# The Surface of 4 Vesta: a petrologist's view

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**Introduction:** *How do HED meteorites constrain the data to be returned from 4 Vesta by the Dawn Discovery Mission?* Vesta has long been equated with the “eucrite parent body” in its various iterations and the spectroscopic similarities between Vesta and HED meteorites are compelling**.** The assumption is made that Vesta is a fully differentiated body. In common with other terrestrial planets, the surface of the 'asteroid' Vesta (more realistically a planetoid) has provinces with distinct spectral characteristics. On the Earth, Moon, Mars and Venus, dichotomies between highlands and lowlands provinces are clearly delineated in existing planetary maps. On Vesta, the presence of a dichotomy is manifested as the huge elevation difference between the south polar region and the northern hemisphere when compared to an ideal spherical body. Petrologically, the uplands and lowlands provinces of Vesta have variable spectral signatures. These lithologies are assumed to correspond to the dominant lithic components in the basaltic achondrite meteorites (eucrites and diogenites) but the regolith of 4 Vesta is better represented spectrally by polymict breccias, especially howardites, that contain additional lithic components. The howardite group of meteorites provide the optimum sample suite for constraining the spectral data.

**The Major Provinces of Vesta:** The (S*outhern) Lowlands province* is a huge crater (multiring basin with central uplift?) that may have excavated as much as 10-20% of the original body and presumably exposes material from the Vestan mantle and perhaps even the core in its central uplift. The impact(s) that produced this depression must have triggered magmatism with associated thermal metamorphism and systematically reset the ages of several isotopic systems. For example, young crystallization ages associated with some cumulate eucrites reflect late stage magmatism associated with the Southern Lowlands impact.

At present, limited spectral evidence exists for mantle material on the surface, but that may be the effect of Vesta's axis of rotation, relative to the observations so far. If the Southern Lowlands disect a thick planetary crust(~65km), then the area of mantle (+/- core) derived material may be geographically limited

The (*Northern) Uplands province* presently encompasses much of the surface of Vesta. (Observations of Vesta suggest that other 100+km impact structures are present and may represent an intermediate 'province'.) The Uplands are significantly older then the Southern Lowlands. The age distribution of eucrites, between 4.5 and 3.5 Ga, probably straddles the province forming event. Older lithologies (e.g. most eucrites) sample the Northern Uplands province (perhaps concentrated near the equatorial plane) while younger lithologies are from the Southern Lowlands. Eucrite genesis models reflect the history of the uplands rather than the lowlands.

**The Vestan Sample Suite: HED achondrites:** The research emphasis of the past three decades is dominated by eucrites and needs to be realigned. *Eucrite*s are a class of basaltic meteorites that are a relatively homogeneous with tightly constrained compositions, most being (near) peritectic melts of presumed chondrite-like precursors in the olivine -plagioclase -silica system. *Diogenites* are essentially monomineralic orthopyroxenites considered to have crystallized from magmas related to the eucrites. Both rock types occur as major mixing components in the third group (*howardites*). The howardites are breccias, sampling numerous lithologies. While eucrites and diogenites are most common they are not the only lithic components.

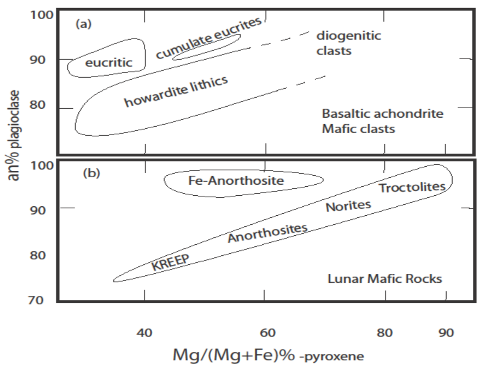
Vesta is small (~258km radius), and its regolith is probably globally mixed. The spectral evidence requires significant surface heterogeneity with variation in ratios of basaltic and pyroxenitic lithologies on the surface. Two possible interpretations of the heterogeneity exist. (1) The limited spatial resolution (subhemispheric) of the asteroidal spectra integrates signals from a wide variety of rock types on the surface of the asteroid. (2) The regolith on the surface of Vesta resembles howardite meteorites. The former is inevitable. The latter is the focus here. The limited spatial resolution of the current spectra suppresses the true spectral variation of lithologies on the regional scale (100's $km^2$). Despite this, hemispheric scale variations exist. Variations in lithology are already known on the surface of Vesta. The forthcoming orbital (Dawn) results should provide the distribution of lithology on Vesta at scales of ~150+m. We expect a much greater variety of spectral signatures. At this scale, compositionally distinct localities will be defined and the relationship with lithologies represented by clasts in howardites can be clarified. The scale of clasts in howardites (sub-millimeter) of course implies that Dawn will see less diversity than is seen in howardites, but the presence of sub-kilometer scale lithological features on Vesta can provide the comparison needed with lithological samples in the howardites, if they are adequately characterized.

The lithic components present in the howardites and the closely related polymict eucrites vary in mineral and bulk composition, in many ways, as do the various mafic suites on the Moon.

**Components of howardites:** Lithic and mineral clasts in howardites are the most complete sample set of the Vestan surface. The abundance of clast types in the howardites represents their immediate excavation site but provincial and global distributions of relative abundance on the Vestan surface remain to be constrained

Relative abundances of lithologies in howardites is derived: (1) using the distribution of Fe/Mg in pyroxene, the dominant mafic phase. Such distributions demonstrate clearly that although 'eucritic' and 'diogenitic' compositions are dominant, they are not the only components present. The distribution continuum observed is not consistent with simple binary mixing of eucrites and diogenites, but requires that other components be included. Intermediate compositions are present that correspond to the range of the cumulate eucrite group but petrographically are not members of that group. (2) These intermediate compositions belong to suite of lithologies that have distinctive Na/(Ca+Na+K) ratios (Figure 1). This may also be reflected in K/Na ratios of the feldspathic phases.

*Figure 1: Pyroxene-plagioclase trends in howardites & lunar samples*




These Mg/(Fe+Mg)vs Na/(Na+Ca) trends are analogous to lunar mafics (ANT and FAN suites) and require that a variety of magmatic processes were involved.

**Depth of sampling:** Diogenites, eucrites and polymict achondrites were delivered to earth by several ejection events (from 6 - 73 Ma ago). Ejection events, randomly scattered about the surface are required. However, olivine is essentially absent! Most impacts on Vesta did not sample olivine rich horizons. The thickness of crust based on chondritic precursors has been estimated to be up to 65 Km. Only the very largest impacts, such as the central uplift in the Southern Lowlands crater, will excavate significant amounts of olivine bearing mantle samples. Most craters will sample only crustal lithologies – the mafic and pyroxenitic components of howardites. In contrast, the impact that produced the Southern Lowlands structure must have had a dramatic effect on the interior of a body as small as Vesta. Potentially the mantle *and* core of Vesta were disrupted and mobilized by this event. Mantle and metal bearing lithologies may exist in uplifted portions of the Southern Lowlands and that the relationship between howardites and the mesosiderite meteorites may need to be reexamined. The overall similarity between mesosiderites and howardites is very well known, but consensus has them from different parent bodies. The systematic differences between the two groups may reflect only variants in planetary differentiation, impact melting and processing, (impact driven) meta-morphism, and redox phenomena (metal-silicate exchange). All combinations of these processes will occur in the planetary context of the surface of Vesta.

*The role of redox in differentiation. E*vidence of redox exchanges within HED mafic lithologies has been ambiguous. However, detailed studies of Fe-Mn-Mg systematics for the mafic suites in howardites suggest that lithologies that formed under variable, oxygen fugacity are present. The role of redox processes, e.g. metal-silicate exchanges, as in mesosiderites, is becoming clearer. This adds a new dimension to the standard models of eucrite and diogenite evolution.

**Howardites and DAWN spectrometry:** Links between the observed magmatic/metamorphic history of the meteorites and the Dawn observations begin with the VIS-IR spectrometry of the surface. If, as expected, the howardite lithologies, despite their small sample size, reveal local surface heterogeneity, then Dawn observations may relate directly to the howardite lithic assemblages rather than classical eucrites alone. Estimates of the degree of partial melting, fractional crystallization, metamorphic overprinting and redox exchanges will need spectral data from Dawn on the distribution of elements such as H, K, Ca, Ti, Cr , Fe, Ni. K and Ca may reflect the feldspathic variations seen in Figure 1. Ti, Cr and Fe and Ni reflect overall redox conditions as oxide minerals chromite, Ti-chromite, ilmenite are all known to occur in different achondritic clasts and imply variable redox conditions in addition to the evidence from Fe-Mn=Mg in silicates. (assumed to be untestable by Dawn instrumentation). Fe and especially Ni are of particular interest in locating metal, if present, on the surface.

**Summary** Howardite lithic clasts should be the focus of meteorite research prior to insertion of Dawn into orbit around Vesta. Eucrites and diogenites though abundant are limited subsets of the Vestan sample suite. The howardites provide samples of lithologies from Vesta never seen as eucrites or diogenites and are the optimum sample of Vesta for comparison with observations from orbit