PRIMITIVE FARSIDE HIGHLAND MATERIALS DETECTED BY MG NUMBER. M. Ohtake[1], H. Takeda[2], T. Mastunaga[3], Y. Yokota[3], J. Haruyama[1], T. Morota[4], S. Yamamoto[3], Y. Ogawa[5], T. Hiroi[6], Y. Karouji[7], K. Saiki[8] and P. G. Lucey[9] [1]Planetary Science Department, Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Sagamihara, Kanagawa, 229-8510, Japan (ohtake.makiko@jaxa.jp), [2]Chiba Inst. of Technology, [3]National Institute for Environmental Studies, [4]Nagoya University, [5]The University of Aizu, [6]Brown University, [7]Japan Aerospace Exploration Agency, [8]Osaka University, [9]Univ. of Hawaii at Manoa.

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 process of a planetary body. However, previous evidence is not able to specify whether the dichotomous features are directly produced by the lunar magma ocean (LMO)[5, 6] or by other secondary processes such as a large impact[7] or mantle overturn[8].

A key geochemical parameter of lunar highland rock to address the origin of 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. In this study, Mg# is used to discuss the origin of dichotomy and to know the early cooling history of the LMO.

Most anorthosites exhibit low Mg# relative to other nonmare rocks, with a typical spread of 40 to 70 (ferroan anorthosite; FAN)[9]. 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. However, a few anorthosites[10, 11], notably some in meteorites presumably from the lunar farside, exhibit high Mg# (up to 80), which is not consistent with current versions of the magma ocean crystallization model of spatially uniform differentiation process. The source location and extent of these high Mg# anorthosites are not known because of the lack of available data.

Method: We utilize a new algorithm that derives Mg# from spectral reflectance data to derive a global map of Mg# at high spatial resolution. We focus on FAN in this study because it is thought to be the oldest and most primitive crustal material[12]. We apply this new algorithm to the global data set obtained by the Kaguya Spectral Profiler (SP)[13], which has spectral coverage from 500 to 2600 nm in 300 bands and a spatial resolution of 500 x 500 m.

We used 26 million spectra after data screening to select data with a high signal-to-noise ratio and low correction errors. These spectra were binned into 1-degree intervals, with 30 km resolution at the equator. The Mg# algorithm uses 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[14].

The estimated error in our modal mineralogy estimation is ±1 vol.% as absolute error, ±3.5 as relative error of Mg#, and -2.0 to + 6.0 as absolute error of Mg#. Presence of high-Ca pyroxene possibly causes large error in Mg# estimation, but HCP/LCP uncorrected Mg# is minimum for each spectra. Therefore, we discuss HCP/LCP uncorrected value in this study.

Results: The derived Mg# distribution (Fig. 1) of the lunar highlands clearly indicates its dichotomic distribution, with a higher Mg# in the farside highlands (up to 81.4) than in the nearside. The estimated Mg# of the Apollo 16 landing site in this study (61.6) matches well with the average of Apollo 16 FAN measurements (61.5); this result supports the validity of our method.

The most extensive high Mg# region is located at the center of the feldspathic highland terrain[4] around the Freundlich-Sharonov and Dirichlet-Jackson basin, where the lowest abundance of Th[15] and the maximum crustal thickness[16] was detected by Kaguya observations. This high Mg# region (from 70 to 81) 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.

Mg# appears to vary continuously from the higher farside to the lower nearside, suggesting a possible continuous Mg-Fe differentiation mechanism rather than a foreign source of the farside highland material[17]. Mare contamination does not account for the dichotomy because the farside Mg# is higher than both FAN and mare basalt. Our nearside estimation is more susceptible to mare contamination, but the Mg# we derived is similar to the Mg# of known FAN without mare contamination, and also highland material from Apollo 16 landing site indicate contamination of mare material is not enough to explain the observed Mg#. Magnesian basin ejecta contamination is not favored because of the observed lower mafic abundance in the farside highlands.

High Mg# (magnesian) anorthosites are detected from lunar meteorites[10, 11]. Magnesian anorthosites as widespread magma ocean flotation cumulates are problematic because of the apparent need for iron-rich melt to enable plagioclase flotation[12]. However, the results

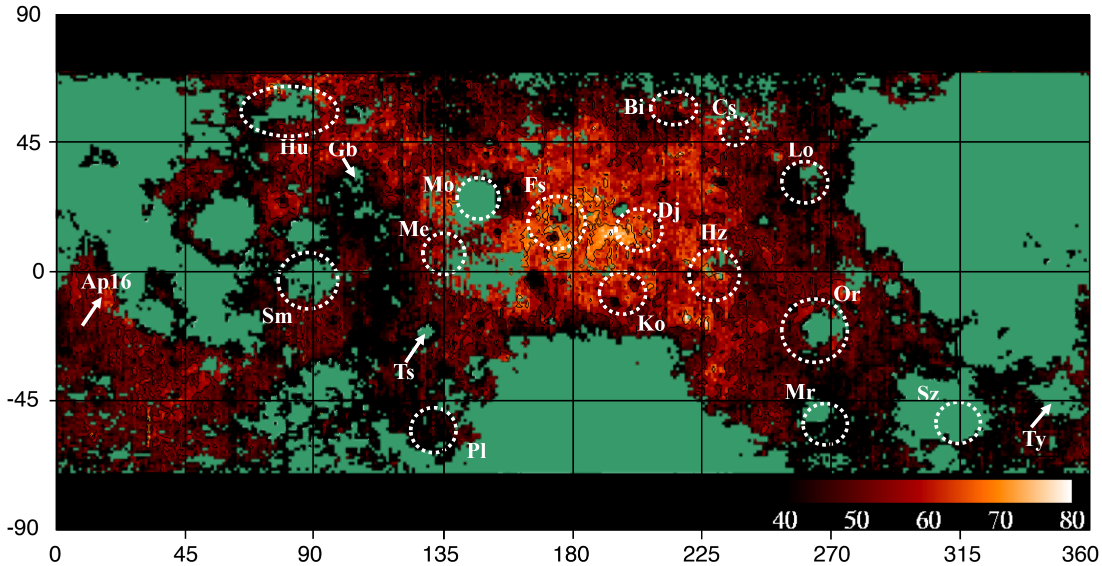

Fig. 1. Estimated Mg# of the lunar highlands.
Dotted circles and arrows denote major basins and bright craters in the highland region. Regions with greater than 11 vol.% of mafic mineral abundance and regions with high HCP/LCP ratios (exceeding 0.2) are indicated in sea green. Abbreviations: Ap16: Apollo 16 landing site. Ts: Tsiolkovskiy. Ty: Tycho. Abbreviations for basin names are adopted from ref 16. The contour lines are drawn at intervals of 10. The farside highlands have higher Mg# than the nearside highlands. Note that the Mg# at the similar mafic mineral abundance on the nearside has lower value than the farside.

here indicate that very high plagioclase abundances and high Mg# mafic minerals occur over vast areas.

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[10, 11].

Discussion: The higher Mg# in the farside highlands observed in this study indicates higher Mg# of the melt during plagioclase crystallization on the farside than previously estimated based on FAN compositions[9]. Also, if generation of the highland crust by plagioclase flotation is assumed with no major secondary processes, the higher Mg# of the melt during plagioclase flotation (which is evolved from the bulk LMO) further suggests the possibility of a higher Mg# of the bulk LMO. A simple yet plausible model for interpreting our observations is dichotomic crustal growth based on a model[5] in which, a convectional force from the nearside to the farside is generated on the lunar surface by a temperature gradient (the hotter nearside) caused by thermal shielding by the Earth. During the first stage of crustal formation, plagioclase crystallized and was transported, and relatively high Mg# anorthosite rock-burgs were generated from the less evolved melt and piled up at the equatorial region on the farside, possibly assisted by a surface coriolis force or other dynamic support and accompanied by efficient segregation of the plagioclase crystal[18]. In the second stage, a ferroan anorthositic crust, which was crystallized from the more evolved LMO, forms on the nearside as the crust formation proceeds.

Our first identification of the Mg# dichotomy and high Mg# anorthosite crust in the farside highlands emphasizes the need for study of a new LMO solidification (post-concentric) model.

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