TRANSMISSION ELECTRON MICROSCOPY OF "BROWN" COLOR OLIVINES IN MARTIAN AND LUNAR METEORITES.
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Introduction: NWA2737 and Chassigny are the only samples belonging to a chassignite Martian meteorite group. They have generally similar mineral compositions, but their appearances are totally different [1]. Chassigny looks grayish in hand specimen, whereas NWA2737 is black in color. In thin sections, olivine in Chassigny is almost colorless, although olivine in NWA2737 shows dark brown in contrast. Recent TEM studies revealed that Fe-Ni metal nano-particles in olivine are responsible for the dark color of olivine in NWA2737, which was formed by reduction of olivine due to heavy shock events [2]. Similar brown color olivine is fairly common among Martian meteorites, and Fe nano-particles may be widely present in Martian olivines. If this is the case, brown color olivine may be also commonly present in heavily shocked meteorite parent bodies such as the Moon and Mars. In contrast to Martian meteorites, brown olivine is not common in lunar samples, but Dhofar 489 contains reddish olivine which is believed to have originated from the lunar far side [3]. Color change of olivine is also significant to understand the remote sensing data as is the case for space weathering [4,5]. Furthermore, nano-phase Fe particles can be magnetic carrier of the meteorites, and is significant for their magnetic studies [6]. In this abstract, we report TEM observation of "brown" olivines in 4 Martian meteorites (NWA2737, ALH77005, LEW88516, and Y000097) and 1 lunar meteorite (Dhofar 489).

Analytical methods: We selected the above 5 samples because their thin sections contain brown olivines although the strength of the color is on many levels. In general, both colorless and brown areas are present in a common single crystal, but we found that there was no clear compositional difference when analyzed by electron microprobe. We prepared TEM samples by crashing small rock chips of each sample into powder by hand. The TEM observation was performed by JEOL JEM 2010 TEM equipped with EDS. We used FIB (Hitachi FB-2100) to make a TEM section of NWA2737 because thin colorless bands (2μm wide) developed in many olivine grains. We also analyzed thin sections by micro-XANES (beam diameter is ~10 μm) using synchrotron radiation at Photon Factory, Tsukuba [7] to compare Fe^{3+} abundance between colorless and brown areas.

Results: Careful observation by TEM revealed the presence of nano particles in olivines from ALH77005 and Y000097. EDS shows that these particles are enriched in Fe with small amounts of Ni. The electron diffraction patterns show that they are Fe metal. The FIB NWA2737 section shows the presence of two distinct areas attaching to each other. The colorless band is free from nano particles, and possibly a product of recrystallization as suggested by [8]. The brown color area instead contains abundant Fe-Ni particles.

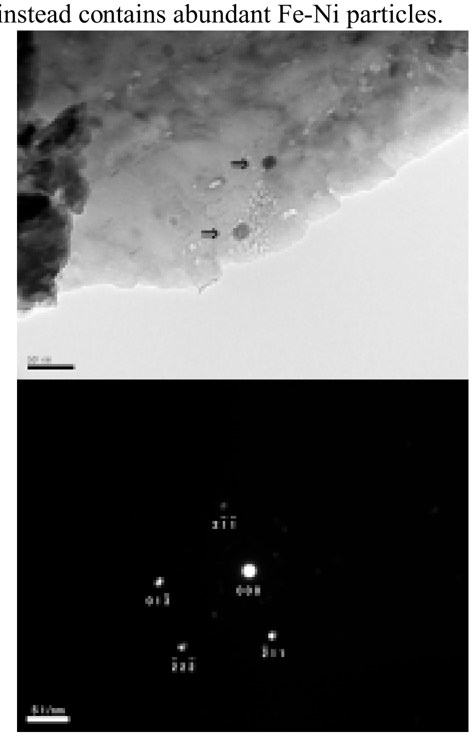

Fig. 1 TEM image of nano-phase iron in ALH77005 (above). Electron diffraction pattern of iron metal particle in Y000097 olivine (below).

In contrast to these metal-bearing samples, nano particles in LEW88516 are slightly different. EDS shows that they are enriched in Fe, but no Ni was observed. Electron diffraction patterns show that they are magnetite.

In the Dhofar 489 lunar meteorite, Fe-rich nano particles do not contain Ni. The obtained electron diffraction pattern can be indexed by hematite rather than Fe metal or magnetite. These particles show similar appearance to those in Martian meteorites and were mostly 5 to 20 nm in diameter. The reddish color of olivine is different from other samples and consistent with hematite.

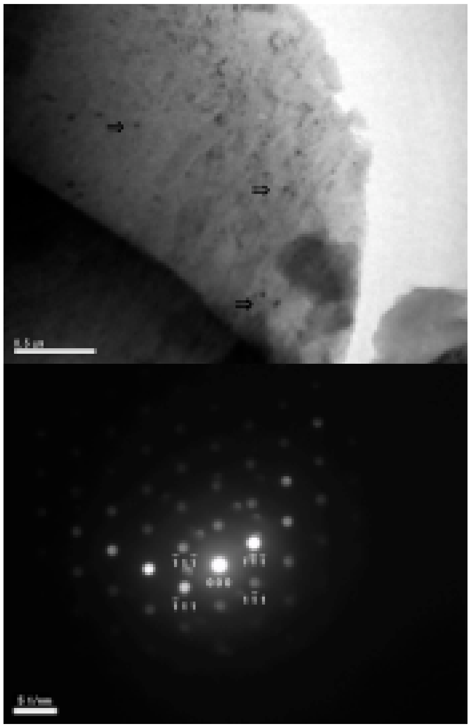

Fig. 2 TEM image of LEW88516 nano particles (above). The obtained diffractions pattern shows that it is magnetite.

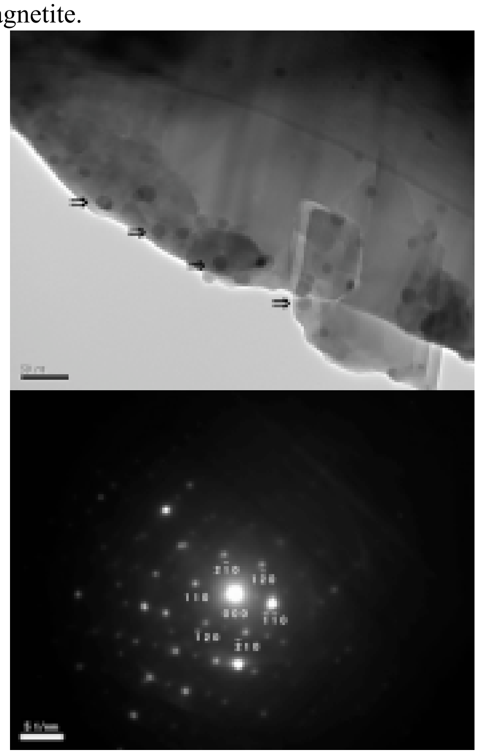

Fig. 3 TEM image of Dhofar 489 nano particles (above). The obtained diffractions pattern shows that it is hematite.

Discussion and Conclusion: Brown color olivine may be formed by terrestrial oxidation. However, this is probably unlikely for the samples studied here since distribution of dark parts in olivines (color of olivine grains are heterogeneous) is not along grain surfaces or cracks. As previously reported in NWA2737, Fe-Ni metal particles are distributed only in dark parts in olivine, also confirmed by this study using the FIB sample. In contrast, the clear part in olivine has no Fe-Ni particle. Thus, Fe-Ni particles are controlling color of their host olivine.

Our shock experiments [9] indicate that redox state during shock affects the formation of Fe-rich particles. Fe-Ni metal particles were formed under relatively reducing condition and magnetite particles were formed under relatively oxidizing condition. It is likely that hematite in Dhofar489 was produced by terrestrial oxidation from originally Fe-Ni metal particles, because this meteorite experienced severe terrestrial weathering.

Because nano phases are directly in contact with the host olivine, Fe reduction was achieved by volatilization of Si, rather than the formula (1) $3Fe^{2+} \rightarrow Fe^0 + 2Fe^{3+}$. In contrast, the formation of magnetite requires oxidation of Fe^{2+}, which may be caused by oxidizing atmosphere.

The results of TEM studies are consistent with the magnetic studies of Martian meteorites [6]. Hoffmann et al. [6] found that ALH77005 and Yamato 000097 contain Fe metal phases in brown color olivines and showed that they are carriers of magnetic remanences. Therefore, the role of iron metal grains in shocked olivine is important in interpreting Mars crustal magnetic anomalies.

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