Icarus 259 (2015) 181–193

Contents lists available at ScienceDirect

Icarus

journal homepage: www.elsevier.com/locate/icarus

Spectral analysis of the quadrangles Av-13 and Av-14 on Vesta

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ARTICLE INFO

Article history:
Received 16 January 2015
Revised 11 May 2015
Accepted 12 May 2015
Available online 2 June 2015

Keywords:
Asteroid Vesta
Mineralogy
Spectroscopy

ABSTRACT

The Av-13 (Tuccia) and Av-14 (Urbinia) quadrangles are located in the south-west region of Vesta. They are characterized by a large topographic variability, from the highest (Vestalia terra highlands) to the lowest (Rheasilvia basin). Many geological units in these quadrangles are not associated with mineralogical variability, as shown by the color-composite maps. Maps of mafic absorption band-center position reveal that the principal lithology is eucrite-rich howardite, but diogenite-rich howardite areas are also present, corresponding to particular features such as Antonia and Justina craters, which are characterized by strong mafic absorptions. These quadrangles, especially Urbinia, contain many bright ejecta, such as those of Tuccia crater, which are the highest reflectance materials on Vesta (Zambon et al., 2014). Dark areas are present and correspond to regions with deeper OH-signature. The two quadrangles contain many vertical ridge crests associated with the Rheasilvia impact. These ridges do not show mineralogical differences with respect to their surroundings, but have a distinctive appearance in color-ratio composite images.

1. Introduction

Vesta, the second most massive body in the main asteroid belt (Thomas et al., 1997; Zuber et al., 2011), can be considered a relic of the protoplanetary disk, revealing the history of the early Solar System (Coradini et al., 2011). Dawn, the NASA discovery mission devoted to the study of Vesta and Ceres, covered a large part of Vesta's surface during the orbital phase. Dawn has three instruments: the Framing Camera (FC), the Visible and InfraRed Spectrometer (VIR), and the Gamma Ray and Neutron Detector (GRaND) (Sierks et al., 2011; De Sanctis et al., 2011; Prettyman et al., 2011). Before the arrival of Dawn, Vesta's surface was divided into fifteen quadrangles which were later named for their respective individual features (Fig. 1) (Russell and Raymond, 2011). For each quadrangle geological (Williams et al., 2014) and mineralogical maps (Frigeri et al., 2015b, this special issue) have been produced. In this paper, we discuss the mineralogy of two contiguous quadrangles, Av-13 (Tuccia) and Av-14 (Urbinia), located in the southern hemisphere (Fig. 1). These quadrangles contain several geological units, and part of the Rheasilvia basin (McSween et al., 2013; Ammannito et al., 2015), the Vestalia Terra highlands (Frigeri et al., 2015a), and enigmatic "orange" materials (Le Corre et al., 2011; Garry et al., 2014; Tosi et al., 2015). Moreover Av-13 and Av-14 contain numerous ridges and grooves also present in other quadrangles (see Longobardo et al., 2015; McFadden et al., 2015). Kneissl et al. (2014) and Mest et al. (2012) performed the geological analysis of the quadrangles, mapping a variety of geological units. In this paper, we analyzed the general mineralogy of the Tuccia and Urbinia quadrangles, as well as specific features, using several tools, such as spectral parameters, temperature maps and spectral unmixing. Ground-based observations (Gaffey, 1997) and Hubble Space Telescope (HST) data (Li et al., 2010) of Vesta have previously revealed the ubiquitous presence of pyroxenes but also mineralogical variations on Vesta's surface. The Dawn mission provided many high-resolution observations of Vesta, allowing for the derivation of the distribution of global and local lithologies (De Sanctis et al., 2012a; Ammannito et al., 2013a). VIR, the Dawn visible and infrared spectrometer, acquired more than 20 million spectra at different spatial resolutions, providing a large coverage of Vesta's surface. VIR confirmed the presence of pyroxenes

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http://dx.doi.org/10.1016/j.icarus.2015.05.015
0019-1035/

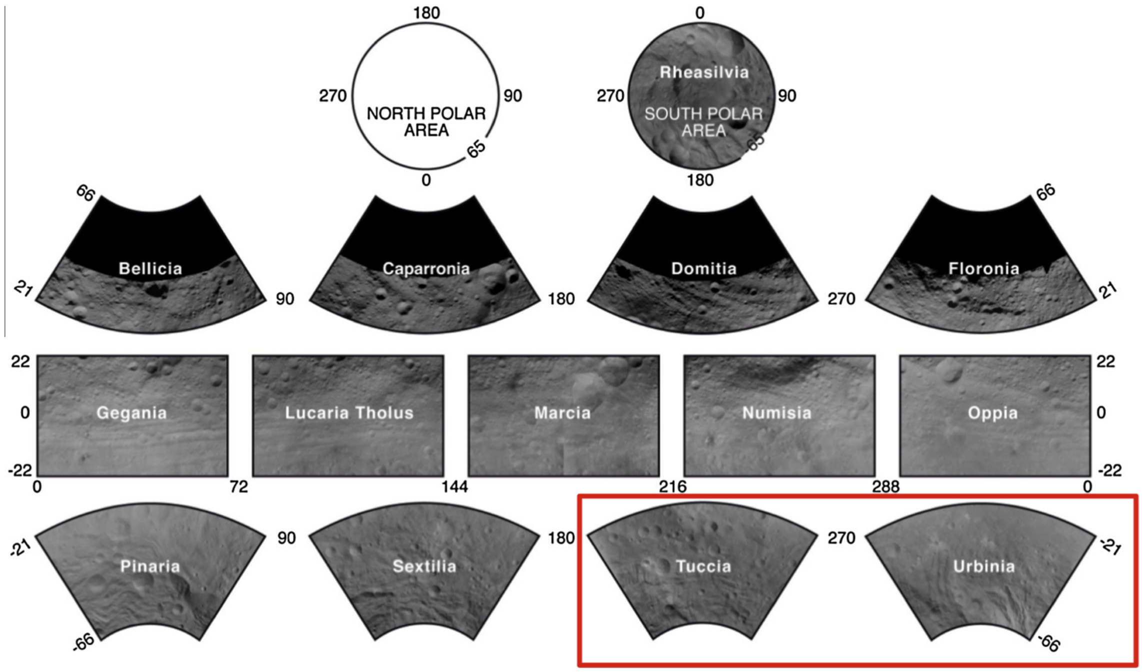

Fig. 1. Vesta's surface divided into quadrangles. Tuccia (Av-13) and Urbinia (Av-14) quadrangle are indicated in the red rectangle. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(McCord et al., 1970) associated with the howardite, eucrite and diogenite (HED) meteorites at global scale (Drake, 1979; Feierberg and Drake, 1980; De Sanctis et al., 2012a, 2013), but other minerals have also been found in localized areas. Olivine has been discovered in the northern hemisphere, in correspondence with Bellicia and Arruntia craters (Ammannito et al., 2013b; Ruesch et al., 2014) (see also Combe et al., 2015b), while opaque hydrated material, likely associated with carbonaceous chondrite impactors, has been detected in dark units (Jaumann et al., 2012; McCord et al., 2012; Palomba et al., 2014) and in the region of the Marcia crater (De Sanctis et al., 2015a,b). The VIR spectra of Vesta are characterized by the two pyroxenes bands at 0.9 (band I) and 1.9 μm (band II) typical of Fe-bearing pyroxenes (McCord et al., 1970; De Sanctis et al., 2012a). Spectral parameters, such as the band center, reveal lithologies from diogenite to eucrite. The center position of the two bands are associated with iron content (Adams, 1974). A band center shifted toward longer wavelengths is indicative of a higher content of Fe^{2+} and vice versa (Klima et al., 2007, 2011). The depth of a band gives an indication of the abundance of the absorbing minerals, the grain size and the presence of other materials (Clark, 1999). The signature at 2.8 μm is related to the abundance of OH, and reveals the existence of hydrated areas in association with dark material (Jaumann et al., 2012; McCord et al., 2012; De Sanctis et al., 2013; Palomba et al., 2014). A color composite map is very useful in emphasizing spectral slope differences. The spectral slope gives information on the composition and maturity of the soil, and each color indicates a particular terrain type on Vesta's surface (see Section 3.2). Lithological variation on Vesta can also be analyzed by application of a spectral linear unmixing algorithm. We select a plausible laboratory spectra sample of Vesta's analogues (called endmembers), we found the best linear combination of these endmembers for each VIR spectrum. This technique allows for identifying the lithologies present in some interesting regions and the relative abundance of each endmember, providing a quantitative information of the abundance of the lithologies on Vesta (for more detail see Section 3.5 and Zambon et al., submitted for publication). All these tools are very useful in performing an in-depth spectral analysis of the two quadrangles.

2. Data

Dawn acquired data at different spatial resolution based on the altitude of the spacecraft from the surface (Russell et al., 2007, 2012, 2013; Russell and Raymond, 2011). The mission at Vesta consisted of five principal phases. The mission phases are summarized in Table 1.

VIR is made up of two spectral distinct detectors, or "channels". The visible channel covers the wavelengths ranging between 0.25 μm and 1.07 μm, and the infrared channel is sensitive from 1.02 μm to 5.10 μm (De Sanctis et al., 2011). Each channel has 432 bands, which defines the spectral resolution of the two detectors. The average spectral sampling is 1.8 nm/band for the visible channel and 9.8 nm/band for the infrared channel (De Sanctis et al., 2011).

The VIR spectral range allows for a mineralogical and a thermal analysis of Vesta surface. VIR data, in units of calibrated reflectance factor (I/F) from 0.4 μm to 3 μm, are fundamental for the characterization of the two pyroxene bands, and for analysis of the OH-signature at 2.8 μm. Bridging between the two VIR channels is performed in post-processing. A gap in the spectra near 1.1 μm is due to the junction between the visible and infrared channels. To reduce the noise, we removed recurrent spikes due to damaged pixels or calibration residuals, and we smoothed the spectra before deriving the spectral parameters. The spectra have been smoothed with a boxcar average of 3 spectral channels (supplementary online material of De Sanctis et al., 2012a). The Dawn Framing Camera obtains images through a broad-band clear filter and seven narrow-band filters (center wavelengths in the range 0.4–1.0 μm) (Sierks et al., 2011). With these filters color-ratio composite maps have been produced using band ratios similar to those often adopted for Clemetine ratio maps of the Moon (e.g. Pieters et al., 1994).