Searching for Mg-rich Dunite Boulders on Lunar Surface and Implications to Mantle Compositions. Lingzhi Sun[1], Paul Lucey[1], [1]Hawai'i Institute of Geophysics and Planetology University of Hawai'i at Mānoa, Honolulu, HI 96822, USA (lzsun@higp.hawaii.edu).

Introduction: The lunar magma ocean hypothesis suggests that the differentiation of global magma generated an Mg-olivine and pyroxene rich mantle; after the crystallization of Mg-rich minerals, more iron-rich minerals and oxides (especially ilmenite) crystallized and cumulated above the Mg-rich minerals, which might have caused gravitational instability and overturn of the mantle [1, 2]. The overturn might have redistributed the Mg-rich olivine and pyroxenes to the upper mantle [2, 3]. Therefore, olivine has been considered as major indicator of mantle exposures.

Yamamoto et al. [4] reported the olivine-rich spots near impact basins using Kaguya Spectral Profiler (SP) data, since basin-forming impacts are likely to penetrate the crust and excavate mantle materials, some of these olivine-rich spots may represent mantle material. The hydro-code impact model of Miljković et al [5] also suggested that mantle materials could be exposed by impact basins like Imbrium, Serenitatis, Crisium, Nectaris, Humorum and Moscoviense.

However, several studies have pointed it out that the olivine may have other origins other than mantle, for example, impact melt [6], basaltic lava flow [7] and crustal intrusions [8]. Using Moon Mineralogy Mapper (M^3) and Diviner data, Arnold et al. [9] examined the olivine exposures of [4] and found that they could not determine an area containing over 90 wt% Mg-rich olivine (dunite) on lunar surface at 250 meter/pixel resolution.

Previous remote sensing studies failed to detect Mg-rich dunite (>90% olivine) on lunar surface. One possible reason is that they were focusing on the particulate regolith surface, which is composed of powered rock fragments, glasses and impact ejecta from nearby areas. The dunite mineralogy might have been diluted from the regolith mixing progress. However, this pristine mantle composition may be preserved in igneous rocks. It is possible to find Mg-rich dunite boulders on central peaks and basin rings where deep originated rocks are supposed to be exposed.

In this work, we present a search for Mg-rich (Mg#>80) dunite boulders at the olivine-rich spots at Imbrium and South Pole-Aitken (SPA) basin [4] using a two-layer radiative transfer model.

Data and Method: We extracted the M^3 spectra of the olivine exposure sites at Copernicus central peak, Aristarchus wall and ejecta, Sinus Iridum wall, and Montes Alpes hill within Imbrium basin and Schrödinger basin ring and Zeeman Crater central peak within SPA basin. To estimate the Mg# of these olivine sites, we build a spectral library consists of olivine, orthopyroxene, clinopyroxene and plagioclase, and the Mg# of the three mafic minerals varies from 45 to 95. We calculated the Mg# of each olivine site by searching the best match of their M^3 spectrum to the spectral library.

At the spatial resolution of 20 meter/pixel in visible and 60 meter/pixel in near-infrared wavelengths of the Kaguya Multiband Imager (MI), boulders larger than 100 meters are recognizable. The boulder area can be constrained using the rock abundance map from LROC Diviner [10]. Using the LROC NAC images as a reference, we located boulders on MI images for high Mg# olivine sites.

The lunar surface is covered by a layer of fine-grain dust [11], and this dust lying on top of boulders may obscure the spectral feature of the substrate boulder [12]. A two-layer radiative transfer model can be applied to resolve the spectroscopy of this two-layer system [12]. We consider the dust overlying rock as a two-layer optical system, and the detected MI boulder spectrum consist the two-layer reflectance, and nearby regolith consist the top layer dust spectrum (Figure 1). An inverse two-layer radiative transfer modeling can be applied to solve the substrate rock spectra.

After deriving the substrate boulder spectra from MI images, we calculated the mineralogy and Mg# for the boulders. We established a spectral library that contains olivine and plagioclase mixtures, each varies from 1% to 100% at 1% steps, and the Mg# of olivine varies from 55 to 95 at an interval of 5. The mineral content and Mg# are derived by matching MI spectra to the spectral library.

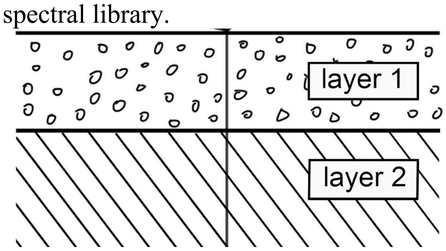

Figure 1. A two-layer schematic model, layer 1 is dust and layer 2 is rock.

Results: We calculated the Mg# of Imbrium and SPA olivine-rich spots and labeled the average Mg# of each spot in Figure 1. Most of the Imbrium basin olivine exposures show Mg# near 60, including the wall and ejecta of Aristarchus crater, the central peak of Eratosthenes crater, the south-facing wall of Sinus Iridum and a hill within Montes Alpes; the central peak of Copernicus crater shows Mg# higher than 70. The average Mg# of the inner ring of Schrödinger basin is 67 and the Mg# of the central peak of Zeeman crater is 60, both are smaller than 70. Considering that the accuracy of Mg# estimation is ±10 [13], the most promising site that mantle dunite may exist is the central peak of Copernicus crater.

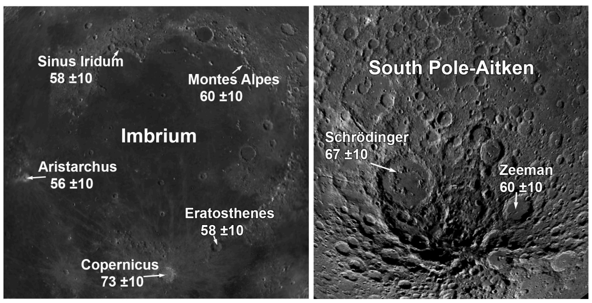

Figure 2 Mg# of olivine-rich sites. Left is Imbrium basin and right is SPA basin.

We then analyzed the spectra of sixteen boulders on one of the Copernicus central peaks using MI images, and their olivine abundances varies from 5% to 100% (Figure 3d). We found one boulder that contains pure olivine with 90 Mg#, which is highly possible to be a dunite boulder; the location of this boulder is shown in Figure 3a, b.

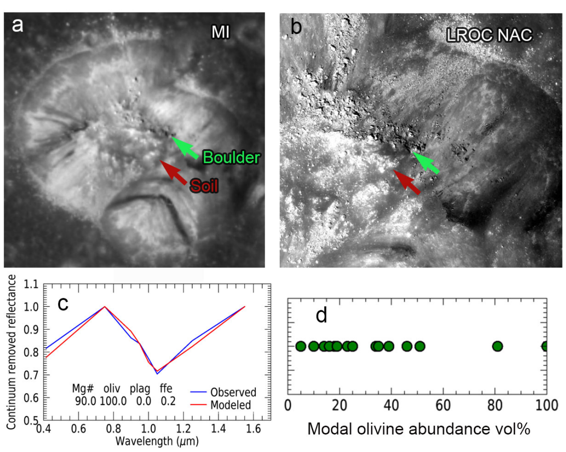

Figure 3. Dunite boulder shown on a) MI and b) LROC NAC images. c) spectral match result of the two-layer modeled boulder spectra. d) modeled olivine abundances for Copernicus central peak boulders.

Discussion and Conclusion: Imbrium and SPA basins are large enough to penetrate the lunar crust and excavate the mantle [5, 14]. As predicted by the Lunar Magma Ocean hypothesis, upper mantle materials may feature Mg-rich olivine. However, our Mg# analysis of Imbrium and SPA olivine rich spots shows that most of these areas do not contain high Mg# olivine. Therefore, the low-Mg# olivine may have a shallow origin, for example, differentiated from impact melts or basaltic lava flow [6, 15].

There is one exception, the Copernicus central peak, located on the basin ring of Imbrium, contains highly Mg-rich dunite. The dunite boulder might be originated from upper mantle or lower crust Mg# suite. The discovery of dunite is consistent with the mantle overturn hypothesis.

Schrödinger basin and Zeeman Crater are the only two olivine exposure sites within the SPA basin [16]. Our Mg# analysis indicate that they both contain relatively low Mg# olivine (<70), suggesting that these olivine may be not related to a upper mantle or plutonic source, but rather differentiated from the massive impact melt [17]. SPA basin has penetrated more than 100 km to the inside of the Moon, and its excavation of mantle material is guaranteed. However, the lack of Mg-rich olivine within SPA basin seems not consistent to the mantle overturn scenario.

The lack of Mg#-rich olivine in Imbrium and SPA basins imply that the distribution of dunite within upper mantle may not be homogeneous, in other words, the overturn of lunar mantle may not occur globally.

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