CHARACTERIZING THE SURFACE ELEMENTAL COMPOSITION OF 4 VESTA BASED ON HED METEORITES: PROSPECTIVE STUDY OF GAMMA-RAY AND NEUTRON SPECTROMETER FOR THE DAWN MISSION

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Introduction: DAWN, the ninth NASA Discovery mission, will explore two of the largest main-belt asteroids, 1 Ceres and 4 Vesta [1], which are complementary protoplanets that have remained intact since their formation. Vesta is highly differentiated by igneous processes and is believed to be the parent body of the howardite, eucrite and diogenite (HED) meteorite suite [e.g. 2]. The DAWN spacecraft is equipped with gamma-ray and neutron spectrometers (GR/NS), which will enable measurement and mapping of some major (O, Si, Fe, Ti, Mg, Al, and Ca) and trace element (U, Th, H, and K) abundances on Vesta's surface [3]. However, GR/NS analysis has an uncertainty for determining elemental abundance, which is influenced by the mission scenario (e.g. altitude of the spacecraft and radius of the parent body) [4]. The ratios of two analyzed elements are more accurate than the absolute abundances, so we have focused on element ratios.

In this study, we compile 42 whole-rock compositions of 39 HED meteorites and present two diagnostic compositional diagrams to characterize the surface type of Vesta from GR/NS data.

Results and Discussions: The HED suite contains three main igneous lithologies—basalt, cumulate gabbro, and orthopyroxenite; they correspond to basaltic eucrite, cumulate eucrite, and diogenite, respectively [5]. Moreover, the HED suite include a wide variety of polymict rocks—polymict diogenite, howardite, and polymict eucrite; these are mixtures of diogenite and basaltic or cumulate eucrites [5]. Hubble Space Telescope observations [6, 7] suggest that the average surface of Vesta is analogous to howardite and/or polymict eucrite assemblages, although the diogenite spectral signature is also sporadically observed. The spatial resolution of GR/NS analysis (>100 km) [4] is much greater than the scale of compositional variability observed in the HED meteorites (~cm) [8]. Since polymict rocks are mixtures of diogenite and basaltic or cumulate eucrite [5], the spectra obtained by GR/NS analysis are expected to reflect the mixture of these three rock types. Mixing relations of three end-components can be displayed by appropriate two-dimensional diagrams.

Whole-rock compositions of howardite, eucrite, and diogenite are plotted in Mg/Si versus Al/Ca (Fig. 1a) and Al/Ti versus Al/Si diagrams (Fig. 1b). Representative compositional ranges of major constituent minerals in the HED suite are also shown in these diagrams. Basaltic eucrite and diogenite have relatively uniform compositions compared to the polymict rocks. These polymict rocks are plotted between basaltic eucrite, cumulate eucrite, and diogenite, which is consistent with previous geochemical and petrological studies [e.g. 5]. Many two-dimensional diagrams can be drawn by selecting any two element ratios from the 11 elements that will be measured by GR/NS analysis. Among these diagrams, Mg/Si-Al/Ca and Al/Ti-Al/Si diagrams (Fig. 1) are most diagnostic of mixing relationships of the HED suite, because these plots most strongly reveal difference mineral modes (cf. Fig. 2).

To evaluate the contribution of the three rock types to GR/NS spectra, we propose three meteorites, Shalka, Serra de Magé and Nuevo Laredo, as end-members which represent diogenite, cumulate eucrite, and basaltic eucrite, respectively. Shalka is known to be a typical diogenite consisting of >90 vol% coarse-grained cumulus orthopyroxene [9]. Serra de Magé is characterized by coarse-grained plagioclase with equant cumulate texture, resulting in high whole-rock Al content [8]. Nuevo Laredo is believed to be a product of most evolved residual melts after different degrees of fractional crystallization of primary melts with compositions similar to main group eucrites [10]; this component reflects the most differentiated mineral assemblages such as Fe-rich pigeonite and plagioclase. Because these three meteorites plot near the ends of the ranges of individual meteorite groups in Fig. 1 (and also in any other compositional diagram), most chemical compositions on the surface of Vesta could likely be explained by the mixing of these three components.

The number of elements obtained by GR/NS analysis is limited, although surface data for other elements (e.g. Na, Cr, S, rare earth elements) are also important to understand evolution of Vesta. Once surface data from GR/NS is quantitatively evaluated as a mixing ratio of the proposed three end-components, other element abundances of the surface which are not measured by the GR/SN analysis might be estimated by combining the calculated mixing ratio with the chemical compositions of the three end-member components. These mixing ratios can be checked for consistency with those from visible and infrared spectra [11].

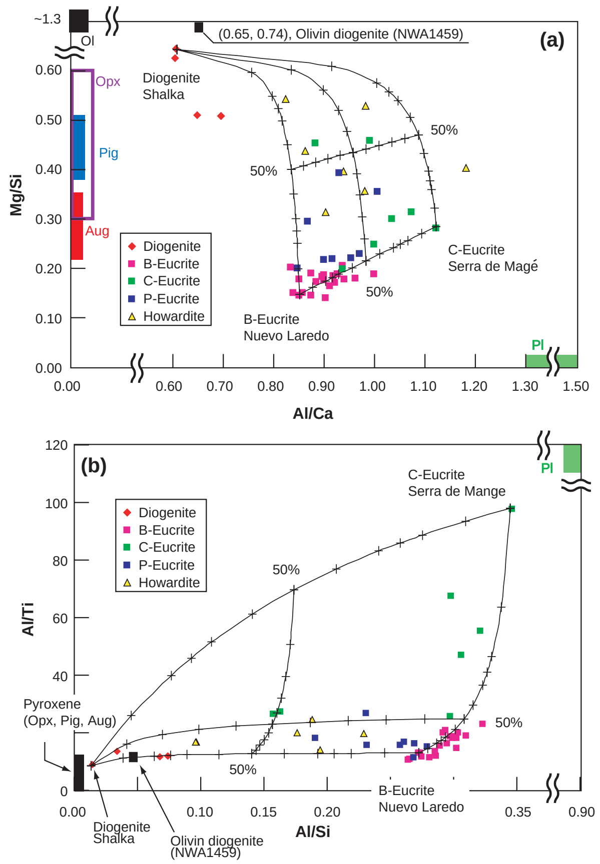

Figure 1. Whole-rock (a) Mg/Si versus Al/Ca and (b) Al/Ti versus Al/Si weight ratios for the HED meteorites. Mineral compositions of the HED meteorites are also shown. Thin lines with crosses show binary mixing curves between the Shalka, Nuevo Laredo and Serra de Magé components. Abbreviations: B-Eucrite: basaltic eucrite; C-Eucrite: cumulate eucrite; P-Eucrite: polymict eucrite; Opx: orthopyroxene; Pig: pigeonite; Aug: augite; Pl: plagioclase; Ol: olivine.

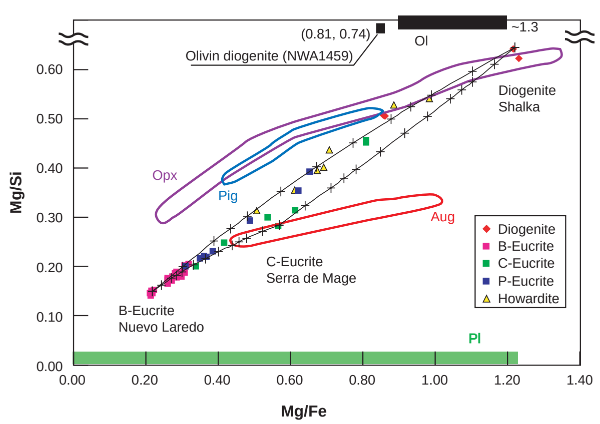

Figure 2. Whole-rock Mg/Si versus Mg/Fe weight ratios for the HED meteorites. Abbreviations are as in Fig. 1.

Vesta has experienced significant impact events, one of which excavated a huge crater (460 km in diameter and 13 km in depth) near its south pole [12]. Spectral variations within this large crater demonstrate compositional stratigraphy, probably reflecting a mantle and/or lower crust enriched in olivine relative to surficial materials [13]. Moreover, most models of a differentiated asteroid have supported a presence of an olivine-rich mantle [e.g. 14]. These studies appear to be inconsistent with the fact that few olivine-bearing meteorites occur in the HED suite [e.g. 8]. However, some recently recovered North African olivine diogenites (NWA1877 and NWA1459) contain >40 vol% of olivine [15, 16]. The whole-rock composition of NWA1459 is also plotted in the diagrams for comparison. For interpreting GR/NS data for this large crater and possibly other parts of the crust, olivine-rich diogenite should be considered as forth end-component.

There is no consensus on the petrogenetic relations between the HED meteorites despite the large literature concerning them. Combining the GR/NS data with topography can yield information on stratigraphic chemical variations. Linking chemistry of well analyzed HED meteorites and elemental mapping data from GR/NS, our study could constrain the geological context for HED meteorites and provide new insights into the internal structure and thermal evolution of Vesta.

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