene content maybe in pigeonite/augite with trends towards Hedenbergite composition. Alongside the increase of wt%Feo there is a reduction in the mean reflectance of the spectra, yet their curves are parallel (identical signal) suggesting a gradual lateral mixing across the Mid-Crescent, Head and Surveyor craters, not showing any mineralogical layers difference as expected in earlier work. At the most it shows a potential difference of maturity/age of the regolith across the site.

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