SPACE WEATHERING ON ASTEROID (4) VESTA: WAITING FOR DAWN. M. J. Gaffey, Space Studies Department, John D. Odegard School of Aerospace Sciences, University of North Dakota, Box 9008, Grand Forks, ND 58202-9008, Email: gaffey@space.edu

Introduction: In July 2011, the DAWN spacecraft is scheduled to arrive at asteroid 4 Vesta to commence a nearly year-long orbital mission. The spacecraft instruments include multi-filter imaging systems, a UV to near-infrared spectrometer, and a neutron / gamma ray spectrometer to characterize the surface structure, mineralogy, and composition [1].

Asteroid 4 Vesta is the second largest asteroid and is surfaced with basaltic-type lithologies indicating that igneous processes operated early in its evolution [2-10]. A strong case has been made that Vesta is the probable parent body of the HED (Howardite–Eucrite–Diogenite) group of meteorites and of the small asteroids with Vesta-like spectra (Vestoids) which are located around Vesta as well as in near-Earth space [10-13].

Space Weathering: Space weathering is the collective name for the processes that optically alter the surface material of objects exposed to the space environment. The importance of space weathering was first identified in the soil samples returned from the Moon by the Apollo missions [e.g., 14]. Space weathering altered the spectral albedo of lunar soils relative to the bedrock lithology by lowering the albedo, reddening the spectral slope, and weakening the mafic mineral absorption features near 1 and 2 μm. Subsequent investigations established that this was primarily due to impact vaporization of soil grains by micrometeorites and subsequent condensation of the vapor to form glassy coats on the surfaces of soil grains. During vaporization, disproportionation of iron oxide (FeO) present in the mafic silicates into iron metal (Fe^0) and oxygen (which was lost) seeded the glassy grain coats with tiny iron metal blebs, producing the optical and albedo effects. This nanophase metallic iron ($npFe^0$) model [15-18] is now recognized as the primary mechanism for lunar-style space weathering.

Space Weathering and Asteroid Characterizations: The expectation that the most common types of meteorites (the ordinary chondrites / H-, L- & LL-types), which constitute ~75% of all meteorite falls [e.g., 19], should come from an abundant asteroid class led to the invocation of lunar-style space weathering to reconcile the spectra of ordinary chondrites with the spectra of S-type asteroids. The assumption that lunar-style space weathering operated on S-asteroid surfaces turned out – at best - to be of only very limited validity, since the majority of mineralogically characterized S-type asteroids had compositions incompatible with ordinary chondrite assemblages [20]. Only a subset of S-type asteroids, the S(IV)-subtype, had compositions which were compatible with – but not necessarily diagnostic of – ordinary chondritic assemblages. Subsequent work identified one of these S(IV) asteroids (6 Hebe) as the probable parent body of the H-chondrites [21].

Spacecraft Insights: The spacecraft encounters with 243 Ida and 433 Eros showed clear evidence of space weathering on these two asteroids. However, although these are both S-type objects, they exhibit very different styles of space weathering, and both styles differ from that seen on the Moon [22,23]. In retrospect, this is not particularly surprising. The lunar-style space weathering involves substantial vaporization of both the impacting micrometeorites and the soil grains that they impact at velocities of ~20 km/sec [24,25]. The mean impact velocity in the asteroid belt is much lower (~4.4 km/sec) [26]. This corresponds to more than an order of magnitude difference in impact energy, allowing extensive vaporization on the lunar surface but little or no vaporization on main belt asteroid surfaces. A number of potential processes could be important space weathering mechanisms on asteroid surfaces, including: (a) formation of glassy phases by impact melting[e.g., 27], (b) comminution of bedrock and soils to form fine powders [e.g., 28], (c) differential electrostatic sorting of silicate and metallic phases, (d) formation of an amorphous phase by charged particle irradiation, (e) comminution and redistribution of chondritic NiFe metal grains [e.g., 27], and (f) contamination by exotic material from outside the asteroid.

Space Weathering on Asteroid (4) Vesta: Asteroid (4) Vesta will should provide important insights into one type of asteroid space weathering. Compared to the spectra of HED meteorites, which nominally represent the bedrock lithologies of Vesta, the surface albedo of Vesta is higher, the Vesta spectrum is not reddened, and the mineral absorption features are weakened (Figure 1). Figure 2 schematically shows the apparent "space weathering" behavior of Vesta compared to the Moon, and S-type asteroids 243 Ida and 433 Eros. The mineralogy of Vesta (primarily anydrous mafic "basaltic" assemblages) is generally similar to that of the Moon, but the micrometeorite bombardment and the solar wind environments are substantially different. As far as we know, the bedrock of Vesta lacks a metallic NiFe metal phase, a phase probably present in the bedrock of Ida and Eros.

DAWN at Vesta: One of the first products of the DAWN mission at Vesta will be a characterization of the space weathering process(es) on Vesta's surface, which will be a joint effort of two instruments. Following the example of the Moon and 433 Eros, we expect that downslope movement will expose relatively fresh unweathered material while more weathered material will accumulate at the bases of slopes. Downhill streaks on the interior walls of craters and on the slopes of topographic highs will confirm mass wastage. Multi-color images obtained during the normal operation of the Framing Camera will be examined for albedo and/or color features that show these topographic relationships, and to detect any associated color (spectral slope) changes.

Recent work [23] has demonstrated that neither space weathered lunar samples or samples exposed to space weathering simulations exhibit variations in diagnostic spectral parameters (absorption band central wavelengths, band area ratios) which affect the mineralogical interpretation of visible and near-infrared (VNIR) spectra of mafic assemblages. Data from the visible and infrared mapping spectrometer can then be used to test whether this is also true for Vesta. Dawn at Vesta will provide critical data sets to understand the nature and variations of space weathering processes operating on asteroid surfaces.

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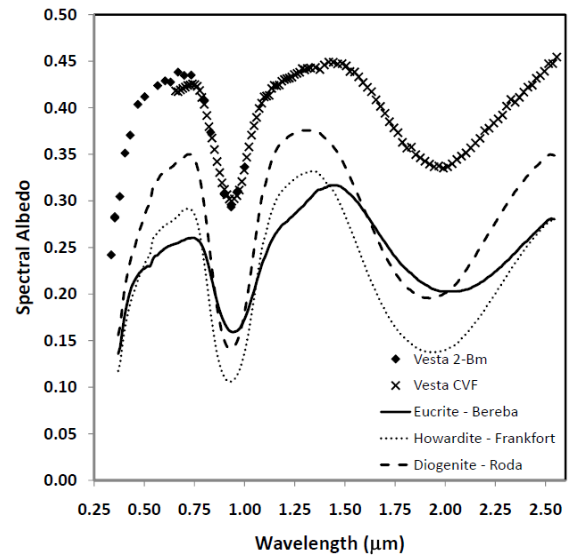

Figure 1: Reflectance spectra of Vesta compared to those of typical HED meteorites. Vesta has a higher albedo, flatter slope across the 1 µm band, and relatively weaker absorption bands.

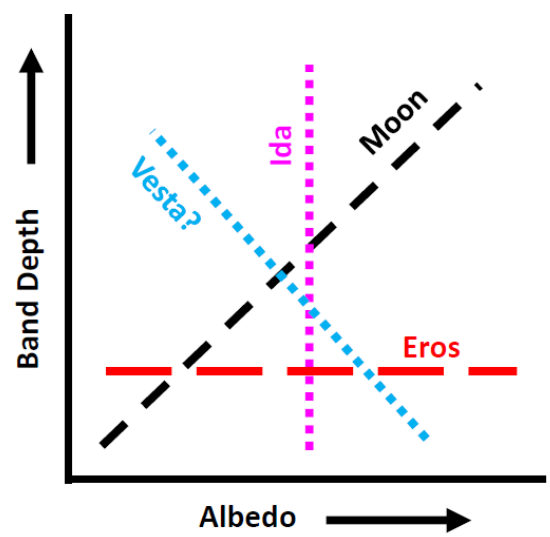

Figure 2: Schematic representations of the effect of space weathering observed on the Moon, and S-type asteroids 243 Ida and 433 Eros, and inferred from existing data for asteroid 4 Vesta.