ORIGIN OF INDIVIDUAL OLIVINE EXPOSURES ON THE MOON.

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Introduction: Resent remote sensing data obtained by the SELENE (Kaguya) Spectral Profiler (SP) found exposures with olivine-rich spectral features, globally distributed on the lunar surface[1]. Based on their being surrounded by large basins, their spectral characteristics indicating olivine-rich (pyroxene-poor) composition, and distribution of the olivine-rich unit at relatively recent crater walls and ejecta and high Mg/Fe ratio of olivine at the evaluated exposures, these olivine-rich exposures may have originated from the mantle that is excavated from depth by basin-forming impacts[1].

Previous studies of returned lunar samples and the lunar magma ocean differentiation model indicate that olivine-rich rocks have the following three major origins: 1) mantle material, 2) volcanic material with olivine-rich composition, and 3) crustal material including rocks intruding into the crust (troctorite) [2]. Though most of the olivine exposures identified in [1] were located near basin rings, the origins of individual olivine sites may not be the same. Furthermore, no mantle material and only a small number of olivine-rich mare materials are available in the lunar sample collection and the distribution of all three types of olivine-rich material on the Moon is not known. Therefore, understanding the origin of individual olivine exposures and advancing our knowledge about the distribution and composition of the three types of olivine-rich materials are important for understanding the composition and evolution of the lunar interior.

To address these issues, we geologically and morphologically investigated all of the identified olivine exposures in detail to assess the origin of each site in this study.

Methods: All of the 70 million latest calibrated reflectance spectra (version 03) obtained by Kaguya SP [3] were used to re-identify olivine-rich exposures on the lunar surface (http://l2db.selene.darts.isas.jaxa.jp/index.html.en) by finding diagnostic absorption features of olivine around 1050 nm as described in [1]. Data of the Kaguya Multiband imager (MI) [4], Lunar Reconnaissance Orbiter Camera (LROC) [5], and SLDEM2013 (digital elevation model generated using the Kaguya Terrain Camera [6], MI, and Lunar Orbiter Laser Altimeter [7] aboard LRO) of each of the identified olivine sites were used to evaluate reflectance, space weathering, geologic context, distribution and size of the exposures, composition (FeO abundance using the Lucey method [8]), surface texture (roughness and rock abundance), and local slopes.

We made a color-composite image from MI data (RGB map). The colors were assigned to continuum-removed absorption depths to generate these images: red for 900 nm (low-Ca pyroxene; LCP), green for 1050 nm (olivine or high-Ca pyroxene; HCP), and blue for 1250 nm (plagioclase) to investigate the geologic context of the region.

Results: About 150 SP reflectance spectra were re-identified as having unambiguous oli-

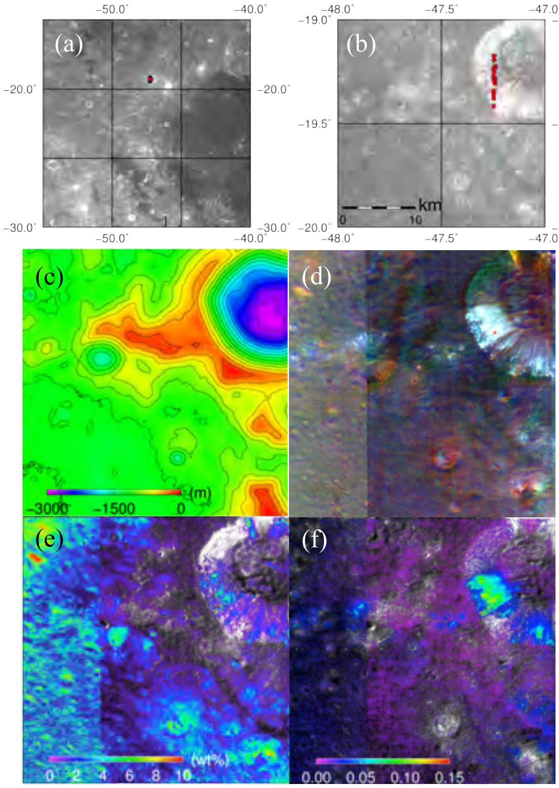

Fig. 1 Example of olivine site analyses. a) Location of the olivine site plotted as red dots on the MI 750 nm reflectance map. b) – f) Close up views of the olivine site. b) MI 750 nm reflectance. c) Elevation. d) Color-composite image (R: 950 nm, G: 1050 nm, B: 1250 nm). e) FeO abundance. f) Distribution of olivine-rich spectra. The 750 nm reflectance image is underlaid in e) and f).

vine-rich absorption features. Locations of the spectra were grouped into 50 sites located within the same latitude and longitude. We also evaluated the origin of all grouped sites.

To estimate the origin of each olivine site is not a simple task in some cases because some of the olivine-rich spectra were identified as located, where multiple impact events and mixing of local materials may occur.

Figures 1 represents an example of the olivine sites, which are estimated to originate in the mantle. This site is located near the northwest part of the Humorum basin ring, and olivine spectra are identified at the crater wall from SP spectra as indicated by red spots. The distribution of the olivine-rich material within the crater wall is observed in the MI RGB color-composite as a cyan colored area extending outside the crater. Note that we identified the clearest olivine-rich spectra among SP datasets, therefore olivine-rich material with less clear spectra may be present at other areas. The mineralogy of these olivine sites is quite different from the surrounding area, which has pyroxene dominant reflectance features (orange area in Fig. 1d). FeO abundance of the cyan colored area ranges from 8 to 10 wt.%, which is higher than feldspathic crustal material and lower than mare material. Its limited areal distribution, higher elevation near the basin ring, and FeO abundance all suggest the mantle origin for this site.

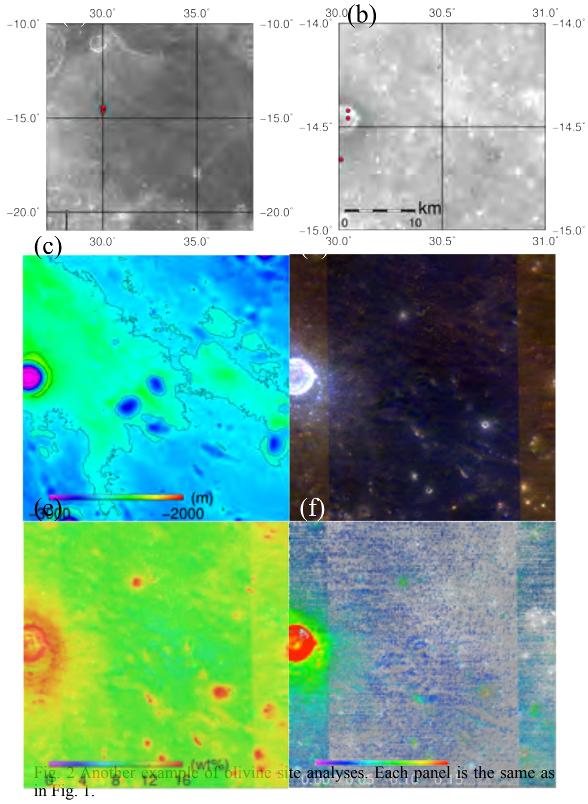

Fig. 2 Another example of olivine site analyses. Each panel is the same as in Fig. 1.

Figure 2 is another example, which is estimated to be of volcanic origin. This site is located at a wall of a small crater in Mare Nectaris, and olivine-rich materials are also observed around the crater as dark halo ejecta in the MI RGB color-composite. It is at low elevation, and has high FeO abundance (~16 wt.%), which is comparable to the surrounding mare. All this evidence suggests that the origin of this site is most likely volcanic.

Similarly, we evaluate the olivine sites except part of the Moscovience and Schrödinger, and categorized their origins as likely mantle, volcanic, crustal, and “unclear”. About 60% of the sites are estimated to be mantle origin, and 5% are volcanic, 30% are crustal, and 5% are of unclear origin respectively. Mantle origin sites surround large basins whereas volcanic origin sites are within mare, and crustal origin sites are either surround or far from large basins.

Discussion: Though the percentage of each origin is not necessarily proportional to the volumes (surface area) of each category, at least there are many olivine sites of mantle origin around Crisium, Imbrium, and Nectaris. Estimation of excavation depth of these basins indicates it is likely to reach the mantle, which is consistent with the mantle origin of these olivine sites. We also identified volcanic and crustal olivine-rich sites, which have not been reported previously. A compositional study of each category will be important in the future.

References: [1] Yamamoto et al. (2010), *Nature GeoSci.* 3, 533-536. [2] Shearer et al. (2015), *Meteorit. Planet. Sci.*, 50, 1449-1467. [3] Matsunaga et al. (2008), *Geophys. Res. Let.*, 35, L23201. [4] Ohtake et al. (2009), *Nature* 461, 236-240. [5] Robinson et. al. (2010), *Space Sci. Rev., 150*, 81-124. [6] Haruyama et al. (2009), *Science,* 323, 905-908. [7] Chin et al. (2007), *Space Sci. Rev.,* 129, 391-419. [8] Lucey et al. (1998), *J. Geophys. Res.*, 103, 3701-3708.