THE COMPOSITION OF VESTA FROM ALL DAWN DATA AND ANALYSES. T. B. McCord[1] and J. E. C. Scully[2], [1]Bear Fight Institute, Winthrop, WA 98862 (tmccord@bearfightinstitute.com), [2]University of California, Los Angeles CA 90095 (jscully@ucla.edu).

Historical Knowledge: The global composition of Vestaös surface was known from ground-based telescopic spectral observations, before the Dawn spacecraft orbited Vesta in 2012, to be basaltic, rich in the mineral pyroxene, and have mineralogy similar to that of an abundant class of meteorites, the basaltic achondrites (Howardites, Eucrites, and Diogenites -HEDs), suggesting that Vesta was differentiated and could be the source of the HED meteorites [1]. Later observations greatly improved the quality of the spectra and confirmed and extended these findings. These telescopic observations of the spinning Vesta also showed sub-global compositional variations, which are limited to a differing pyroxene-dominated mineralogy similar to that observed in the HEDs. Based on Vesta being the source of HEDs, laboratory studies of the HEDs were used to infer the evolutionary history of Vesta [2]. An argument was also developed that a family of other, smaller, objects of similar spectroscopic character are pieces from Vesta [3], suggesting the HED-like composition extends below Vestaös surface.

The Dawn Context: The Dawn Mission [4] provided the first look at Vestaös surface with spatial resolution sufficient to define surface features, thus providing a dramatic new dataset for studying Vesta and major improvements in our understanding of Vestaös origin and evolution. Dawnös instrument arsenal is capable of providing much new information about the two most important aspects of a planetary bodyös surface: 1) surface features, the topographical expressions of surface and interior processes, and 2) composition, mineral, molecular and elemental, resulting from thermochemical processes.

The Framing Camera (FC) [5] provided a color view of nearly the entire surface and revealed surface features that include giant impact craters, grooves, ridges, and dark and bright materials. Especially important for the topic of this report, the FC also enables detailed mapping of some compositional units using the color imagery, although the FC spectral sampling does not allow for detailed analysis of spectral features. For example, FC photometrically corrected reflectance and Clementine-type color ratio mosaics identify east-west and north-south dichotomies in the surface composition of Vesta, and more diogenitic material is identified in the southern hemisphere. Furthermore, FC color data is one line of evidence that leads to the interpretation of the surface compositions of smaller-scale terrains on Vesta. For example, reflectance in the 0.75-εm filter, and ratios of other FC filters, allow for the identification and classification of dark material, and these data contribute to the interpretation of dark material as exogenic carbonaceous chondrite [6]

The Gamma Ray and Neutron Detector (GRaND) [7] mapped elemental composition on a regional to global scale. The physics behind the GRaND observations limited its spatial resolution, and does not allow association of elemental abundances with smaller individual surface features. However, GRaND findings do provide important, unique compositional information on the regional and global scales, and they provide important context for the detailed mineralogical findings. For example, they independently confirmed the association of the HEDs with Vestaös surface, and detected the unexpected presence of H-bearing materials.

The Visible and Infrared Mapping Spectrometer (VIR) [8] obtained reflectance spectra of the surface at wavelengths of 0.25-µm to 5-µm, which resolved most of the imaged surface features (spatial) and the strong spectral absorptions present (spectral). The spectra are especially informative of the surface mineralogy, as shown by the early telescopic observations, allowing, for example, detailed pyroxene chemistry determinations and identification of areas of diogenitic, howarditic and eucritic compositions. Further, VIR spectral imaging determines the associations of mineralogy with surface morphology, linking chemistry with geology.

A special issue of Icarus is in the publication process that contains articles describing the first systematic study of the surface mineralogy of Vesta, using the entire VIR data set and the latest calibrations from the Dawn at Vesta campaign. Information from the GRaND and FC investigations are also utilized, especially as they augment the mineralogy analyses. This presentation is an overview of these and related Dawn studies. The special publication concerning Vesta composition follows the recent special publication (Icarus, 244, 2014) that provided a systematic geological analysis of Vestaös surface features using the entire Vesta campaign FC imagery. These two different, yet complimentary, studies provide critical elements of a multilayered information base that can be used to infer the origin and evolution of Vesta.

Some first results from the Vesta mineralogical analysis using parts of the VIR data set and early calibrations have been published, e.g., [9]. In general, these early results confirmed and strengthened the Vesta-HED link and the concept that Vesta is differentiated. HED-like mineralogy differences across the surface were detected and all the different HED lithologies were found to be present. Basic diogenitic materials, expected to be associated with a differentiated Vesta◌̂s mantle, were found to be scarce, with most but not all deposits generally associated with the deep basin in the Rheasilvia region. Dark material deposits with OH spectral signatures [9] and excess H [10] were interpreted to be due to infalling carbonaceous chondrite-like material contaminating the brighter endogenous Vesta pyroxene-rich surface [6], consistent with inclusions especially in the brecciated howardites [2].

Conclusions: Overall, the results from the Dawn composition analysis confirm early telescopic global observations and interpretations, but extend them to a regional and local extent. Furthermore, these results tie together more tightly Vesta and the HED meteorites; the mineralogy is closely related to that of the HED meteorites in every way analyzed, strongly confirming and extending the inferences made from the early observations. Moreover, the regional and global elemental composition strongly agrees with this mineralogy and Vesta being the source of the HEDs (Fig. 1).

In general, the surface composition of Vesta is remarkably uniform, being basaltic and pyroxene rich. Some (darker) hydrated material (and likely mafic-rich material as well) has been added through infall of exogenic meteorites, which were mixed into (bright) endogenic Vestan material by repeated, relatively low velocity impacts. Giant, basin-forming impacts in the south polar region have redistributed material globally (and beyond) and exposed material that should have been well below the crust of this differentiated body. Little or no chemical space weathering is evident and formation of impact melt seems limited or non-existent. There are significant differences in pyroxene chemistry across the surface and limited exposures of what is interpreted to be olivine-bearing material, possibly related to the basin-forming impacts in the south polar region, although an alternate interpretation is suggested that a combination of pyroxenes only, perhaps from infall, with no olivine detected, could explain the spectra [11].

The composition of Vesta presents a clear and fundamental example of a silicate body that melted and differentiated (even a dense core is reported) and was subsequently subjected to heavy, repeated bombardment, which redistributed materials and contributed external contamination. A major puzzle is the lack of large or perhaps any exposures of olivine-rich mineralogy (although in is suggested that ~25% olivine may be needed to detect it by spectroscopy in a mix with small-grained pyroxene), suggesting that a pure magma ocean hypothesis for Vesta◌̂s early evolution may be at least diluted by regional and local partial melting and incomplete differentiation. Dawn has greatly improved our knowledge and understanding of Vesta and has shown Vesta to be an endmember example of the evolution of a silicate body within our Solar System.

References: [1] McCord, T. B. et al. (1970) Science, 168. [2] McSween, H. Y. et al. (2011) Sp. Sci. Rev., 163. [3] Binzel, R. P. and Xu, S. (1993) Science, 260. [4] Russel, C. T. and Raymond, C. A. (2011) Sp. Sci. Rev., 163. [5] Sierks et al. (2011) Sp. Sci. Rev., 163. [6] McCord et al. (2012) Nature, 491. [7] Prettyman et al. (2011) Sp. Sci. Rev., 163. [8] DeSanctis et al. (2011) Sp. Sci. Rev., 163. [9] DeSanctis, M. C. et al. (2012) Science, 336 and (2013) MAPS, 48; Ammannito, E. et al. (2013) MAPS, 48; McSween et al. (2013ab) JGRP, 118 and MAPS, 48. [10] Prettyman et al. (2013) MAPS, 48. [11] Combe, J-Ph. et al. submitted to the Icarus special issue.

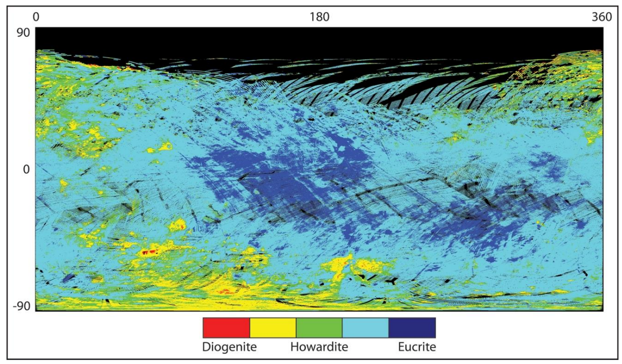

Figure 1. Global lithological map of the surface of Vesta, derived from the VIR HAMO data, after Ammannito et al. 2013.