Preliminary Unsupervised Classification of 4 Vesta's Surface using Multiband Reflectance Data Obtained by DAWN Framing Camera.

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Introduction: 4 Vesta is like the differentiated rocky inner planets. The mineralogy of 4 Vesta is diverse. Earth-based remote-sensing data indicates that 4 Vesta is a differentiated body consisting of crust, mantle, and core. Compositional information about 4 Vesta is based on ground-based and Hubble Space Telescope (HST) spectroscopic observations, as well as lab analyses of Howardite-Eucrite-Diogenite (HED) meteorites, which are probably impact-produced fragments of Vesta [1, 2]. Therefore, 4 Vesta is one of the best examples for studying the origins and evolution of proto-planetary bodies and terestorial planetary bodies during the first 10 million years after the solar system formation. To study the origin and evolution of the planetary bodies, geologic mapping is the basic and essential tool, and the recent Dawn mission provides us a new in-situ remote-sensing dataset. We started a new project to create a geologic map of 4 Vesta using Dawn's dataset. As the first step, we try to classify Vesta's surface in terms of reflectance characteristics, that may reflect mineralogical information.

Data: The Dawn Framing Camera (FC) [3] captured the entire (visible) surface of 4 Vesta from three different orbits in 2011 and 2012. The FC is equipped with one clear (panchromatic) and seven color filters, covering a wavelength range between 400 and 1000nm (438, 555, 653, 749, 829, 917, and 965nm) [1]. These filter bands enable us to distinguish between the eucritic (pyroxene-plagioclase basalts) and diogenitic (orthopyroxenites) dominated lithologies. Vesta was mapped from Survey, High-Altitude Mapping (HAMO), and Low-Altitude Mapping (LAMO) orbits at spatial resolutions of 250 m/pixel, 60 m/pixel, and 20 m/pixel, respectively. In this study, we used FC HAMO color mosic data (DAWN-A-FC2-5-MOSAIC-V1.0, spatial resolution 60 m/pixel) (Figs. 1, 2).

Analysis and Result: Although 4 Vesta is an asteroid, it is still too big to classify the whole surface by fully manual processsing. We therefore try to use some machine learning base methods, such as k-means, Gaussian Mixture Model (GMM), Variational Beysian Gaussian Mixture Model (VBGMM), and ISODATA[4], all of which are unsupervised methods. ISODATA and VBGMM are fully unsupervised classification methods. Naturally, nobody knows how many geological units/classes exist at 4 Vesta in advance. Both methods only require the accountable range of classes. In addition, ISODATA requires two more parameters to merge classes and to divide a class. K-means and GMM are both semi-unsupervised classification methods, that means we have to give a number of classes.

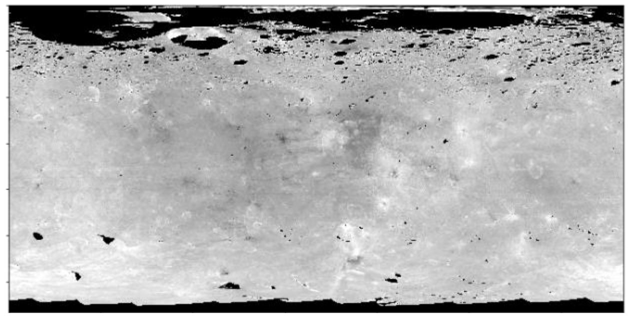

Fig. 1 FC 749 nm band reflectance map of the 4 Vesta

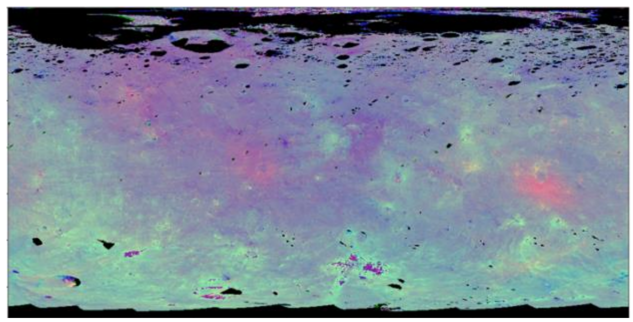

Fig. 2 FC global color mosaic of the 4 Vesta (R = 749/438 nm, G = 749/917 nm, and B = 438/749 nm).

Pre-Classification Data Treatment. In our previous lunar classification studies [5, 6, 7, 8], classification using raw reflectance spectra did not work well. Because the albedo-related component is too strong, some kind of normalization and/or transformation is required. Finally, we used continuum removed hyperspectral (160 bands) data (SP-Cube-Depth) in our previous lunar study [8]. In this Vesta study, we only have seven data bands, so we tested what kinds of transformation or normalization of limited spectral band data (we selected seven bands that have almost same wavelength of FC data) could reproduce hyperspectral results. We tested the following cases,

1) Normalization by 750nm band values
2) Normalization by the mean reflectance of each band.
3) Principal Component Analysis (PCA) of seven bands of data and selection of PCs

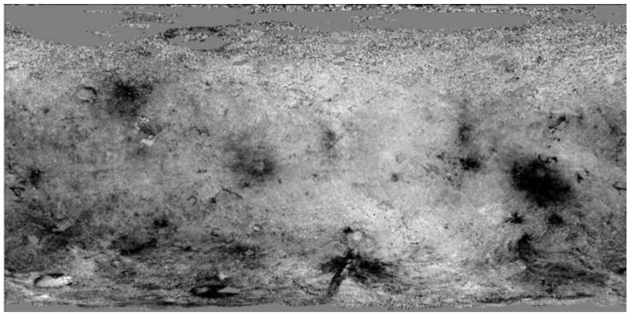

Fig. 3 Principal Component 7 Map for FC HAMO color mosic data

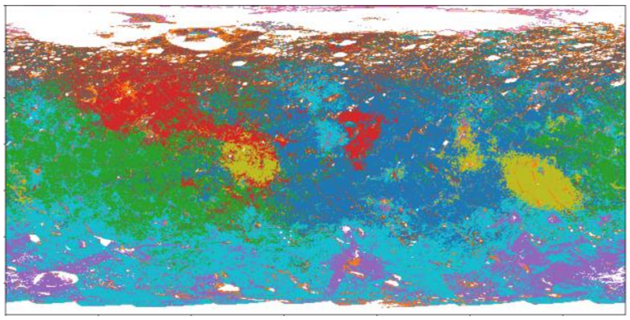

Fig. 4 Classification results of GMM (n_class = 10)

and got the best result in case 3. Therefore, we adopt a PCA transformation for the first step of analysis. Figure 3 shows the principal component 7 (PC7) map of the FC HAMO color mosic data.

Classification. In this study, we tried to apply some different classification methods as mentiond before. The input data for all classification methods are the same 7 principal component data.

Classification result. Here, we show the result using the GMM method with a number of classes (n_class) set as 10. The classification map (Fig. 4) correlates well with the color mosic map (Fig. 2) and presents some collocated feasures with the PC7 map (Fig. 3). This suggests that the classification reflects both the albedo difference and the mineralogical difference of Vesta's surface for each region. The average reflectance spectrum of each class is shown in Fig. 5. The overall features of the mean spectrum of each classe are similar but could capture the difference of weak absorption around the 600nm band, the pseudo-depth of the 1 μm absorption band, and the pseudo-band-minimum of 1 μm absorption. These differences reflect the mafic mineral type, in other words, the difference of HED meteorite type. However, these classification results have also been affected by some artificial effects such as mosaicing of data. Before comparing the classification map with other kinds of datasets, such as topographic structures, we have to improve data treatment to reduce non-natural factors included in the data.

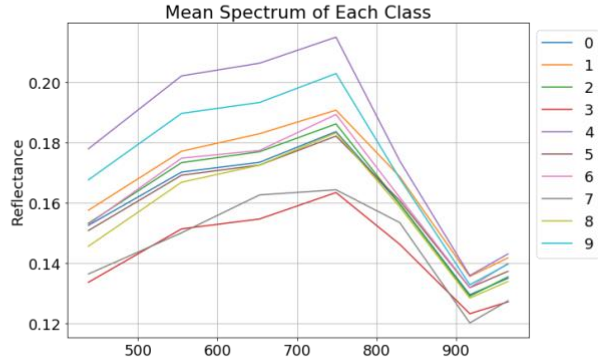

Fig. 5 Average Reflectance Spectrum of Each Class

References: [1] Kel, K. (2002) in *Asteroids III*, 573-584. [2] McSween et al. (2011) *Space Sci. Rev. 163*, 141-174. [3] Sierks, H. et al. (2011) *Space Sci. Rev. 163*, 263-327. [4] Tou J. T. and Gonzalez R. C. (1974) *Pattern Recognition Principles*, *Addison-Wesley Publishing Company*, *Reading*, *Massachusetts*. [5] Ishihara et al. (2015) 46th *LPSC*, Abstract #1633. [6] Hareyama et al. (2016) 47th *LPSC*, Abstract #1390 [7] Hareyama et al. (2017) 48th *LPSC*, Abstract #1706 [8] Hareyama et al. *in preparation*.

Acknowledgements: This study is supported by JSPS KAKENHI (Grant-in-Aid for Scientific Research(C)) Grant Number 17K05644 (P.I.: Yoshiaki Ishihara).