DETERMINING CONSTRAINTS ON CRUSTAL FORMATION PROCESSES ON VESTA USING DATA FROM THE DAWN MISSION. T. H. Burbine[1] and P. C. Buchanan[2], [1]Department of Astronomy, University of Massachusetts Amherst, Amherst, MA 01003, USA, tomburbine@astro.umass.edu, [2]Kilgore College, Kilgore, TX 75662, USA.

Introduction: In 2011, the Dawn spacecraft will rendezvous with asteroid 4 Vesta [1]. Vesta is the first asteroid [2] to be convincingly linked with particular meteorite groups (howardites, eucrites, and diogenites or HEDs) due to Vesta's spectral similarity to the distinctive reflectance spectra of HEDs in the visible and near-infrared spectral regions.

HEDs are a clan of ~900 achondritic meteorites that have continuous variations in mineralogy and chemistry. Eucrites are predominately basaltic rocks and are composed primarily of anorthitic plagioclase ($CaAl_2Si_2O_8$) and low-Ca pyroxene, which contains augite [$(Ca,Mg,Fe)SiO_3$] exsolution lamellae. Diogenites are predominately magnesian orthopyroxene [$(Fe,Mg)SiO_3$]. Howardites are polymict breccias containing fragments of both lithologic units.

Eucrites can be subdivided on the degree of equilibration [3,4]. Unequilibrated eucrites are similar to terrestrial volcanic rocks in that they cooled quickly and have experienced minimal post-crystallization metamorphism. These volcanic rocks are thought to have formed by the extrusion of eucritic melts onto the surface of the HED-parent body. Unequilibrated eucrites are relatively rare. Pyroxenes in equilibrated eucrites represent fine- to medium-grained pyroxenes that have either been cooled slowly or have experienced significant degrees of post-crystallization metamorphism [5]. Eucrites can also be subdivided on whether they have textures and compositions that suggest that they formed by cumulus processes (accumulation of crystals from a magma either by settling or floating; i.e., cumulate eucrites) and those that were not affected by cumulus processes (basaltic eucrites). Cumulate eucrites are relatively rare.

Dawn has a number of goals. These goals include determining the origin and evolution of Vesta; determining and mapping Vesta's surface composition; identifying, mapping, and characterizing geological and cratering processes and their chronology; and testing the link between Vesta and HED meteorites, and providing a geologic, compositional, and geophysical context for them.

To accomplish these goals, Dawn has a Visible and Infrared Mapping Spectrometer that will be able to obtain reflectance spectra of Vesta from 0.25 to 5 μm. At closest approach, the resolution of the spectrometer is ~200 m. Howardites, non-cumulate eucrites, and diogenites have distinctive band centers in the 1 and 2 μm wavelength regions and these meteorite types can be distinguished using reflectance spectra in the visible and near-infrared.

Dawn also has a Gamma Ray and Neutron Detector instrument (GRaND). For Vesta, GRaND will determine the bulk abundances of a variety of elements such as oxygen (O), magnesium (Mg), aluminum (Al), silicon (Si), calcium (Ca), titanium (Ti), iron (Fe), potassium (K), thorium (Th), and uranium (U). However, GRaND only has a resolution of ~300 km at closest approach.

Therefore, to determine petrological relationships on Vesta on scales of hundreds of meters, data from the Visible and Infrared Mapping Spectrometer must be used. We will discuss how we can possibly determine constraints on the mechanisms for forming Vesta's crust using Dawn reflectance spectra.

Determining Pyroxene Mineralogy and Mg#: Formulas have been developed by Gaffey et al. [6] and Burbine et al. [7] for determining the pyroxene mineralogy of a HED-like material from the band centers determined from its reflectance spectrum. These formulas calculate the molar contents of ferrosilite (Fs) and wollastonite (Wo) from Band I and Band II centers determined from a reflectance spectrum. The Gaffey et al. [6] equations were derived primarily from terrestrial pyroxene data while the Burbine et al. [7] equations were derived from howardites, eucrites, and diogenites with known average pyroxene mineralogies. Band centers are band minima after a spectral slope has been divided out of the spectrum. Both sets of formulas have uncertainties for the calculated Fs and Wo contents.

An important quantity that can be used to petrologically characterize HEDs is the Mg# of the pyroxenes. The formula for Mg# is

$$Mg\# = Mg \times 100/(Mg + Fe)$$

where *Mg* and *Fe* are the concentrations of these two elements expressed in molar proportions. The Mg# of the pyroxenes can easily be calculated from the ferrosilite and wollastonite contents since

$$En = 100 - Fs - Wo$$

and

$$Mg\# = En \times 100/(En + Fs).$$

Therefore, Mg#s can be derived from Fs and Wo contents determined from Vesta's reflectance spectra.

The importance of Mg# is that the first ferromagnesian minerals that crystallize from a melt tend to be enriched in Mg relative to the melt. Minerals that crystallize later tend to have lower Mg#s. Diogenites have high pyroxene Mg#s (~70-80), most eucrites tend to have low pyroxene Mg#s (~35-50), and howardites have pyroxene Mg#s that are variable with averages that are intermediate between diogenites and eucrites. However, cumulate eucrites have pyroxene Mg#s (~51-67) that overlap the average pyroxene Mg#s of the howardites due to the cumulate eucrites appearing to be the products of fractional crystallization from an Fe-rich eucritic melt. The most Fe-rich eucrites have Mg#s of ~30. Mapping the Mg# over the surface of Vesta will provide important information about the spacial distribution of various petrologic types of HED materials and, hopefully, elucidate the petrologic processes that acted on Vesta.

Vesta: Dawn is expected to see spectral variations on Vesta's surface. Spectral variations on Vesta are very apparent in Earth-based rotational spectra [8] and Hubble spectroscopic measurements [9]. Craters will provide an opportunity to probe the interior of Vesta. Thomas et al. [10] has identified a 460-km diameter crater at Vesta's South Pole that has spectral features consistent with excavation deep into a high-calcium pyroxene-rich crust or olivine-rich upper mantle. Many more craters will be observed by Dawn. Mapping the Mg#s over these craters will give insight on the mineralogy of Vesta's subsurface.

There are a number of proposed models for forming Vesta's crust [11]. The most widely proposed one incorporates the idea that most eucrites are associated with a magma ocean that formed on Vesta [12]. This magma ocean might have led to a layered crust with diogenites being early cumulates found at the deepest depths of the crust. This diogenitic material might have been overlain by pyroxene cumulate eucrites which would have been overlain by eucrites that represent residual melts. The latest discussion of the magma ocean model can be found in Barrat et al. [13]. Takeda [14] has suggested that unequilibrated eucrites would have extruded onto the surface from residual liquids in the center of the magma ocean after the surface had cooled sufficiently to support the weight of these lava flows.

Evidence for a magma ocean might be craters with floors with mineralogies similar to diogenites or cumulate eucrites. Diogenites should be easy to distinguish spectrally due to their distinctive Mg#s and spectral properties. However, since cumulate eucrites and howardites have overlapping Mg#s, it may be difficult to distinguish these units based on Band I and Band II centers. Klima et al. [15] has found that cumulate eucrites lack a feature at ~1.2 μm. This feature has been attributed to Fe^{2+} in the M1 crystallographic site in the pyroxene [16]. This ~1.2 μm feature tends to be stronger for pyroxenes that cooled relatively quickly, which "traps" some Fe^{2+} in the M1 crystallographic site. Such pyroxenes are found in non-cumulate eucrites. However, howardites also have relatively weak ~1.2 μm features, which may make it difficult to conclusively identify cumulate eucrites just based on this feature.

Another suggested model proposes that Vesta's crust was formed by serial magmatism [5]. In the serial magmatism model, most of the crustal units on Vesta would be variably metamorphosed extrusives, except for small magma chambers (dikes and sills) that would be the probable source of the cumulate eucrites and the diogenites [17]. Hence, if this model is correct, *in situ* cumulate eucrites and diogenites may be limited to small bodies exposed on the sides of impact craters.

If the serial magmatism model is correct, craters should have floors with mineralogies resembling non-cumulate eucrites. Diogenitic and cumulate eucritic material would be found in relatively small intrusive bodies on the side of craters.

Conclusions: The Visible and Infrared Mapping Spectrometer on Dawn will map Vesta with a resolution of ~200 m. Mg#s can be derived from the reflectance spectra, which can be used to distinguish different lithologic units on Vesta. The relationships between these units should allow different models for forming Vesta's crust to be tested.

References: [1] Russell C. T. et al. (2007) *Earth, Moon, and Planets, 101,* 65-91. [2] McCord T. B. et al. (1970) *Science, 168*, 1445-1447. [3] Reid A. M. and Barnard B. M. (1979) *LPS X*, 1019-1021. [4] Takeda H. and Graham A. L. (1991) *Meteoritics, 26*, 129-134. [5] Yamaguchi A. et al. (1996) *Icarus, 124,* 97-112. [6] Gaffey M. J. et al. (2002) *Asteroids III*, 183-204. [7] Burbine T. H. et al. (2009) *Meteoritics & Planet. Sci., 44*, 1331-1341. [8] Gaffey M. J. (1997) *Icarus, 127*, 130-157. [9] Binzel R. P. et al. (1997) *Icarus, 128,* 95-103. [10] Thomas P. C. et al. (1997) *Science, 277*, 1492-1495. [11] Keil K. (2002) *Asteroids III*, 573-584. [12] Mason B. (1962) *Meteorites*. [13] Barrat et al. (2009) *Meteoritics & Planet. Sci., 44*, 359-374. [14] Takeda H. (1997) *Meteoritics & Planet. Sci*., 32, 841-853. [15] Klima R. L. et al. (2008) *Meteoritics & Planet. Sci., 43*, 1591-1604. [16] Klima R. L. et al. (2007) *Meteoritics & Planet. Sci., 42*, 235-253. [17] Wilson L. and Keil K. (1996) *JGR, 101*, 18927-18940.