Metallic iron particles in an eucrite, a new insight of weak space weathering on Vesta. Zhuang Guo[1], Yang Li[1], Hongyi Chen[2], Mingming Zhang[1], Shijie Li[1], Xiongyao Li[1] and Ziyuan Ouyang[1]. [1]Center for Lunar and Planetary Sciences, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang, China; [2]College of Earth Sciences, Guilin University of Technology, Guilin, China.
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Introduction: The Howardites-Eucrite-Diogenite (HED) clan of meteorites are generally considered to be derived from the 4-Vesta asteroid [1-2]. Dawn mission has successfully completed orbiting Vesta and further proved the lack of nanophase iron particles (np-Fe^0) that depress the absorption band of spectral reflectivity on Vesta's surface, which is not fit with its old age in the solar system (~4.56 Ga) [2]. Previous studies have suggested that lower average impact velocity (~5km/s), lower impacts fluxes or solar wind sputtering rates and metal-free surface mineralogy mixing with carbonaceous chondrite-like material are the plausible reasons for the weak space weathering on Vesta [2-3]. A few of possible np-Fe^0 found in Howardite, however, building an obstacle again for us to understand the airless bodies' space weathering process [4].

Our study provides a new mechanism (disproportionation of Fe^{2+}) for the formation of metallic iron particles in basaltic eucrite NWA 11592, which hold that the recently resurfaced events should be a reason for the weak space weathering on Vesta.

Sample and analytical techniques: The NWA 11592 is a basaltic eucrite found in Algeria, 2016. The polished thin section of NWA 11592 was observed by the FEI scios-FIB emission field scanning electron microscope (SEM). The chemical compositions of minerals were performed utilizing the JEOL JXA-8530 F Plus electron microprobe (EPMA). Two FIB cross sections were prepared by the FEI scios dual-beam methods and characterized utilizing FEI talos F200X field-emission scanning transmission electron microscope. Electron energy loss spectra (EELS) of Fe were acquired by GIF Quantum ER system Modal 965 parallel EELS spectrometer attached on Titan ETEM field-emission gun TEM.

Results: NWA 11592 is a basaltic unbrecciated eucrite that mainly consists of millimeter-sized pyroxene and plagioclase with an ophitic texture, as well as minor amounts of olivine, troilite, chromite and ilmenite. Augite exsolution lamella (~20 μm in width) is pervasively observed within the pyroxene grains, and the homogeneous composition of equilibrated plagioclase (An88.8-91.8) grains are also consistent with other eucrite samples in known, indicating a certain high degree of thermal metamorphism experienced by NWA 11592. In addition, the compositions of low-Ca pyroxene ($En_{34.6}Fs_{61.8}Wo_{3.6}$,) and high-Ca pyroxene ($En_{29.5}Fs_{28.3}Wo_{42.2}$) of exsolved pyroxene indicating the host rock of NWA 11592 ought to have experienced an equilibrium temperature of 920 ± 49 ℃ [5]. Besides, all these mineral grains in NWA 11592 exhibit numerous fractures and crosscut the exsolution lamella, suggesting that the thermal metamorphism occurred no later than the ubiquitous impact events.

Two melt veins and one shocked melt pocket are observed in NWA 11592. Thereinto, the melt pocket displays a typical quenched texture which is featured by dark acicular materials within the sub-micron sized matrix (Fig 1A.), and comes to become the primary focus of this study. Abundant metal droplets scattered attaching to the acicular material were observed, and the pure metallic iron (Fe^0) particles were confirmed by the TEM analysis.

Two foils located in melt pocket were extracted by Focused Ion Beam (FIB) methods. The matrix of the melt pocket is basically composed of the sub-micron scaled pyroxene and plagioclase grains (Fig 1B.), and the pyroxene present significantly various Ca content. The TEM X-ray mapping results show that Fe^0 grains (~200 nm) are extremely enriched in iron element but with no S, Ni, O contents, and the Fast Fourier Transforms (FFT) from the high-resolution transmission electron microscopy (HRTEM) imagery of Fe^0 can be indexed by α-Fe (Fig 1C.).

Acicular material had been confirmed as the abundant nano-sized hercynite crystals (~20 nm) embedded in the plagioclase by TEM observations (Fig 1D.). Besides, Al rich-clinopyroxene filled in the interstice between acicular material within the melt pocket was observed as well. The TEM X-ray EDS spectra testify that the clinopyroxene has a mixed component of pyroxene and plagioclase (contains Fe, Mg, Si, Ca and Al elements), and the SAED patterns present a single crystal nature of clinopyroxene.

Since hercynite and Al rich-clinopyroxene contain significant iron content and were formed under extreme conditions, the confirmation of their origins requires the information of the valence states of Fe. Here, we obtained the $L_{3,2}$ electron energy loss spectra of iron within each phase (including metallic iron, hercynite and Al rich-clinopyroxene) by EELS. The characteristics of EELS spectra suggest that iron in Al rich-clinopyroxene is mainly ferric iron, while the hercynite is dominated by the ferrous iron.

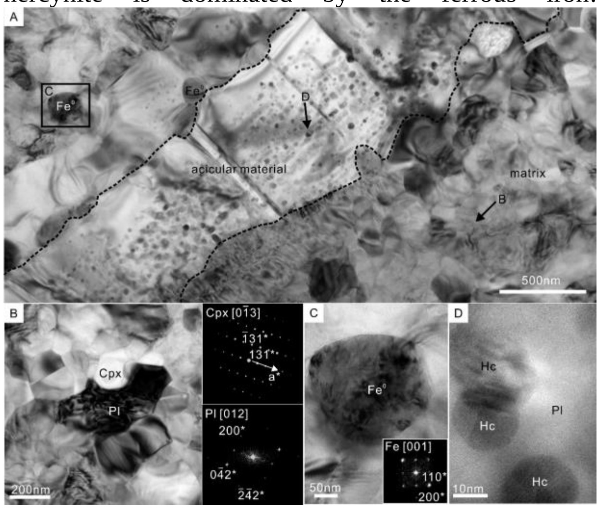

Fig 1. (A) TEM image of the foil. Black rectangle and arrows represent the locations of image of (B-D). (B) A more detailed view of the melt pocket matrix. (C) A close up view of the metallic iron particle (Fe^0). (D) More detailed view of the interior of acicular material, abundant nano-sized hercynite (Hc) crystals embedded in the plagioclase (Pl).

Discussion: The presence of pure metallic iron without the associations of silica and vesicles in this study excludes the in-situ reduction of pyroxene or troilite [6]. Except for this, Ni-poor characteristics and free of oxidation of pure metallic iron particles excludes the exotic origins. Nonetheless, with the advent of metallic iron particles-associated minerals, the metallic iron should be formed as a product of igneous melts. Meanwhile, the ferric iron detected in Al rich-clinopyroxene suggests that the formation mechanism of metallic iron particles in the NWA 11592 should be disproportionation of Fe^{2+} ($3Fe^{3+} = Fe^0 + 2Fe^{3+}$) within pyroxene.

Crystallization of hercynite in the melt pocket suggests the reaction temperature should be higher than 1310 ℃. Thus, the melt pocket may not be formed by individually thermal metamorphism (~ 920 ℃) or shock event (> 80 GPa). One possibly practical scenario for interpreting the formation of melt pocket in NWA 11592 is that the shock event occurred during the thermal metamorphism on Vesta, which could provide such high enough temperature (~ 30 GPa required) to form these mineral assemblages. Sub-micro sized matrix without high pressure phases and larger pure metallic iron particles suggest the melt pocket had experienced a relatively longer cooling time, which further proves that the formation of melt pocket should be the overlap of impact and thermal metamorphism during the early-staged evolution of Vesta.

No space weathering effects observed on Vesta's surface is a mystery for understanding the essential of space weathering processes. Large impact basins on Moon indicate that the Moon has subjected to an intense period of bombardment from 3.90 Ga to 3.84 Ga, which is known as the Late Heavy Bombardment (LHB) occurred in the inner solar system (e.g., Earth, Mars and Vesta) [7]. Similar to the Moon's early environment, Vesta has also experienced much more frequently collisions during its early evolution period [8], which provide feasible conditions for the formation of pure metallic iron particles on Vesta' surface (by disproportionation of Fe^{2+} or decomposition of pyroxene and troilite). Dawn mission observed giant craters (e.g., Rheasilvia, ca. 500 km-diameter and 19 km deep; Veneneia, ca. 400 km-diameter) on south polar of Vesta, and giant craters have formation ages of 2-1 Ga [2]. According to the estimate about 6 final crater radii of ejecta deposits by basin forming, such Rheasilvia' ejecta blanket can efficiently resurface the whole Vesta's crust. Considering the constituent of howardites and the formation mechanisms of metallic iron particles, resurfaced howardites (Rheasilvia basins formed) on vesta should be effortlessly weathered under intense micrometeorites impact or high solar wind flux. However, the distinct observations prove that space weathering in the solar system is not significant in the last 1 Ga, which is consistent with the evolutions of impact flux and solar wind flux [9-10]. Above all, weak space weathering on Vesta's surface is caused by the resurfaced events during the formation of giant craters, and the lower impact flux and weak solar wind in the last 1 Ga of inner solar system.

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