CONSTRUCTION OF NEW RESTRICTED GAUSSIAN MODEL TO DERIVE MODAL MINERALOGY AND ELEMENTAL COMPOSITION FROM SPECTRAL DATA.

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Introduction: Determining of mineral abundance and elemental composition of lunar surface is essential to understand the formation processes of the crust and the volcanic history of the Moon [e.g., 1–4]. Several previous studies have developed methods to determine the modal mineralogy and elemental composition of rocks from reflectance spectra [5–7]. The modified Gaussian model (MGM) [6, 8] is generally used for deconvoluting an observed spectrum into individual mineral components. However, it is difficult to fit the spectrum of complicatedly mixed material such as mare basalts by the MGM because each rock has multiple absorptions. Nimura et al. [9] improved the MGM by obtaining the relations between chemical compositions of minerals (the ratio of Fe/(Fe+Mg) in olivine and the ratios of Ca/(Ca+Fe+Mg) and Fe/(Ca+Fe+Mg) in pyroxene) and absorption band parameters (center wavelength, width and strength ratio of Gaussian curves). This method was applied to the spectra of asteroids [10]. However, although some Gaussian parameters do not have significant correlations with chemical composition, these parameters are modeled as functions of chemical compositions. Furthermore, applicability of the method to the Moon was not verified. In this study, we reevaluate the correlation between Gaussian parameters and chemical compositions by adding spectrum datasets recently obtained, and formulate the relation. Also, we test whether Fa# of olivine and modal mineralogy are calculated exactly with our models.

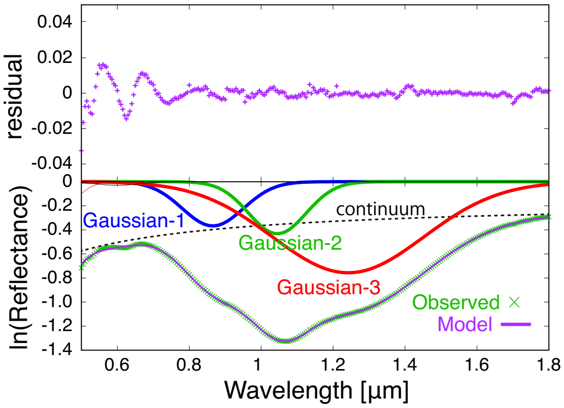

Fig. 1 An example of MGM fitting to an olivine spectrum. Three Gaussians were used to fit olivine spectra.

Methods: We used reflectance spectra from RELAB and USGS library. Figure 1 shows an example of MGM fitting to a reflectance spectrum of synthetic olivine. Figure 2 shows the relationship between Fa# and Gaussian parameters of synthetic olivines. The center wavelength has good correlation with Fa#, while other parameters show lower correlation. We constructed six models to test the sensitivity of correlation between Gaussian parameters and Fa#. The first is the model that all Gaussian parameters are given as functions of Fa# (LGM_O1). The second is the model that the center wavelength is given as function of Fa#, but the width and strength ratio, which have less correlation with Fa#, are constant value (LGM_O2). The third is the model that the width and strength ratio are free parameter (LGM_O3). These three models use only Gaussians of olivine. On the other hand, the models, LGM_M1, LGM_M2 and LGM_M3, are mixture model that use not only the Gaussians of olivine but also those of pyroxene and plagioclase.

Results: As the result of linear fitting to the relation between Gaussian parameters and Fa#, we obtained a following relational expression in case of LGM_O1,

$$\mathbb{U} = \mathbb{A}\times \mathrm{Fa\#} + \mathbb{B}$$

$$\mathrm{R}(\lambda, c_0, c_1, Fa\#, s_2) = c_0 + \frac{c_1}{\lambda} + \sum_{i=1}^{3} s_i \times \exp\left\{\frac{-(\lambda-\mu_i)^2}{2\sigma_i^2}\right\}$$

where R is reflectance at a wavelength λ. μ_i, σ_i and s_i represents Gaussian center, width and strength. $c_0 + c_1/\lambda$ is called Continuum, which represents continuous component. Table 1 shows constant values of A and B. R^2 of correlation between parameters and Fa# are also shown in Table 1. Gaussian centers have stronger correlation than the other Gaussian parameters. We performed verification tests whether or not Fa# and modal mineralogy are correctly estimated by our models using spectra of synthetic and natural olivines and mixtures of olivine, pyroxene, and plagioclase [11]. The results indicate that LGM_O1 or LGM_M1 could calculated Fa# and modal mineralogy most successfully. Figure 3 shows the result of Fa# estimation of synthetic and natural olivines using the model LGM_O1.

Table 1 Constant value of relation expression of model LGM_O1

U		A	B	R^2
u1	$\mu1$	6.0×10^{-4}	0.8449	0.4537
u2	$\mu2$	3.7×10^{-4}	1.0258	0.6200
u3	$\mu3$	9.1×10^{-4}	1.2015	0.8858
u4	$\sigma1$	2.1×10^{-4}	0.0652	0.1240
u5	$\sigma2$	-4.0×10^{-5}	0.0815	0.0213
u6	$\sigma3$	3.5×10^{-4}	0.1759	0.1949
u7	s1/s2	2.9×10^{-3}	0.5163	0.1062
u8	s3/s2	9.4×10^{-3}	1.0535	0.3735

Applications for Olivine Exposures on the Moon: Then, as a first step, we applied this method to the spectra of two olivine exposure sites in Mare Frigoris and Mare Nectaris, which were found by the global survey of olivine spectra [12]. To avoid the effect of the space weathering, spectra of fresh crater walls were used. We used GEKKO system [13] to choose spectral data. Figure 4 shows the result of LGM fitting using LGM_M1. The olivine site in Mare Frigoris has higher plagioclase content. Both olivine site show roughly Fa# = 30 , which is consistent with the result of Ohtake et al. [14] that these olivine site might be volcanic origin.

References: [1] Pieters C. M. (1978) *LPS IX,* 2825–2849. [2] Lucey P. G. et al. (1998) *JGR, 103,* 3679-3699. [3] Ohtake M. et al. (2012) *Nature GeoSci. 5,* 384–388 [4] Kato S. et al. (2017) *Meteoritics & Planet. Sci.,* 52: 1899–1915. [5] Hapke B. (1993) Cambridge Univ. Press, New York. [6] Sunshine J. M. et al. (1990) *JGR, 95,* 6955–6966. [7] Zhang X. et al. (2016) *JGR Planets, 121,* 2063–2080 [8] Sunshine J. M. et al. (1999) *LPS XXX,* Abstract #1306. [9] Nimura T. et al. (2006) *LPS XXXVII,* Abstract #1600. [10] Nimura T. et al. (2010) *LPS XXXXI,* Abstract #2711. [11] Hiroi T. and Pieters C. M. (1994) *JGR, 99,* 10,867–10,879. [12] Yamamoto S. et al. (2010) *Nature GeoSci. 3,* 533–536. [13] Hayashi Y. et al. (2015) *Journal of Space Science Informatics Japan, 4,* 91–103. [14] Ohtake M. et al. presentation in this meeting.

Acknowledgement: We thank the SELENE Data Archive and the web GIS GEKKO (http://fructus.u-aizu.ac.jp/). This work was supported by the Japan Society for the Promotion of Science under a Grant-in-Aid for Young Scientists (B) (25870314, T. Morota) and a Grant-in-Aid for JSPS Fellows (15J10249, S. Kato).

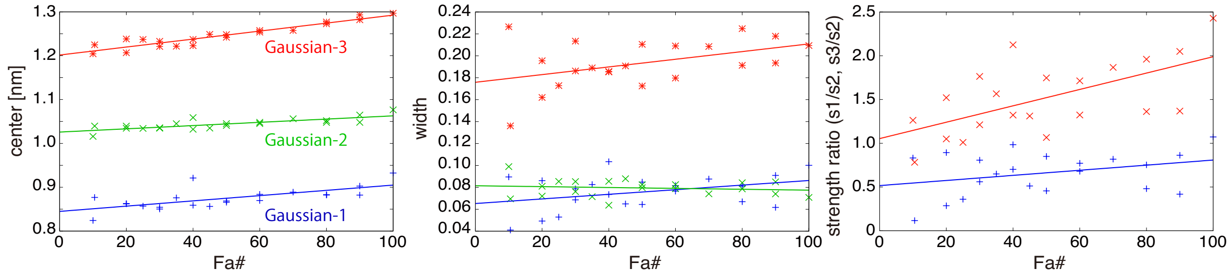

Fig. 2 Relationship of Fa# of synthetic olivines and Gaussian parameters by MGM analysis.

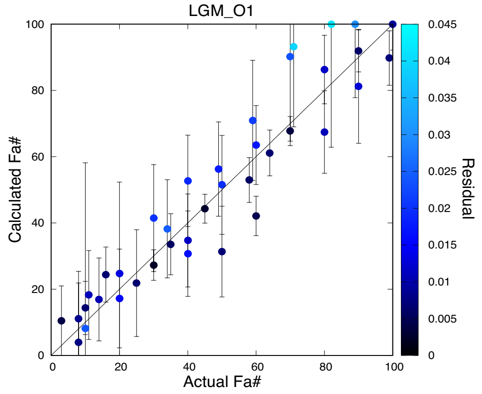

Fig. 3 Comparison between actual and Calculated Fa# of synthetic and natural olivine using the model LGM_O1.

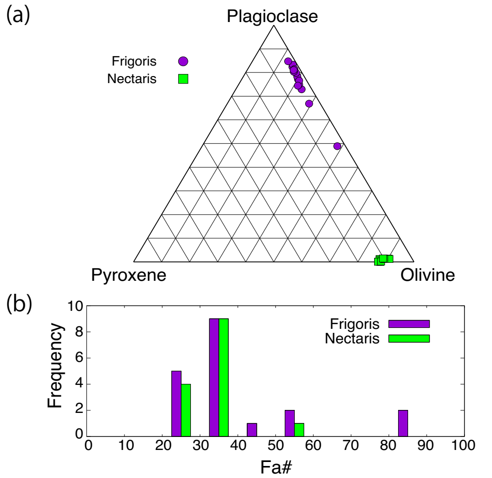

Fig. 4 Calculated (a) modal mineralogy and (b) Fa# of the Frigoris and Nectaris olivine site.