VESTA EVOLUTION FROM SURFACE MINERALOGY: MAFIC AND ULTRAMAFIC MINERAL DISTRIBUTION.

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Abstract Vesta is the only intact, differentiated, rocky protoplanet and it is the parent body of HED meteorites [1,2]. Howardite, eucrite and diogenite (HED) meteorites represent regolith, basaltic-crust, lower-crust and possibly ultramafic-mantle samples of asteroid Vesta. Only a few of these meteorites, the orthopyroxene-rich diogenites, contain olivine, a mineral that is a major component of the mantles of differentiated bodies, including Vesta. The HED parent body experienced complex igneous processes that are not yet fully understood [2] and olivine and diogenite distribution is a key measurement to understand Vesta evolution. Here we report on the distribution of olivine and its constraints on vestan evolution models.

Diogenite and Olivine distribution

The Visible and Infrared Mapping Spectrometer (VIR) on board NASA's Dawn spacecraft has been used in a global search for olivine on the vestan surface [3]. At spatial scales ranging from tens of meters to tens of kilometers, infrared spectra of Vesta are characterized by prominent pyroxene absorptions at 0.9 and 1.9 μm. Several spectral different regions of Vesta have been identified. They are characterized by distinctly different band depths, widths, shapes and centers [4,5] suggestive of different HED lithologies. VIR data revealed a global-scale dichotomy (fig.1), with diogenite-rich material exposed predominantly in the deeply excavated southern basins. VIR spectra did not provide definitive evidence for pure olivine within the two large basins of the southern hemisphere. However, typical olivine-bearing diogenites cannot be easily distinguished spectrally from olivine-free diogenites because of the difficulty in identifying olivine at low concentrations when abundant orthopyroxene is present; thus, olivine may be occurr within the southern basins but only in modest amounts.

Unexpectedly, highly localized olivine-rich areas have been discovered in the northern hemisphere [6]. The VIR spectra of ejecta surrounding Arruntia crater and the nearby Bellicia crater reveal clear olivine signatures. The Vestan olivine-rich spectra and derived parameters are consistent with a mixture of 50–80-vol% olivine with pyroxene occurring over a broad area of hundred-kilometre size, encompassing both Bellicia crater and Arruntia crater.

The geological setting suggests that olivine-rich lithologies occur as a bright layer partly obscured by slump deposits and gardening of the surface. Unlike its occurrence in HED meteorites, mainly as a small volume fraction in diogenites, here a lithology rich in olivine (>50 vol%) in patches hundreds of metres in size is mixed with howarditic regolith. The possible identification of other few locations with a small amount of olivine [7] indicates a concentration in the eastern hemisphere of Vesta, where also hemispherical enrichment in diogenite has been mapped [4,5,6].

Clues on the interior

The identification of olivine-rich lithologies on Vesta can constrain different petrologic scenarios, each of which predicts different abundances and distributions of olivine.
The two main petrogenetic models for Vesta are: 1) magma ocean models [8], which invoke widespread early crystallization of olivine, and 2) fractionation in multiple crustal plutons [9,10].
Magma-ocean models of Vesta predict an olivine-rich mantle composed of harzburgite below an orthopyroxene (diogenitic) lower crust, and a basaltic upper crust. This model, with olivine well below the crust, predicts that olivine-rich material would only be excavated by large, basin-forming impacts. Alternative models consider that some diogenites and harzburgites (diogenites with olivine)may have formed at the base of, or within, the vestan basaltic crust. The serial-magmatism model envisions smaller scales of petrologic variation, suggesting a mixed lithology of olivine and orthopyroxene that is not observed.

The occurrence of several olivine spots a few hundreds of metres across, as seen in the walls of Bellicia, seems hard to reconcile with a crustal pluton origin. The large exposures of olivine-rich material and their association with howardite may favour a magma-ocean model for the origin of the olivine. However, the apparent absence of olivine concentrations in Rheasilvia suggests that the internal distribution of lithologies was heterogeneous, perhaps supporting the serial-magmatism model, or that the crust–mantle boundary was deeper in the region excavated by Rheasilvia than in the Bellicia–Arruntia region.

In any case, the lack of olivine-rich materials in the southern deeply excavated basins and its unexpected discovery in the northern hemisphere of Vesta indicate a more complex evolutionary history than inferred from pre-Dawn models.

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References

[1] Russell, C.T. et al., Science, 336, 684, 2012.

[2] McSween H. Y., et al., Space Science Reviews 163:141–174, doi:10.1007/s11214-010-9637-z.

[3] De Sanctis M.C. et al., Space Sci. Rev., DOI 10.1007/s11214-010-9668-5 , 2010.

[4] De Sanctis M.C. et al., Science, 336, 697, 2012.

[5] Ammannito et al., . Meteorit. Planet. Sci. maps.12192, 2013.

[6]Ammannito E., et al. , Nature, 122, vol. 504., 2013

[7] Ruesch O., et al., LPSC 2014.

[8] Mandler B. E. and Elkins-Tanton L. T. (2013), MAPS 48, 2333-2349.

[9] Barrat, J.-A et al. Geoch. Cosmoch. Acta 74, 6218-6231. 2010.

[10] Beck, A.W., McSween, H.Y., MAPS, 45, 850-872 2010.

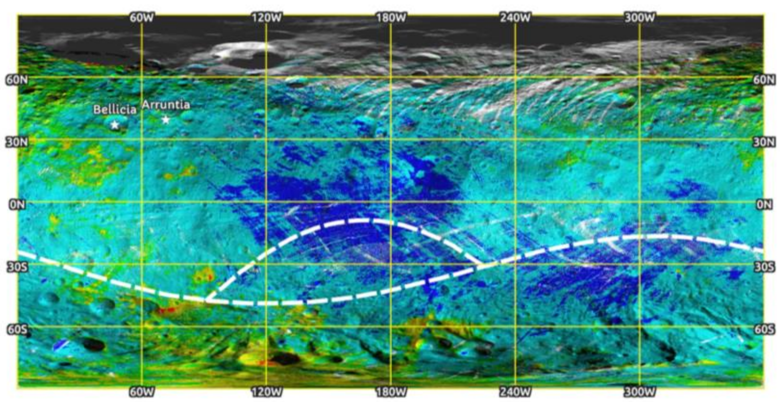

Fig.1: Lithological map of Vesta's surface derived from VIR spectra: red for diogenite, green for howardite, blue for eucrite, with overlapping fields of yellow for diogenite–howardite and cyan for eucrite–howardites. Olivine rich region in Arruntia and Bellicia craters are indicated.