

**VERTICAL COMPOSITIONAL TREND WITHIN THE LUNAR HIGHLAND CRUST.** M. Ohtake<sup>1</sup>, T. Mastunaga<sup>2</sup>, H. Takeda<sup>3</sup>, Y. Yokota<sup>2</sup>, S. Yamamoto<sup>2</sup>, T. Morota<sup>1</sup>, Y. Ogawa<sup>4</sup>, T. Hiroi<sup>5</sup>, R. Nakamura<sup>6</sup> and J. Haruyama<sup>1</sup>, <sup>1</sup>Planetary Science Department, Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Sagamihara, Kanagawa, 229-8510, Japan (ohtake.makiko@jaxa.jp), <sup>2</sup>National Institute for Environmental Studies, <sup>3</sup>Chiba Inst. of Technology, <sup>4</sup>The University of Aizu, <sup>5</sup>Brown University, <sup>6</sup>National Institute of Advanced Industrial Science and Technology.

**Introduction:** The magma ocean hypothesis is based on the assumption that Fe-bearing plagioclase-rich rocks exists globally as the lunar crust, but no crystalline plagioclase had been detected by remote-sensing methods before SELENE [1], except for some ambiguous or indirect indications of the existence of plagioclase. However a global distribution of rocks of very high plagioclase abundance (approaching 100 vol.%; purest anorthosite) has been detected at central peaks, crater walls, and ejecta using an unambiguous plagioclase absorption band recorded by the SELENE Multiband Imager (MI) [2]. The estimated plagioclase abundance is significantly higher than previous estimates of 82 to 92 vol.% [3], providing a valuable constraint on models of lunar magma ocean (LMO) evolution.

To understand the spatial and vertical compositional trends (if any) of these high plagioclase abundance anorthosite rocks is important for addressing the crustal generation mechanism because to generate such monomineralic rocks by simple plagioclase flotation from a lunar magma ocean is difficult according to a general differentiation mechanism of magma [3][4]. However, recent study [5] suggests possible generation of these high plagioclase abundance anorthosite rocks by a combined process of segregating liquid from solid by compaction and melt migration, and segregating solids by granular shearing.

Therefore, in this study we investigated spatial and vertical compositional (modal abundance) trends of these high plagioclase abundance anorthosite rocks over the entire lunar surface within the upper crust by using continuous reflectance spectra derived by the SELENE Spectral Profiler (SP) [1] and images derived by the SELENE Multiband Imager (MI) [2].

**Data:** SP is a line-profiling sensor with spectral coverage from 0.5 to 2500 nm and a spectral resolution of 6 nm at visible wavelengths range and 10 nm at near-infrared wavelengths. It has a foot print of 500 m x 500 m and observed the illuminated side of the Moon every orbit (about 7000 orbits) throughout the SELENE mission periods except checkout. All of the observed SP data except data for calibration were used as input for this study (roughly 10,000 spectra are acquired per orbit). These data were mixtures taken at various phase angles. The average gap in the longitude direction between each SP observation line, which means the gap between each SELENE orbit, is about 2 km.

SP data were used here because SP's spectral resolution is higher than that of MI and it is better able to detect the absorption center wavelength of even very weak plagioclase absorption bands.

#### **Data analyses:**

We calibrated SP data with the laboratory reflectance measurements of Apollo 16 soil samples [6]. Photometric function correction by [7] was applied for the data. Data with phase angles exceeding 75 degrees were omitted from the data sets because of the larger errors in the photometric function correction. SP spectra with reflectance at 750 nm below 5% were also omitted from the data sets because of the lower S/N of these data.

The absorption depth of each wavelength was calculated after the continuum was removed. Spectra with the greatest absorption depth around 1250 nm (absorption generated by plagioclase) and a ratio of absorption depth at 900 nm (absorption generated by mafic minerals) to the absorption depth around 1250 nm of less than 0.9 were ultimately selected to detect the high plagioclase abundance anorthosite. The high plagioclase abundance anorthosite spectra can be detected by this method because only rocks with high plagioclase abundance have this spectral feature caused by the plagioclase absorption band generated by a minor amount of Fe<sup>2+</sup> (0.1 wt% FeO) contained in the plagioclase. The plagioclase absorption band is located around 1250 nm (1300 nm is reported in [8] for terrestrial anorthite), so we allowed a wavelength range of the absorption center (from 1200 to 1300 nm) to accommodate possible compositional variation of the absorption center wavelength.

The location and geologic context of SP spectral data were derived by matching each SP signal to corresponding pixels in MI images. Thus, the original burial depth of each high plagioclase abundance anorthosite rock outcrop was estimated from a crater scaling law [9] using the crater diameter of each outcrop observed in MI data.

**Results:** Figure 1 depicts locations and absorption depths around 1250 nm of each detected PAN rocks (colored squares). About 200 spectra were selected using the above criteria. Figure 2 depicts the correlation of the absorption depth ratio of mafic minerals to plagioclase (900nm/1250 nm) to the crater diameter and estimated original burial depth.

As presented in Fig. 1, the detected high plagioclase abundance anorthosite rocks are distributed glob-

ally and relatively homogeneously within the highland region. Some of the locations where purest anorthosite (PAN) rocks are found in MI data [2] are missing in Fig. 1 (for example, Aristarchus) because outcrops of the PAN rocks are smaller than the SP footprint or no data fitting to the above phase angle and reflectance criterion were acquired for these outcrops. There is no apparent spatial dependence in the absorption depths of each anorthosite rocks distribution.

However, Fig. 2 indicates that the majority of the derived absorption depth (strength) ratios (900/1250 nm) of the detected high plagioclase abundance anorthosite rock spectra appear to form a trend that increases as their estimated original burial depths increase within the crust (the trend is observed at original burial depth of up to 30 km).

**Discussion:** Although understanding the actual cause of this trend requires further study, such a trend may indicate a decrease in the mafic mineral abundance within the already very mafic-poor rock and/or an increase in the  $\text{Fe}^{2+}$  content of plagioclase with depth. Assuming a low-Ca pyroxene (with Mg# is 60) and plagioclase (with constant 0.1 wt% FeO content) mixture, modal abundances of these rocks are estimated to be from 95 to  $97 \pm 1$  (from 3 to 30 km in depth) vol.% plagioclase based on the absorption depth ratio (900/1250 nm) of intimate mixing modeled spectra (spectra from the top 2 to 3 km layer are omitted in these estimates because they came from mixing layer and may suffer mixing and melting effects caused by impact). Assuming constant modal abundance (96 and 4 vol.% plagioclase and low-Ca pyroxene respectively), estimated FeO content of plagioclase changes from 0.05 to 0.15 wt% with depth.

More detailed spectral analyses are required to precisely estimate the modal abundance of rocks at each location. However, current results suggest either an increase of plagioclase abundance with depth and/or an increase of FeO in plagioclase within the upper

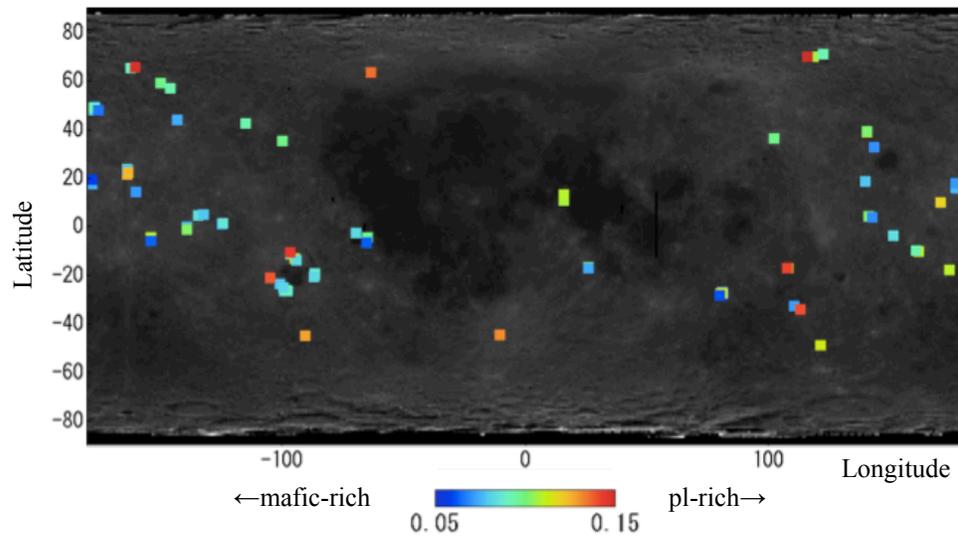


Fig. 1 Distribution and absorption depth around 1250 nm of detected PAN rocks derived by SELENE SP. Squares indicate locations of the PAN rocks plotted on the SP 750 nm map. Colors of each square indicate the absorption depth around 1250 nm (largest absorption depth) of each spectrum after continuum removal.

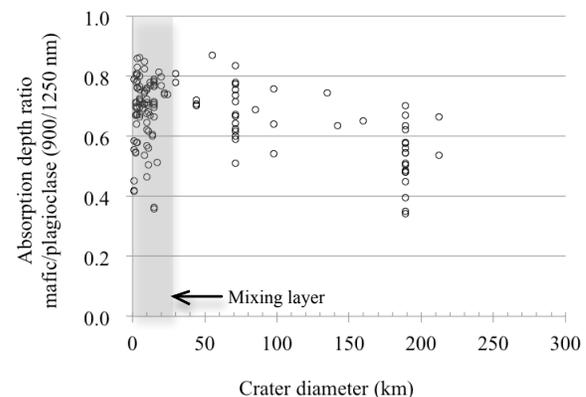


Fig. 2 Correlation of the absorption depth ratio of mafic minerals to plagioclase (900nm/1250 nm) to the crater diameter.

highland crust, supporting generation of highly plagioclase-rich rocks by flotation from the LMO.

**References:** [1] Matsunaga T. et al. (2008) *Geophys. Res. Lett.*, 35, L23201, doi:10.1029/2008GL035868. [2] Ohtake M. et al. (2009) *Nature*, 461, doi:10.1038. [3] Warren P. H. (1990) *Am. Mineral.*, 75, 46-58. [4] Longhi J. (2003) *J. Geophys. Res.*, 108, 5083, doi:10.1029/2002JE001941. [5] Permentier E. M. and Liang Y. (2010) *Lunar Planet. Sci. Conf.* 41st, 1824. [6] Pieters C. M. (1999) *New Views of the Moon II, Workshop*, 8025-8026. [7] McEwen A. et al. (1998) *Lunar Planet. Sci. Conf.* XXIX, 1466. [8] Pieters C. M. (1996) *Lunar Planet. Sci. Conf.* XXVII, 1031. [9] Cintala, M. J. and Grieve, R. A. F. (1998) *Meteoritics & Planetary Sci.*, 33, 889-912.