LABORATORY HEATING OF HED + CC MIXTURES INDICATES LOCALIZED OXIDATION ON VESTA.

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Introduction: On asteroid Vesta, pyroxene-dominated materials prevail (i.e., HED meteorite-like material; e.g., [1-3]) and since NASA's Dawn mission it has been known that a dark component – likely OH-bearing carbonaceous chondrite (CC) material – reduces the spectral characteristics of the Vestan regolith (e.g., [4-6]).

Pitted impact deposits on Vesta have been shown to exhibit distinct spectral characteristics [7]: higher reflectance and pyroxene band strength with respect to their immediate surroundings. These immediate surroundings are likely deposits with same ages and initial composition [7], thus the origin of spectral differences is still unclear and inconsistent with variations in grain size, roughness, shock or glass content.

These pitted impact deposits indicate rapid devolatilization of the host material ([7-9]). The driver of this devolatilization is likely impact heat and here we present heating experiments of HED + CC material in order to elucidate what could cause the distinct spectral characteristics of the pitted impact deposits.

Method: The execution of the heating experiments occurred in the PSL (Planetary Spectroscopy Laboratory, [10]) at DLR Berlin. Mixtures of fine- to coarse-grained HED and CC material (about <25 – 250 μm) were firstly cooled to about -80 °C and then heated to various temperatures and durations under a vacuum of about 0.1 to 0.01 mbar. The samples were heated in a 1 cm wide, round sample holder with approximate thicknesses of 1-2 mm. We let the samples cool down under vacuum and then measured their reflectance in air (measurements in vacuum were terminated due to degassing events during the measurements). Measurements were taken from the unchanged surface and again from the mechanically mixed sample. This was done as we observed different characteristics of the interior material with respect to the surface material. The mechanically mixed sample is termed "interior" for simplification (the mixture still contains surface particles). A mechanical separation of interior and surface particles was not possible.

Due to the development of steep visible spectral slopes in most of the sample interiors we analyzed the samples by means of EPMA at the Museum für Naturkunde Berlin. These measurements were explicitly done to identify possible iron oxides with a focused beam at 15 kV and 15 nA.

Results: Figure 1 shows the unheated (grey) and heated (600 °C, 72h, orange and pink) spectra of a mixture of North West Africa 5748 (Howardite, 80 wt%) and Murchison (CM2 chondrite, 20 wt%).

With respect to the surface of the heated sample, the mechanically mixed sample exhibits higher overall reflectance, a steep visible slope and a stronger pyroxene absorption. We observed this spectral behavior of the interior vs. surface for multiple variations of temperature, heating duration and mixtures. We also observed a similar behavior when heating only Murchison, yet not when heating only pyroxenes/HED material. Thus, we speculated that iron oxides formed due to the mobilization of volatiles from Murchison and subsequent oxidation.

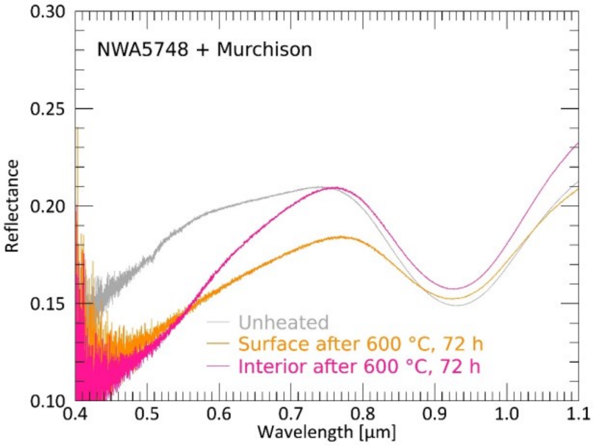

Figure 1: Spectra of NWA 5748 + Murchison mixtures: unheated (grey), surface of heated spectra (orange) and interior of heated spectra (pink). The aliquots were heated to 600 °C.

Figure 2 shows two EPMA images of mainly pyroxene grains of the heated (600 °C, 72 h) mixture of NWA 5748 and Murchison. Hematite appears as thin coatings around pyroxenes, sulfides and metal. This was not observed in the unheated aliquot.

Discussion: The formation of hematite indicates oxidation of the sample, where volatiles are likely derived from Murchison (as Murchison contains abundant OH-bearing minerals). This process does not appear to occur with surface grains, indicating that volatiles were quickly lost to the vacuum without the possibility to react. However, the mere formation of hematite cannot explain the strengthening of the pyroxene absorption. In addition, such a steepening of the visible spectral slope is not observed for the pitted impact deposits on Vesta [7].

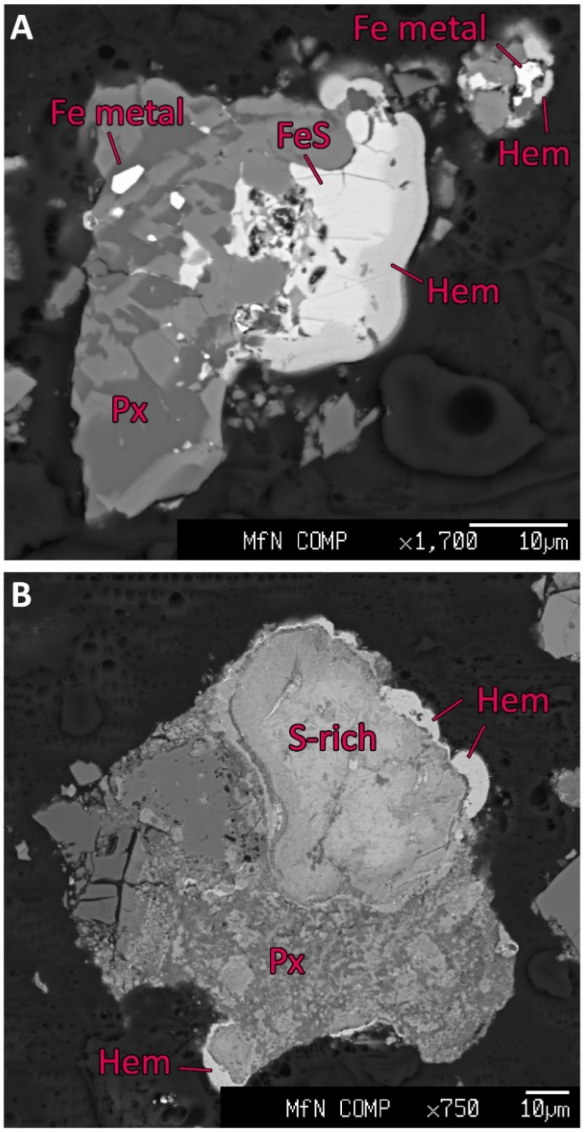

Figure 2: EPMA images of two grains of the heated NWA 5748 + Murchison sample (600 °C, 72h), depicting thin coatings of hematite on the edges of the grains. Legend: Hem – hematite, FeS – iron sulfide, Fe metal – pure iron, Px – pyroxene. The sulfur-rich (S-rich) phase in panel B contains both sulfur and silicate material and could not be determined.

Cutler et al. [11] similarly observed the development of hematite, steep visible spectral slopes and partly stronger pyroxene absorption when heating pyroxenes in air. They speculated that the stronger pyroxene absorptions arise from changes to the M2 crystallographic site in the pyroxenes, namely either the reordering and accumulation of Fe cations in the M2 sites due to heating as well as a relative disorder in the pyroxenes prior to heating or a migration of Fe cations to the grain edges due to the oxidation (and subsequent formation of hematite) so that the spectrum imitates a higher Fe content of the pyroxene grains.

Higher Fe contents in the M2 site would also imply a shift of the pyroxene band position to longer wavelength, which we do not observe consistently, neither in our experiments nor on Vesta [7]. However, McCanta et al. [12] observed that with ongoing oxidation, pyroxene band positions tend to shift to shorter wavelengths. Thus, these processes might counterbalance each other.

As we do not observe hematite formation at the pitted impact deposits' sites on Vesta [7], we speculate that hematite or other iron oxides were not able to form due to too short timescales of heating/devolatilization, or cannot be detected due to insufficient abundances. Moreover, other iron oxide species could have formed. Still, the change of cation occupation of M2 sites within the pyroxene grains is the most likely explanation for the stronger pyroxene absorptions, as the M2 absorption band is stronger than the M1 absorption band.

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References: [1] McCord (1970) *JGR, 90,* 1151–1154. [2] De Sanctis et al. (2012) *Science 336*, 697-700. [3] De Sanctis et al. (2013) *Meteoritics & Planetary Science 48*, Nr. 11, 2166-2184. [4] McCord et al. (2012) *Nature Letter 491*, 83-86. [5] Reddy et al. (2012) *Icarus 221*, 544-559. [6] Jaumann et al. (2014) *Icarus 240*, 3-19. [7] Michalik et al. (2021) *Icarus 369*, Article 114633. [8] Denevi et al. (2012) *Science 338*, 246-249. [9] Tornabene et al. (2012) *Icarus 220*, 348-368. [10] Maturilli et al. (2019) SPIE Proceedings *Vol. 11128*, Infrared Remote Sensing and Instrumentation XXVII, 111280T. [11] Cutler et al. (2020) *The Planetary Science Journal*, Vol. 1, 1:21. [12] McCanta et al. (2020) *Icarus 352*, Article 113978.