COMPOSITION AND CRYSTALLINITY ANALYSIS OF LUNAR DARK MANTLE DEPOSITS. T. Arimoto[1, 2], M. Ohtake[1], J. Haruyama[1] and T. Iwata[1], [1]Japan Aerospace Exploration Agency (JAXA), 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa 252-5210, Japan (arimoto@planeta.sci.isas.jaxa.jp), [2]The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-0033, Japan

Introduction: The lunar mantle makes up 90% of the Moon's volume. Therefore, it is important to determine the mantle composition for understanding the lunar bulk composition, which contains information about the Moon's origin and evolution. It is also essential to study the mantle composition in order to understand the process of its differentiation from the lunar magmatic ocean. However, the composition of the lunar mantle remains unclear.

Pyroclastic beads provide a direct clue to lunar mantle composition. These very low albedo beads on the lunar surface are Fe-bearing volcanic glass or partially crystallized spheres. The color variation of pyroclastic beads corresponds to their composition and to the cooling rate of magma drops which formed them. In particular, TiO_2 content strongly affects the color, in order of higher TiO_2 content (e.g., orange glass (>8wt%), yellow glass (3 to 5wt%), green glass (<0.5wt %)) [1].

Previous studies suggested that if erupted magma is quenched slowly, the erupted magma of intermediate to high TiO_2 content can form small crystallized ilmenite grains and generate black beads, instead of generating orange and yellow glass as with faster quenching [2]. Therefore, the TiO_2 content of the beads and the quenching rate of the erupted magma correlate with the colors and crystallinities of the pyroclastic beads.

Chemical studies of pyroclastic beads acquired by Apollo missions indicate that these beads are the result of an explosive fire-fountain originating deeper (300 to 500 km) in the mantle than basaltic magma [3]. It is also assumed that pyroclastic beads retain the initial composition of the magma because the beads have higher Mg / (Mg + Fe) than mare basalts [4] and do not completely crystallize during eruption, due to the high upward speed [3, 5]. Thus, by estimating the composition and crystallinity of pyroclastic beads based on remote-sensing data, we can investigate the composition of the magma generated in the deeper lunar mantle and its eruption mechanism (e.g., eruption speed and volume) on a global scale.

Dark Mantle Deposits: Dark Mantle Deposits (DMDs) are believed to contain pyroclastic beads, as were found in the Taurus-Littrow region near the Apollo 17 site. This region is one of the darkest and smoothest areas on the Moon, and dark smooth terrains similar to that in this region on the lunar surface are categorized as DMDs [6]. However, a detailed spectral analysis comparing remote-sensing data of the DMD region with laboratory-measured pyroclastic beads is lacking because of the limited wavelength coverage and spatial resolution of previous remote-sensing data. Nonetheless, previous studies have identified several DMDs [7, 8].

This study focused on larger DMDs distributed globally over the Moon using spectral data obtained by the Multiband Imager (MI) on the SELenological and ENgineering Explorer (SELENE). We analyzed DMDs at Aristarchus Plateau, Sinus Aestuum, Rima Bode, Smythii NW, Orientale, Cruger, Sulpicius Gallus, Vaporum, Taurus-Littrow, Nectaris SE, Harbinger, Dopplemayer, Smythii SW, Titius, Petavius, Oppenheimer, Humorum SW, Riccioli, Cleomedes, and Mosciense SE. Previous studies reported that these 20 regions are the largest regional DMDs identified [8] and may have a more voluminous and stable reservoir for their source. This study estimates the composition and crystallinity of these regions in detail and investigates the compositional relationships of the magmatic sources, among DMDs and between DMDs and the surrounding mare basalt, using data with wide spectral and high spatial coverage.

Method: We used MI spectral data to estimate the TiO_2 content and crystallinity of the DMDs in these regions. The MI is a high-resolution (20 m x 20 m per pixel) spectral imager with both visible and near-infrared coverage in the spectral bands at 415, 750, 900, 950, 1000, 1050, 1250, and 1550 nm. At each location, the reflectance is derived by averaging an area corresponding to 6 x 6 pixels in the MI-VIS. Using MI spectral data, we can identify mineral types based on the absorption depths after removing a continuum [9]. We can also distinguish pyroclastic glass from mare basalt by judging whether or not a spectrum has an absorption center from 1000 to 1250 nm and a unique glass-absorption shape, which is convex downward at 1250nm (Fig. 1).

In order to select locations representing DMDs suitable for checking the compositional variation within the DMDs, we mapped these regions and other regions in the vicinity using the MI reflectance data for 750 nm. We then selected locations where the reflectance is lower than 5.5% (this criterion represents the darkest region of the analyzed area and corresponds to less contaminated DMD) except Orientale, Nectaris SE, Petavius, and Cleomedes DMDs located on high-reflectance material. We also generated an MI color-composite mosaic based on the differences in absorption characteristics in order to distinguish pyroclastic beads from the surrounding mare basalts.

We then estimated the type (TiO_2 content) of pyroclastic beads observed at each location by comparing the wavelength of the absorption center in the MI data with that of the laboratory-measured data for Apollo pyroclastic beads from the RELAB database (www. planetary. brown. edu / relab).

We next generated a diagram [10] of the absorption depth at 1000 nm versus the absorption depth ratio at 1000 nm and 1050 nm, based on the modeled reflectance of a mixture of glasses and black beads and background materials with the observed DMD spectra, in order to estimate the crystallinity of DMD. In this diagram, we used spectra for orange and yellow glass (as two glass endmembers) and black beads (as a crystal endmember) taken from Apollo samples (the grain size was set to 40 μm). By comparing the spectra of different mixing ratios of glass and black beads, we estimated the crystallinity (estimated content of black beads) and TiO_2 content of the DMD.

We also estimated the TiO_2 content of mare basalts surrounding the DMDs in order to compare the composition of the DMDs with that of the mare basalts by producing TiO_2 maps based on parameters derived by [11].

Results and Discussion: The derived wavelength of the absorption centers of the DMD spectra for Aristarchus Plateau, Rima Bode, Smythii NW and SW, Orientale, Vaporum, Harbinger, Dopplemayer, Humorum SW, Riccioli, and Moscoviense SE (group 1) was 1050nm, similar to that of yellow glass with intermediate TiO_2 content. Also, the wavelength of the absorption centers of the spectra for the Sulpicius Gallus and Oppenheimer DMDs (group 2) was 1050nm, similar to that of high-Ti orange glass, and the spectra for the Sinus Aestuum and Taurus-Littrow DMDs (group 3) had double peaks at 750 nm and 1250 nm, similar to that for high-Ti black beads. Thus, the pyroclastic beads in DMD groups are assumed to be yellow glass (group 1), orange glass (group 2), and black beads (group 3).

In contrast, the dark regions of Cruger, Nectaris SE, Titius, Petavius, and Cleomedes appear to be mare, which do not contain glass, judging from the clear pyroxene absorption band and the absence of the unique glass absorption shape, which is convex downward at 1250nm.

Our results suggest that the crystallinity of the pyroclastic beads of DMD groups 1 and 2 ranged from 3 to 35%, while that of group 3 had a high value of 72 to 85%. Also, the TiO2 estimates of DMD group 1 ranged from 5.4 to 6.3wt%, while that of groups 2 and 3 had a high value of 9.1wt%.

A comparison of Ti estimates for DMDs and the surrounding mare basalts indicated that DMDs tend toward higher TiO_2 content than mare.

The greatly differing crystallinity and composition of the Rima Bode and Sinus Aestuum DMDs on the lunar nearside (TiO_2 content: 3.0wt%, crystallinity: 55%) in spite of the short distance (250 km) between these regions indicate the presence of an azimuthal heterogeneity of composition and volatile content in the lunar mantle, assuming that the depth of the magma source for each DMD has the same range.

The possibility of azimuthal compositional heterogeneity in the lunar mantle is consistent with and may suggest compositional diversity [12] after a mantle overturn, which is the vertical transport of the mantle caused by gravitational instability of the high-Ti cumulate layer produced during the final solidification step of a magma ocean [13].

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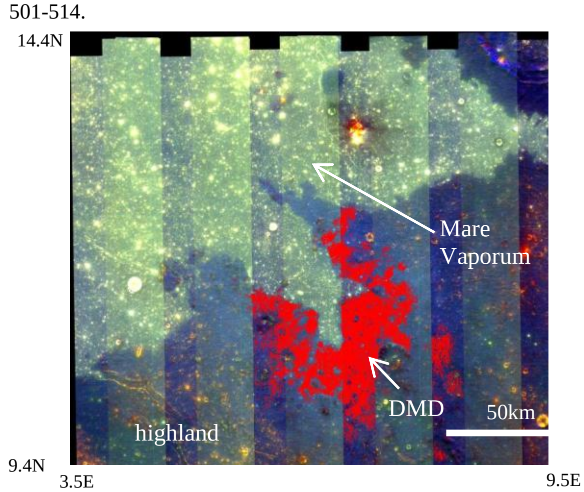

Fig. 1 MI color-composite image of the Mare Vaporum region. The vivid red region (corresponds to low albedo glassy region where a continuum-removed absorption at 1250 nm has a convex downward shape) indicates DMD distinguished from mare. The background RGB colors (red, green, and blue) are assigned to the absorption depth at 950, 1050, and 1250 nm. The mare lava flow overlays DMD that erupted along the boundary between mare and highland.