GEOLOGY OF THE CRATER THEOPHILUS ON THE MOON: LANDING SITE OF THE SMART LANDER FOR INVESTIGATING THE MOON. M. Ohtake[1], K. Saiki[2], Y. Nakauchi[1], H. Shiraishi[1], Y. Ishihara[3], H. Sato[1], C. Honda[4], T. Maeda[5], S. Sakai[1], S. Sawai[1], S. Fukuda[1], and K. Kushiki[1], SLIM project team. [1]Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa, 252-5210, Japan (ohtake.makiko@jaxa.jp), [2]Osaka University, [3]National Institute for Environmental Studies, [4]University of Aizu. [5]Chuo University.

Introduction: Crater Theophilus (11.4º S, 26.4º E) is located in the immediate vicinity (northwest) of the Mare Nectaris on the Moon. It is on the ring of the Nectaris basin. Its diameter is 110 km, and it has a clear central peak at the center of the crater (Fig. 1 a). This central peak includes a unique characteristic of having multiple rare geologic lithologies, including Mg-spinel bearing lithology [1], purest anorthosite (PAN) lithology [2, 3], and olivine-rich lithology [4]. Previous study revealed its compositional diversity and estimated the origin of the Mg-spinel bearing lithology as it existed as a lateral unit before the formation of Theophilus [1]. However, the origin of other lithologies and the relation of these rare geologic lithologies in this unique central peak are still not clear. In addition to their geological (mineralogical) diversity, it is reported that part of this central peak has an hydroxyl absorption feature [5], which makes this crater even more exceptional if it is real. In this study, we analyzed the geology of both the central peak and the wall and ejecta of the Theophilus crater, especially focusing on the contact of each lithology to investigate the origin and relation of these rare lithologies by utilizing the most efficient available datasets.

Methods: We used remote sensing reflectance spectra and spectral images obtained by the SELENE (Kaguya) Spectral Profiler (SP) [6] and Multiband Imager (MI) [7] for geological analyses. The SP covers wavelengths from 520 to 2600nm in 300 bands and its footprint is 500 x 500 m. The MI has 9 bands (band assignments are 415, 750, 900, 950, and 1000 nm for a visible detector and 1000, 1050, 1250 and 1550 nm for a near-infrared detector). The spatial resolution is 20 m/pixel in the visible bands and 62 m/pixel in the near infrared bands. We also used SELENE Terrain Camera (TC) and Lunar Reconnaissance Orbiter Narrow Angle Camera images, and High-resolution Lunar Topography (SELDEM) for detailed morphological analyses.

Results: The central peak of Theophilus consists of three large hill blocks. The northeast block (roughly corresponding to area A in Fig. 1a) has the highest elevation, roughly 3200 m from the crater floor. Spectral analyses of this block revealed that it consists of olivine-dominant lithology, PAN lithology, and pyroxene-dominant lithology (the last one) has a partially molten or flowing texture (Fig. 1). Olivine-dominant and PAN

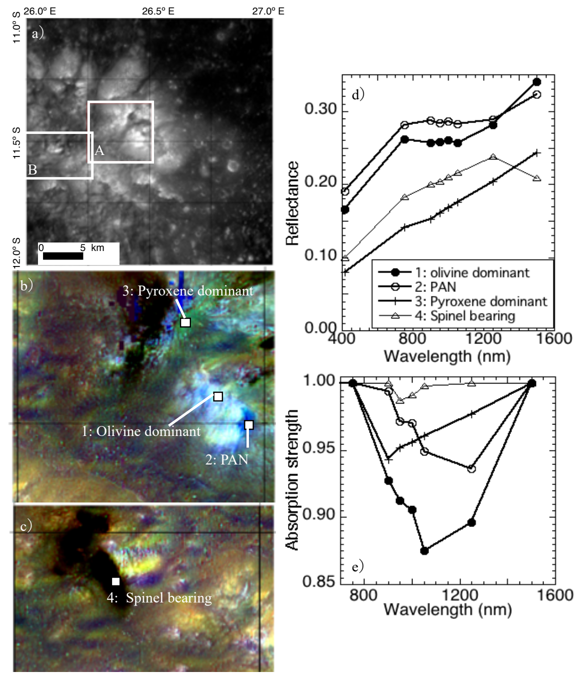

Figure 1. Geology of central peak of Theophilus. a) 750 nm band image. b) and c) are color composite images of areas A and B in a). R, G, and B are assigned as continuum-removed absorption depths of 950, 1050 and 1250 nm. Bright blue, dark blue, green, and black repre-sent olivine dominant, PAN, pyroxene dominant, spinel bearing lithology. d) and e) are reflectance and continuum removed spectra of representative lithology (locations are in b and c).

lithologies have clear diagnostic absorption of olivine and anorthosite respectively, while the pyroxene-dominant lithology has much weaker absorption (Figs. 1d and 1e). Percentage of olivine among olivine and pyroxene of the olivine dominant lithology is estimated to be more than 70 based on the fact that there is no evidence of presence of pyroxene. Abundance of mafic silicate mineral phases in the PAN lithology is less than a few per cent based on the absence (or the weakness) of olivine and pyroxene absorption in the spectra [2]. The FeO abundance of the olivine-dominant lithology estimated by the Lucey method [8] ranges from 5 to 8 wt.%, that of the PAN is nearly zero (the pyroxene-dominant lithology is 3 to 5 wt.%), reflecting their mineralogy. Mg-spinel bearing lithology is most clearly identified at the edge of the northwest block as previously reported [1] and has nearly zero FeO abundance. Olivine-dominant lithology appears to be present as a basal lithology of the central peak blocks, while both PAN and Mg-spinel bearing lithologies are more localized in our datasets.

Pyroxene-dominant lithology is observed widely on the central peak blocks, but it is present as thin layers or partially covers the olivine-dominant lithology.

The major component of the crater wall and ejecta region (outside Theophilus crater) has pyroxene-dominant lithology. However, olivine dominant lithology is also observed as localized exposures at the very edge of the wall or at many small but fresh craters throughout the wall and ejecta region (e.g. Fig. 2). These fresh craters commonly have a very clear olivine absorption feature, and the FeO abundance of these localized olivine exposures ranges up to 12 wt.%, which corresponds to a nearly pure olivine rock, if Mg# (Mg/(Mg+Fe) in mole per cent) of the olivine is assumed to be similar to the olivine-rich rock types (troctolite and dunite) among the Apollo samples.

Discussion: Based on the modal abundance, FeO abundance, distribution, and morphological information of the observed lithologies, we believe that the central peak of Theophilus crater mainly consists of olivine-dominant lithologies with lesser amounts of PAN and Mg-spinel bearing lithologies. Distribution of Mg-spinel bearing lithology is limited in our datasets and they tend to have a relatively sharp vertical boundary with the adjacent lithology. Therefore, we are not sure if it is really presented as a laterally extensive unit before the formation of the Theophilus crater as suggested [1]. We interpret the pyroxene lithology at least in some portion as impact melt origin, which covers central peaks during the uplift of the central peak based on the thinness and molten texture in some areas, though crustal material origin cannot be ruled out. Observed olivine-rich composition comparable to dunite and a sharp boundary with the adjacent PAN lithology suggest that it is not a part of the continuous crustal material. Instead, it is probably mantle (or the lower part of the crustal) origin, which is excavated by the Nectaris basin forming impact as suggested by the global distribution of the olivine-rich sites [4], well before the formation of the Theophlius.

Landing site description of the next Japanese lunar exploration: Even though we can analyze olivine-rich sites using remote-sensing datasets as demonstrated in this study, their origin is still ambiguous. Investigating this lithology by landing on one of these sites is thus very important for understanding their origin and investigating the composition of the lunar unsampled mantle or deep crustal material. To directly investigate this unexplored lithology, one of the small fresh craters just outside of the Theophilus crater is selected as a landing site for Smart Lander for Investigating Moon (SLIM) mission (Fig. 2). SLIM was approved in 2016 and will be launched in fiscal year 2021 as Japan's first lunar-landing mission [9]. It is a technology demonstration mission to pinpoint landing within a hundred meters in radius. The selected landing site is located outside of the Theophilus rim and is on a relatively tiled area compared to the mare region. The area is small and it also has a relatively larger number of boulders than the older surface. Therefore, the pinpoint landing capability of the SLIM mission is essential for this type of exploration. The lander carries one small instrument (high-resolution Multiband Camera) to derive the detailed mineralogy of the olivine-rich exposure (see Nakauchi et al. in this conference). Though SLIM is a small mission, its technology and scientific results are going to be a major contribution for future planetary exploration and planetary science.

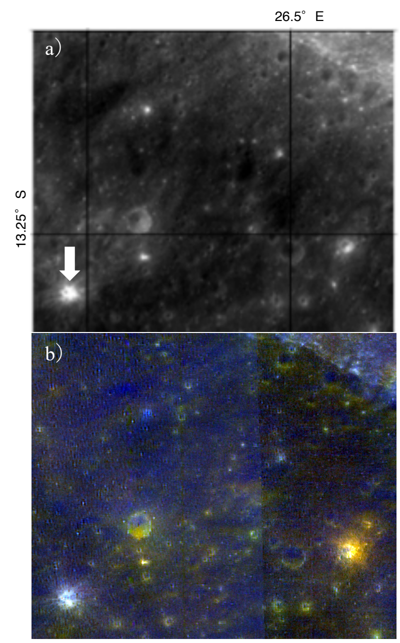

Figure 2. Example of a small fresh crater (arrow) having a clear olivine signature. a) and b) are 750 nm and color composite images. Color assignment is the same as in figure 1. This crater (13.3º S, 25.2º E; diameter ~200 m) located outside the southwest rim of the crater. The SLIM mission selected this crater as its exploration target.

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