Current Understanding of the Evolution of Vesta

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The Dawn spacecraft left asteroid 4-Vesta in September 2012 after spending more than a year accumulating orbital measurements of the only remaining intact planetary embryo that formed and differentiated during the first few 10s of My of Solar System evolution. Diverse data from Dawn’s three principal instruments [Framing Camera (FC), Visible and InfraRed imaging spectrometer (VIR), and Gamma Ray and Neutron Detector (GRaND)] have been calibrated and are available through the PDS for analysis. Although initial results have been reported for this ~525 km massive asteroid, important new insights will continue to emerge as these valuable data are integrated and analyzed in more detail. We highlight some of the important results, surprises, and issues that merit further investigation. Before Dawn’s arrival, telescopic measurements of Vesta revealed that the Howardite-Eucrite-Diogenite (HED) class of basaltic achondrite meteorites are most likely derived from Vesta or the family of similar nearby small bodies that might be the result of a major impact in the past. The highest resolution images from HST suggested the presence a gigantic crater near the south pole of Vesta that could mark such an impact and might (if recent) account for Vesta’s apparently unweathered surface.

As global data were acquired by Dawn’s instruments at increasing higher resolution, not only did the FC images allow the major ~500 km basin at the south pole (Rheasilvia) to be characterized in exquisite detail, but they also revealed a second large basin (Veneneia) and both basins were shown to be relatively old (1-3 Gy) based on different models of crater statistics. The spectroscopic data from VIR identified and mapped diagnostic absorptions of minerals in a spatial context and confirmed that the mineral composition of Vesta is dominated by pyroxene with the same bulk composition as the howardite meteorites (a mixture of eucrites and diogenites). This was substantiated with elemental data from GRaND, confirming Vesta’s early melting and differentiation. Geophysical data imply the presence of a dense ~110 km core. Nevertheless, distinct spatial variations are found to occur in regular patterns across the surface. The giant Rheasilvia basin at the south pole exposed abundant Mg-rich pyroxene (diogenites), but no evidence of olivine, a mineral commonly associated with mantle lithology and expected to have been revealed by such a deep excavation. In contrast, only a few small olivine-bearing areas have been identified in the northern hemisphere.

A significant surprise was to find concentrations of H (from GRaND) and OH (from VIR) which are correlated with large surface areas of relatively low albedo. The pattern is not associated with temperature or latitude variations (as on the Moon), but instead indicates the spatially coherent presence of a minor foreign component of OH-bearing species such as carbonaceous chondrite (CC) regionally embedded within the regolith. The presence of foreign CC components is also consistent with inclusions found in howardite breccias. Similarly, the special form of regolith space weathering observed on Vesta does not follow the formation of lunar-like nanophase opaques on regolith grains, but instead involves minor mixing of the regolith with a small amount of a neutral darkening agent such as CC micrometeorites. On a local scale, the presence of concentrated volatiles is suggested by mysterious clusters of unusual pits that are found in a few major craters, the morphology of which implies a rapid release of volatiles.

Altogether, Vesta has indeed revealed itself to be a fascinating planetary embryo that has survived from the dawn of solar system evolution. It also informs us that surfaces of large asteroids can contain a notable

foreign component. We are fortunate to have the diverse HED samples to constrain the early evolution of this planetary embryo and the Dawn data to constrain Vesta’s complex evolution to the present.

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