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Integrating Near and Thermal Infrared Data to Search for Lunar Mantle

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Abstract

Lunar missions in the last decade and the advancement of sample analysis techniques have resulted in a wealth of new information about the lunar surface. Integration of data across different subdisciplines is critical for addressing the outstanding science and exploration questions and identifying, as a community, what missions or advances would conclusively answer such questions. Recent studies [e.g., 1, 2], have shown the strength of integrating different remote sensing data sets with one another, or with sample studies. We here focus on a joint analysis using data from the Moon Mineralogy Mapper and the Diviner Lunar Radiometer.

1. Introduction

As an early crystallizing mineral, orthopyroxene provides important clues for understanding the evolution of the lunar surface, from the earliest magma ocean cumulates, through the anorthositic flotation crust, to later stage intrusive magmatism. Using data from the Moon Mineralogy Mapper (M^3) to search for Mg-suite norites, concentrations of low-Ca, high-Mg pyroxene have been characterized around the Imbrium and Apollo Basins [3]. These deposits may be exposures of Mg-suite plutons, may represent excavated material from deeper within the primary lower crust or mantle, or may be remnants of melt sheets (differentiated or undifferentiated). Iron-rich orthopyroxenes have been identified elsewhere, in smaller craters throughout the highlands crust.

The Imbrium basin has been extensively studied for many years [e.g., 4-5]. Though the bulk of the basin is flooded by mare basalts, massifs consisting of more generally feldspathic material surround the edges of Mare Imbrium in the northwest, northeast, and southeast (Fig. 1). Telescopic measurements of Apennine mountains revealed regions spectrally dominated by orthopyroxene or pigeonite [5]. Later radiative transfer modeling of Clementine data suggested that Mg-suite-like norites may surround much of the Imbrium basin [6]. In the initial global survey of norites using M^3 data, the norites modeled to have the highest Mg# were found in the Montes Alpes region near Vallis Alpes [3].

The Imbrium basin is large enough to have excavated between 60-85 km into the Moon [5], deep enough to penetrate through the crust and into the mantle. It is also associated with the strongest thorium detections by Lunar Prospector [7], and is likely to be rich in KREEP [8].

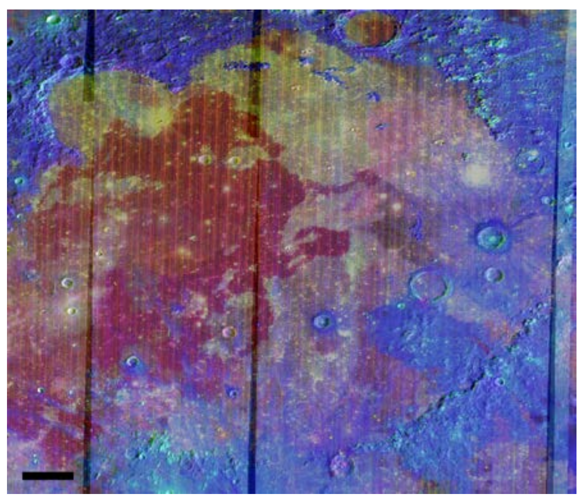

Figure 1: M3 standard color composite (R=integrated 1 μm band depth, G=integrated 2 μm band depth, B=1.58 μm reflectance). Orthopyroxene-rich regions appear as cyan. The highest concentration of Mg-rich orthopyroxene is in the massifs of Montes Alpes (NE corner). The center of Imbrium basin is located at 32.8°N 15.6°W and the scale bar is 100 km across.

2. Searching for Lunar Mantle

The Moon has experienced over a dozen impacts resulting in basins large enough to have excavated mantle material. With many of those basins concentrated on the lunar near side, and extensive regolith mixing since the lunar magma ocean crystallized, one might expect that some mantle material would have been found among the lunar samples on Earth. However, so far, only a small number of candidate mantle samples [e.g. 9] have been identified, and their provenance is still debatable [10].

From orbit, a number of olivine-bearing localities, potentially sourced from the mantle, have been identified around impact basins [11]. Based on analysis of near-infrared (NIR) and imaging data, Ohtake et al. [12] suggest that roughly 60% of these sites represent olivine from the mantle. If this is the case and the blocks are coherent and not extensively mixed into the regolith, these deposits should be ultramafic, containing olivine and/or pyroxenes and little to no plagioclase. In the mid-infrared, they would thus exhibit Christiansen features (CF) at wavelengths in excess of ~8.5 µm, which has not been observed in global studies using Diviner [13].

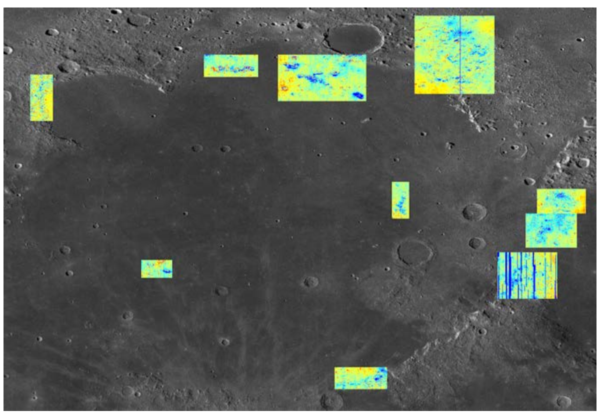

Figure 2: Diviner sites analyzed around Mare Imbrium. Low CF values (cool colors), consistent with anorthosite-dominated lithologies, while higher CF values (warm colors) are found among the mare deposits and in some of the massifs.

We are in conducting an integrated study of the massifs surrounding the Imbrium basin, which, at over 1000 km wide, is large enough to have penetrated through the lunar crust and into the mantle. These massifs are clearly associated with the Imbrium basin-forming impact, but existing geological maps do not distinguish between whether they are likely ejecta or rather uplifted from beneath the surface during crustal rebound [14]. We examine these massifs using visible, NIR and Mid-IR data to xdetermine the relationships between and the bulk mineralogy of local lithologies. Locations where Mid-IR data have been so far obtained are shown in Fig. 2. NIR data suggest that the massifs contain exposures of four dominant minerals: olivine, Mg-rich orthopyroxene, a second low-Ca pyroxene, and anorthite. Mid-IR results suggest that in the Montes Alpes region, the Mg-rich mafic material is present with substantial amounts of plagioclase. However, in the southeastern porting of Mare Imbrium, near Wolff Mons, the higher (~8.15 µm) CF values of these exposures suggest that these are more likely candidates for pyroxenite or very pyroxene-rich norite [15].

3. Conclusions and Future Work

For the specific example of our search for candidate mantle material on the lunar surface, integrated analyses suggest that perhaps the upper mantle is dominated by orthopyroxene instead of olivine. Analyses of these and other data sets will continue around Imbrium and other basins.

Acknowledgements

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