A MULTISPECTRAL VIEW OF STRATIGRAPHY IN MARE TRANQUILLITATIS

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Introduction: During its two months of lunar mapping in the spring of 1994, the Clementine spacecraft's ultraviolet-visible (UV/VIS) camera acquired high-spatial resolution digital images of the lunar surface in five spectral channels. Clementine data of the Mare Tranquillitatis region have been studied within the context of lower resolution Galileo multispectral data obtained during its second lunar flyby in 1992. Together these data sets provide insight into the stratigraphy of mare units, lateral and vertical mixing processes within the mare, and the underlying structure of the basin.

Background: Mare Tranquillitatis contains some of the spectrally bluest and lowest albedo basalts on the Moon [1]. Previous telescopic studies have estimated that the soils of western Tranquillitatis contain the highest lunar abundances of titanium [2,3]. These telescopic studies are based on an application of the empirical relation between the slope of the extended visible spectrum (UV/VIS ratio) and weight percent TiO2 [1,4]. Such UV/VIS maps of soil titanium content suggest the presence of at least two compositionally distinct mare flow units within the basin [3]. However, in many areas of the basin, the spectral properties of these mare soils may have been altered by impact mixing processes [5]. As a result, it is necessary to separate basaltic units from laterally and vertically mixed non-mare materials to stratigraphically map distinct compositional units. Since excavation depth is related to crater diameter, identification of vertically mixed materials provides information on the thickness of mare units and the depth of the sub-mare topography.

Galileo EM2 analysis: A linear spectral mixing analysis was performed on six channels of a Galileo image sequence of the basin in order to identify and map distinct spectral components (for details refer to Staid et al., 1994) [5]. At least two distinct mare flow types are identified, higher titanium flows are most abundant in the central western portion of the basin and lower titanium rich flows dominate the north-eastern and south-eastern portion of Tranquillitatis. Comparison of the distribution of mare units with crater count data and large scale topography suggest that the bluer, more titanium rich flows overly the older lower titanium units [3,5]. Lateral mixing from adjacent highland and vertical impact gardening of the mare result in the large amount of spectral heterogeneity within this basin. Vertical excavation of sub-mare feldspathic materials observed at the crater Arago (26 km) and lack of similar excavation at Ross (25 km) has important implications for basalt thicknesses in the western portion of the basin [5].

Clementine UV/VIS data: High resolution Clementine multispectral data are being analyzed to confirm stratigraphic relationships for key areas within the Galileo analysis. With this data thin veneers of laterally mixed rays and ejecta blankets can be identified by the presence of small spectrally distinct or dark haloed craters. Clementine imagery from orbit 160 over the Lamont structure is consistent with telescopic data identifying regionally low levels of titanium within and surrounding the crater Arago [3]. A subsequent small impact crater in Arago's ejecta blanket exhibits a distinct dark halo that spectrally matches adjacent titanium rich units (figure 1). This example confirms the stratigraphic relation of younger titanium rich flows overlying older lower titanium units within the Lamont region. Analysis of high albedo floor hummocks within the crater Arago are consistent with a vertically excavated feldspathic component predicted in the Galileo spectral analysis [5]. Another site studied with the Clementine data is the Dawes crater (18 km) near the northern Tranquillitatis-Serenitatis border. Lower UV/VIS ratio values for the interior of the crater and in the western ejecta blanket is most likely the result of excavation of the lower titanium unit from below the younger titanium rich unit. A band of spectrally bluer and lower albedo materials along the interior crater wall below the western rim may result from the exposure and talus wasting of the high titanium basalt layer beneath the lower titanium ejecta blanket (figure 2). This asymmetric pattern of the ejecta as seen in the UV/VIS ratio of this crater supports the hypothesis that Dawes resulted from an east to west oblique impact [3]. Alternate explanations would require unusually heterogeneous target stratigraphy. The Galileo mixing results are consistent with previous work indicating that no significant highland component has been excavated by this crater [6].

Discussion: Analysis of high resolution Clementine imagery provides concrete examples of apparent stratigraphic relationships observed in Galileo and telescopic studies [5,3]. Though the distribution of these two compositionally distinct mare units is highly correlated with previous UV/VIS ratio images, lower soil titanium contents in some areas result from the mixing of high titanium basalts with feldspathic materials. This process is particularly relevant in the south-western portion of the basin where telescopic UV/VIS data
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suggest a gradational zone between higher and lower titanium mare units [3]. These spectral analyses indicate that the Apollo 11 site lies within the youngest and most titanium rich mare unit where soils have been contaminated by feldspathic mixing, consistent with the observation that the Apollo samples contain a large non-mare component [7,8]. This mixing appears to have occurred laterally from rays of Theophilus (100 km) and perhaps vertically through thin basalts as indicated by feldspathic mixing at Moltke (6 km). Table 1 provides tentative assignments of younger high titanium and older lower titanium spectral units with the Apollo 11 samples [9,10].

The distribution of vertically mixed feldspathic material allows evaluation of the depth of the mare units and the proximity of the underlying basin topography. Vertical mixing relations observed in both sets of multispectral data support an asymmetric basin structure containing thicker basalts in the western portion of the basin and thinner basalts along the central mare ridges and at the eastern edge of the basin. Evidence for thick basalts northwest of the central mare ridges provides an explanation for the lack of flooded crater data in this area as more voluminous basalts may have resulted in complete burial of any features [11]. This asymmetric model for the basin structure is consistent with interpretations of a Procellarum ring through Tranquillitatis but does not exclude other interpretations such as an east west compressional trough through the Lamont region [10, 12]. A west to east topographic rise and a corresponding gravity anomaly apparent in the Clementine Lidar data occurs from west to east at the ridge boundary as well [13]. It is anticipated that further investigations of the data available may clarify whether the Tranquillitatis basin is in fact a basin at all or whether it is part of a larger asymmetric structure associated with early impact and tectonic events.

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Figure 1: 900nm image and 415/750nm ratio for the crater Arago. Note spectrally blue dark halo crater just above the north rim indicating inverted ejecta stratigraphy.

lower Ti ejecta

high Ti slumping

high Ti

west

lower Ti

east

highland basement

Figure 2: 900nm image and 415/750nm ratio for the crater Dawes (left) and proposed crater stratigraphy (above).

<table>
<thead>
<tr>
<th>Event</th>
<th>Event Age (Ga)</th>
<th>~TiO2 wt %</th>
<th>% mare smpls</th>
<th>Spectral Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.59</td>
<td>11.0</td>
<td>60%</td>
<td>Younger high Ti unit</td>
</tr>
<tr>
<td>B1-&gt;B3</td>
<td>3.67-3.71</td>
<td>10.3</td>
<td>30%</td>
<td>Younger high Ti unit</td>
</tr>
<tr>
<td>B2</td>
<td>3.85</td>
<td>8.6</td>
<td>10%</td>
<td>Older lower Ti unit ?? or laterally mixed material</td>
</tr>
</tbody>
</table>

Table 1: Assignments of Observed spectral units to Apollo 11 samples [9,10].


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