Grain size of the surface regolith of asteroid 4 Vesta estimated from its reflectance spectrum in comparison with HED meteorites

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Abstract - The grain-size distribution of the regolith of asteroid 4 Vesta has been estimated by comparing its reflectance spectra (0.3–2.6 μm) with those of HED meteorites. The finest grain-size separate (<25 μm) of a particular howardite has a reflectance spectrum most similar to Vesta's. In order to better simulate Vesta's surface mineralogy, reflectance spectra of those finest HED meteorite powders were linearly combined, and Vesta's spectrum was scaled for the best fit between them. Both the albedo and the shape of reflectance spectrum of Vesta were well reproduced by regional mixtures of the finest (<25 μm) powders of HED meteorites. The result suggests the heterogeneity of Vesta's surface and provides an estimate of the visible reflectance of Vesta that is close to its IRAS albedo. Thus, this suggests that fine grains can be generated and retained by relatively small bodies (Vesta is approximately 500 km in diameter).

INTRODUCTION

The surface mineral composition of asteroid 4 Vesta is the best understood of all asteroids. Its ultraviolet-visible-near-infrared reflectance spectrum is very similar to those of major basaltic achondrites called HED meteorites: howardites, eucrites, and diogenites (McCord et al., 1970). Heterogeneity of Vesta's surface has been detected by measuring its reflectance spectra at different rotational phases (Gaffey, 1983). The recent discovery of smaller Vesta-like asteroids in near-Earth orbits (Bell, 1988; Cruikshank et al., 1991), among Vesta family, and between Vesta's orbit and the 3:1 Kirkwood Gap (Binzel and Xu, 1993), has strengthened suggestions that HED meteorites came from Vesta-like asteroids.

Existence of particulate regolith on asteroids has been detected by polarimetry studies (Dollfus et al., 1977, 1989). Le Bertere and Zellner (1980) studied polarimetric, photometric, and spectroscopic properties of Vesta and a eucrite and concluded that Vesta's surface is best simulated by a broad mixture of particle sizes mainly >50 μm mixed and coated with particles of <10 μm. However, wavelength range (0.3–2.6 μm) reflectance spectrum of Vesta has not been fully utilized to study Vesta's surface property in comparison with HED meteorites. If the mineral assemblage of Vesta's uppermost regolith is within the range of HED meteorites in terms of pyroxene chemical compositions (Mg, Fe, and Ca contents) and pyroxene-plagioclase mixing ratios, the grain-size distribution can be estimated to a certain extent by comparing its reflectance spectrum with laboratory spectra of HED meteorite powders of various grain sizes.

REFLECTANCE DATA

Three telescopic reflectance spectra of asteroid 4 Vesta were taken from Zellner et al. (1985) for the wavelength range of 0.3–0.4 μm, Chapman and Gaffey (1979) for 0.4–0.8 μm, and Bell et al. (1988) for 0.8–2.6 μm. Fresh portions of three eucrites (Millbilliliea, Juvinas, and Y74450), a howardite (EET87503), and two diogenites (Y74013 and Y75032) were ground with a mortar and pestle and were dry sieved into grain sizes of <25, 25–45, 45–75, and 75–125 μm. Bidirectional reflectance spectra of these HED meteorite powders were measured at 30° incidence and 0° emergence angles at every 5 nm from 0.3 to 2.6 μm in wavelength with RELAB spectrometer. The details of RELAB are described in Pieters (1983) and the RELAB User's Manual.

RESULTS OF COMPARISON OF REFLECTANCE SPECTRA BETWEEN VESTA AND HED METEORITES

Shown in Fig. 1 are the telescopic reflectance spectrum of Vesta and laboratory reflectance spectra of HED meteorite powders of grain size <25 μm. In general, eucrites tend to have their appar-
Vesta's reflectance spectrum was scaled. The linear combination coefficients of the HED meteorites and the scaling factor of Vesta's spectrum were optimized for the best fit between the linear combination and the scaled spectrum of Vesta. End members with negative coefficients were removed and the calculation was redone until there was no negative coefficient. A more detailed description of the method is given in Hiroi et al. (1993).

Reflectance spectrum of Vesta in this study is a combined one of three different observations connected at wavelengths 0.4 and 0.8 μm. Because those three observations may have been made at different rotational phases of Vesta, two different wavelength ranges were used for calculation: (A) 0.3–2.6 μm and (B) 0.8–2.6 μm.

The results of the linear mixing calculations are shown in Fig. 3. Calculations with both wavelength ranges give good fits between Vesta and combinations of HED meteorites. The calculation shown in Fig. 3a gave an estimate of Vesta's visible reflectance 0.37 which is very close to its IRAS albedo 0.38 (Tedesco, 1989). This result corresponds to a howardite-dominant hemisphere of Vesta, although the howardite spectrum may be expressed by an intimate mixing of some appropriate eucrites and diogenites. Another calculation, shown in Fig. 3b, using Vesta's spectrum observed at its same rotational phase gave a slightly better fit and a larger amount of eucrite and diogenite.

DISCUSSION

It is known that dry sieving often cannot remove fine grains even if they are smaller than the opening size of the sieve because fine grains tend to remain on larger grains. However, dry sieving was chosen instead of wet sieving in order to better simulate the actual regolith-forming process on Vesta. Wet sieving would make the absorption bands of larger grain-size fractions of HED meteorites deeper, thereby making their reflectance spectra even more different from Vesta's. The sieve opening sizes (25, 45, 75, and 125 μm) were chosen because those sizes were readily available and had intervals large enough to separate grain-size fractions under a dry condition.

Mineral modal abundances of grain-size fractions can be different from one another because of the difference of mechanical strength among the component minerals. It was experimentally shown that fine grain-size fractions are enriched in plagioclase when a mineral mixture mainly composed of plagioclase and pyroxenes is impacted (Hörz and Cintala, 1984). If plagioclase is enriched, the reflectance should become higher, the 1-μm and 2-μm absorption bands shallower, and the 1.2-μm band deeper. If grinding HED meteorites with a mortar and a pestle could not simulate the impact process on Vesta in terms of the change of mineral modal abundances, Vesta's regolith may contain more plagioclase than the HED meteorite powders in this study. It would take more detailed spectral measurements of individual mineral components of HED meteorites to check whether any difference of mineral modal abundance exists between Vesta and HED meteorites as a whole.

Le Berre and Zellner (1980) compared polarimetric and photometric properties between a eucrite and Vesta and concluded that coarse grains are necessary for producing the same albedo and that very fine grains (<10 μm) are necessary for producing the same polarization inversion angle as Vesta. Our present spectroscopic study confirms their result that very fine grains are necessary but is based on different criteria: fine grains are necessary to produce the albedo and shape of reflectance spectrum similar to Vesta. Coarse grains can exist if they are spectroscopically inactive because of the fine-grain coating, etc. However, the existence of coarser grains is still detectable from reflectance spectra of this wavelength range.
(0.3–2.6 μm) if their fine-grain coating is only a partial one as in the case of the dry-sieved powders in this study (25–45, 45–75, and 75–125 μm fractions).

If 500-km Vesta has a fine regolith, asteroids 1 Ceres and 2 Pallas, which are larger than Vesta (Tedesco, 1989), could also have fine regoliths. Although large-scale impacts on those asteroids may tend to blow smaller grains away from their surfaces, small impacts such as by micrometeorites may have produced fine grains that could be retained on those asteroid surfaces. In that case, fine grains on those asteroids must have been produced after the last large impact that removed the older fine grains from the surface.

The HED meteorite powders used in this study were taken from the internal, fresh portions of the meteorites. Therefore, their similarity to Vesta’s surface suggests that Vesta’s surface regolith was not affected by space weathering to a degree that may have produced highly reddened reflectance spectra of lunar soils.

CONCLUSIONS

If Vesta’s surface material is similar to HED meteorites, Vesta has enough fine grains (e.g., < 25 μm) to dominate its reflectance spectrum. Additional evidence that extremely fine (<25 μm) grains are retained even on a small body such as 500-km Vesta has been shown. Good matches of reflectance spectra and brightnesses between Vesta and HED meteorites support the idea that Vesta’s surface is free from heavy space weathering.

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REFERENCES