

Fragment of Vesta's mantle detected in Near-Earth Space V. Reddy^{1,2}, A. Nathues², and M. J. Gaffey¹,
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Introduction: Vesta is the largest differentiated asteroid in the main belt that is still more or less intact [1] and is considered to be a model for the early stages of planetary formation [2]. The discovery of a large impact crater on Vesta's south pole (~460 km) [2], and the subsequent detection of smaller asteroids with spectral signatures similar to Vesta (Vestoids) [3] serves as a source for the delivery of HED meteorites to Earth. While fragments of Vesta's crust (eucrite meteorites) have been detected among the main belt [4] and near-Earth asteroid (NEA) populations [5] no pure mantle fragments (diogenite meteorites) have been discovered so far [4,5].

It is thought that collisional mixing of crustal and mantle fragments after impact excavation and escape would prevent detection of a pure diogenite Vestoid [5]. [6] have used mid-/far-IR (5-35 μm) spectral data from the Spitzer space telescope, which indicates that the main belt asteroid (956) Elisa could be dominated by a diogenite component with minor cumulate eucrite. However, they report further that the NIR spectrum of Elisa does not support a predominantly diogenitic global surface composition.

Here we report the first spectroscopic detection of Vesta's upper mantle/lower crust on the surface of NEA (237442) 1999 TA₁₀ that shows near-IR spectral absorption bands similar to diogenite meteorites. The derived spectral band parameters and inferred mineralogy support a diogenite-type composition with a lower crust/mantle origin. This discovery also provides us with the first direct evidence for a potential source of diogenite meteorites. The detection of a mantle fragment in the NEA population has important implications for the collisional formation of these fragments during the excavation of the south pole impact crater [3] and provides us with an insight into the internal structure of proto-planets like Vesta.

Observation and Data Reduction: We observed the asteroid on May 11, 2010, using the SpEX instrument [7] on the NASA Infrared Telescope Facility (IRTF) in low-resolution prism mode. The object was originally selected as a potential target of the ASTEX mission scenario [8] and has been investigated in the context of our spectroscopic survey of NEAs. The data was reduced using Spextool [9] provided by the IRTF, for the data reduction. Spectral band parameters including Band I and II centers and Band Area Ratio (BAR) were extracted after dividing the absorption bands to a straight-line continuum. A detailed descrip-

tion of the data reduction procedure can be found in [10].

Results: Near-IR spectral band parameters are diagnostic of the mineral chemistry and abundance and the shape of the absorption features is intimately linked to minerals present on the asteroid's surface. An average of 37 spectra of 1999 TA₁₀ is shown in Fig. 1. This average spectrum shows moderately deep (18-20%) absorption features (Fig. 2) with band centers at $0.925 \pm 0.005 \mu\text{m}$ and $1.92 \pm 0.02 \mu\text{m}$ as well as a BAR of 1.6 ± 0.3 indicating the presence of pyroxene as the dominant mineral phase.

The band centers presented here have been corrected for temperature effects using methods described in [6]. When plotting the spectral band parameters of 1999 TA₁₀ with those of HED meteorites from Vesta, the asteroid plots close to the diogenite meteorites on the Band-Band plot [7] (Fig. 3). Diogenites are composed of pyroxene (87-99%) with minor olivine (~0-5%), chromite (~0-5%) and originate from a plutonic layer deep in Vesta's lower crust/upper mantle [8].

We derived the mean pyroxene chemistry for 1999 TA₁₀ using calibrations developed by [6] and verified its compositional affinity to diogenite meteorites and ultimately to Vesta. Using these calibrations the asteroid has a mean pyroxene chemistry of $\text{Fs}_{27-35}\text{Wo}_{4-7}$, where Fs (ferrosilite; FeSiO_3) indicates iron and Wo (wollastonite; CaSiO_3) indicates calcium content. The presented range in pyroxene chemistry is caused by the uncertainties in the band centers. The mean pyroxene chemistry suggests a diogenite-rich assemblage, which is supported by its location on the pyroxene quadrilateral between diogenites and cumulates eucrites (Fig. 4). The Fe content in HED pyroxenes increases from diogenites ($\text{Fs}_{20-30}\text{Wo}_{1-3}$), to cumulate eucrites ($\text{Fs}_{30-44}\text{Wo}_{6-10}$), to basaltic eucrites ($\text{Fs}_{43-55}\text{Wo}_{9-15}$) [9]. Based on the overall spectral shape, the band parameters, and the inferred mean pyroxene chemistry we see strong evidence to support a diogenite-dominated composition for 1999 TA₁₀.

Apart from the two prominent absorption bands due to pyroxene, the spectrum of 1999 TA₁₀ has a weak absorption feature at $1.2 \mu\text{m}$, which is characteristic for basaltic eucrites [10]. This suggests that apart from a dominant diogenite component, the surface assemblage could have a minor basaltic eucrite component likely due to a collisional mixing formation mechanism. The depths of the two-pyroxene absorption features (18-20%) on 1999 TA₁₀ are severely sup-

pressed (Fig. 2) compared to typical HED features (diogenite: 40-60%).

Several possible mechanisms can be invoked for explaining these differences, including the presence of opaque material like carbon or metal, low bulk rock abundance of absorbing transition elements (e.g., Fe^{2+}), space weathering, phase angle, and particle size effects. Opaques like carbon suppress the absorption features but also reduce the albedo, which is not the case with 1999 TA₁₀ as it has a moderate albedo (≥ 0.15) [11]. Metal, phase angle, and lunar-style space weathering all redden (increasing reflectance with wavelength) the spectral slope.

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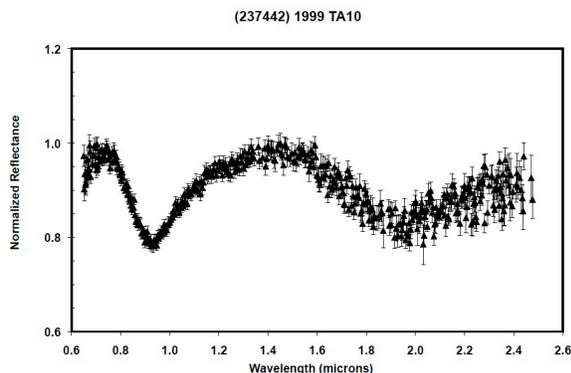


Fig. 1. Near-IR spectrum of 1999 TA₁₀ obtained using the SpeX instrument on NASA IRTF in low-resolution prism mode.

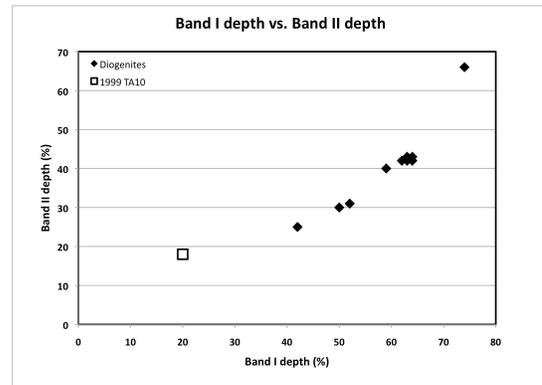


Fig. 2. Band I vs Band II depth plot showing 1999 TA₁₀ bands suppressed compared to diogenites.

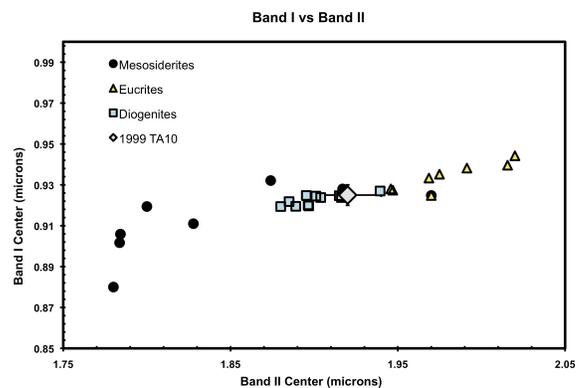


Fig. 3. Band I center vs Band II center plot showing band centers of eucrites, diogenites and mesosiderites along with 1999 TA₁₀.

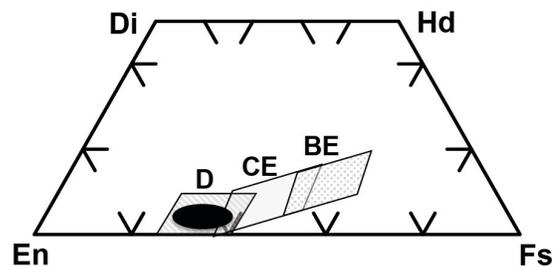


Fig. 4. Pyroxene quadrilateral showing the four end members enstatite (En), ferrosillite (Fs), diopside (Di) and hedenbergite (Hd). The three parallelograms in the middle represent pyroxene chemistry ranges for diogenites (D), cumulate eucrites (CE) and basaltic eucrites (BE). The black oval is the range of pyroxene chemistries for 1999 TA₁₀ given the uncertainties in the band centers and calibration.