

NEGATIVE CORRELATION BETWEEN PRIMITIVE FAR SIDE HIGHLAND MATERIALS AND MAFIC SILICATE ABUNDANCE ON THE MOON. M. Ohtake¹, H. Takeda², T. Mastunaga³, Y. Yokota³, J. Haruyama¹, T. Morota⁴, S. Yamamoto³, Y. Ogawa⁵, T. Hiroi⁶, Y. Karouji⁷, K. Saiki⁸, and H. Otake⁷, ¹Planetary Science Department, Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Sagami-hara, Kanagawa, 229-8510, Japan (ohtake.makiko@jaxa.jp), ²Chiba Inst. of Technology, ³National Institute for Environmental Studies, ⁴Nagoya University, ⁵The University of Aizu, ⁶Brown University, ⁷Japan Aerospace Exploration Agency, ⁸Osaka University.

Introduction: The Moon is globally asymmetric in many properties including topography [1], crustal thickness [2], mare volcanic activity [3], and the concentration of incompatible elements and iron [4]. Knowing the origin of this lunar dichotomy is important for understanding both the evolution of the Moon and the solidification history of all planetary bodies because its large scale suggests an origin that directly correlates with the cooling of a planetary body.

A key geochemical parameter of lunar highland rock for addressing the origin of this dichotomy is the Mg# ($Mg/[Mg+Fe]$ in mole percent in mafic minerals) because it provides a degree of differentiation of the magma ocean at the time of its solidification. Most anorthosites of the lunar samples and lunar meteorites exhibit low Mg# relative to other nonmare rocks, with a typical spread of 40 to 70 (ferroan anorthosite; FAN) [5, 6, 7]. The low Mg# imprinted on the few mafic minerals co-crystallizing with the plagioclase is interpreted to be due to the evolved, iron-rich nature of the magma ocean at the time of plagioclase crystallization. A few anorthosites [6, 7], notably some in meteorites presumably from the lunar farside, exhibit high Mg# (up to 81.4), which is not consistent with current versions of the magma ocean crystallization model of a spatially uniform differentiation process, although the source location and extent of these high Mg# anorthosites are unknown.

However, presence of highland materials with higher Mg# values (up to 80) than those on the nearside were found on the lunar farside [8] by applying an empirical algorithm to lunar reflectance spectra from the Kaguya Spectral Profiler [9]. The estimated Mg# of the Apollo 16 landing site in the study (61.6) matches well with the average of Apollo 16 FAN measurements (61.5), while the high Mg# region (from 70 to 81) on the farside has higher values than the Mg# range of known Apollo FAN (from 40 to 70) and may possibly have a more primitive composition than FAN. High Mg# (magnesian) anorthosites are detected from lunar meteorites. The Mg# of the farside ranges from 45 to 81, and its upper limit is comparable with that of the magnesian anorthosite in lunar meteorites. The average Mg# difference between nearside and farside (7.9) is comparable to the difference between FAN and magnesian anorthosite in lunar meteorites. This indicates that the farside crust consists of rocks that crystallized from less-evolved magma than the nearside crust. The results further indicate that the lunar dichotomy is pos-

sibly directly linked to crystallization of the magma ocean.

This study compared the estimated Mg# of the highland material to the mafic silicate abundance and FeO content to discuss further the origin of this Mg# dichotomy.

Method: We used the derived global map of mafic silicate abundance and Mg# at high spatial resolution reported in [8] to evaluate the correlation between them. The maps were generated by applying a new algorithm to the global data set obtained by the Kaguya Spectral Profiler (SP). The mafic silicate algorithm uses spectral absorption depth, which is calculated as the angle between 750 nm and 920 nm, and the Mg# algorithm uses the spectral absorption angle between 920 nm and 950 nm that are most directly related to the Mg# (it increases with increasing Mg# in assemblages with low-Ca pyroxene as a major mafic mineral component). The Mg# values are derived by applying this algorithm (including mafic mineral abundance correction) to a radiative transfer mixing model [10]. Presence of high-Ca pyroxene may cause large errors in Mg# estimation, but HCP/LCP uncorrected Mg# is minimum for each spectra. Therefore, we used the HCP/LCP uncorrected value to generate the Mg# map.

We also generated a FeO abundance map by applying the algorithm derived by [11] and the parameters derived by [12] to the Kaguya Multiband Imager (MI) data sets [13] which were averaged to the same spatial resolution of the other two maps. We are able to check the consistency of the trend by comparing products generated independently by SP and MI data sets.

Results: The mafic silicate abundance to Mg# and FeO abundance to Mg# (Fig. 1) of the highest Mg# region on the farside are negatively correlated, with the highest Mg# (75 to 78) having the lowest mafic silicate abundance (5.5 vol.%) and FeO (2 wt.%). The consistency of the mafic silicate abundance and the FeO trend of the cross-section from independent data sources (SP and MI) of the two parameters confirms the validity of the estimated trends. Note that exceptional values are observed in the trends where basins and craters affect the estimate (the FeO abundance appears to be affected more than the mafic silicate abundance).

All the observed Mg#, mafic silicate abundance, and FeO abundance appear to vary continuously from the higher farside to the lower nearside for Mg# and from the lower farside to the higher nearside for the

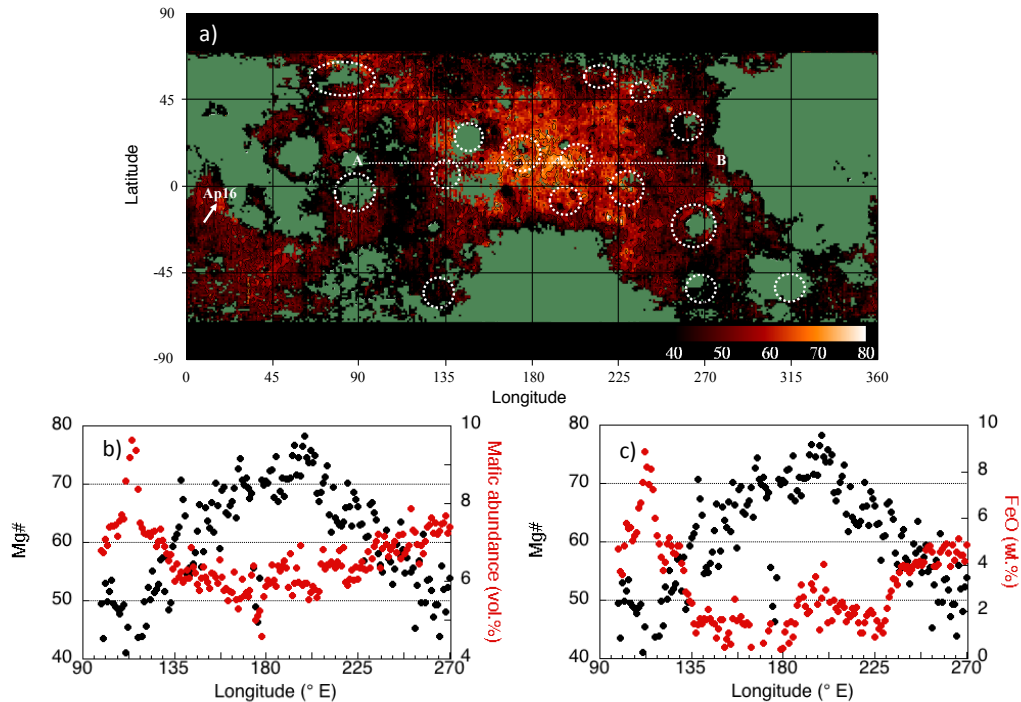


Fig. 1 Correlation between the estimated mafic abundance to Mg#, and FeO to Mg# of the lunar highlands. a) Mg# distribution map with location of cross-section A–B. b) Mg# and mafic silicate abundance, c) Mg# and FeO abundance trend of cross-section A–B plotted as longitude versus Mg#. Black and red symbols indicate Mg# and mafic silicate abundance in (b), Mg# and FeO abundance in (c). Continuous changes of Mg#, mafic silicate abundance, FeO indicates that a continuous process generated the observed dichotomy of Mg#.

other two parameters. These results suggest a possible continuous Mg-Fe differentiation mechanism accompanied by a continuous plagioclase segregation (from mafic silicate) mechanism rather than a foreign source of the farside highland material [14], or magnesian basin ejecta contamination from the deep because of the observed negative correlation.

Discussion: The negative correlation observed in this study indicates that the high Mg# highland material on the farside is produced from the higher Mg# melt during plagioclase crystallization on the farside than previously estimated based on FAN compositions [5].

We measured the average composition of the lunar surface (regolith) in this study instead of individual fresh outcrops, so the observed surface composition may be affected by mixing caused by cratering processes. However, the continuous compositional trend from the farside to the nearside observed in this study (mafic silicate abundance, FeO abundance, and Mg#) was also observed in previous studies (FeO) [4]. This suggests that the original composition of the lunar surface formed when the solidification of the LMO is finished likely reflected in the current lunar surface even after a long period of continuous cratering and mixing (the lunar surface is not completely homogenized by mixing). Also, if generation of the highland crust by plagioclase flotation is assumed with no major second-

ary processes, the higher Mg# of the melt during plagioclase flotation further suggests a global and combined process of generating the trend in mafic silicate abundance and Mg# from the bulk LMO.

References: [1] Kaula, W. M et al. (1974) *Proc. Lunar Planet. Sci. Conf.* V, 3049-3058. [2] Zuber, M. T et al. (1994) *Science* 266, 1839-1843. [3] Head, J. W. and Wilson, L. (1992) *Geochim. Cosmochim. Acta.* 56, 2155-2175. [4] Jolliff, L. et al. (2000) *J. Geophys. Res.* 105, 4197–4216. [5] Warren, P. H (1993) *Am. Mineral.* 78, 360-376. [6] Korotev, L. R. et al. (2003) *Geochim. Cosmochim. Acta.* 67, 4895-4923. [7] Takeda, H. et al. (2006) *Earth Planet. Sci. Let.* 247, 171-14. [8] Ohtake, M. et al. (2012) *Nature GeoSci.* 5, 384-388. [9] Matsunaga, T. et al. (2008) *Geophys. Res. Let.*, 35, L23201. [10] Denevi, B. (2008) *J. Geophys. Res.* 113, E02003. [11] Lucey, P. (2000) *J. Geophys. Res.* 105, 20297-20305. [12] Otake, H. et al. (2011) *Lunar Planet. Sci. Conf. Abstract.* #1905. [13] Ohtake, M. et al. (2008) *Earth Planets Space* 60, 257–264. [14] Jutz, M. and Asphaug, E. (2011) *Nature* 476, 69-72.