MINERALOGICAL STUDY OF REDDISH OLIVINE IN DHOFAR 307 LUNAR METEORITE: COMPARISON WITH BROWN OLIVINE IN MARTIAN METEORITES

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Introduction: Brownish colored olivine, so-called "brown olivine" is known in Martian meteorites. Previous studies reveal that its coloration is induced by iron nano-particles (iron metal and magnetite) formed in olivine [1-3]. Such olivine shows several characteristic features not observed in colorless olivine, for example, heterogeneous and non-equilibrated coloration, slightly brighter contrast in BEI, extra peaks in Raman shift and the presence of trivalent iron [1-4]. Several formation processes are suggested and our previous study supports that iron nano-particles are formed by self-oxidation and reduction of olivine with phase transformation under high-pressure and high-temperature [5]. Although strong shock events are likely to induce such a kind of olivine darkening, no brown olivine is reported in other meteorite groups. However, red colored olivine (reddish olivine) is reported from a Dhofar 303 lunar meteorite paired group. Previous study reported that this olivine contains hematite nano-particles [6]. However, detailed observation and coloring processes of the reddish olivine have not been discussed so far. Therefore, this study tries to reveal the formation processes of the reddish olivine by its detailed observation and comparison with those of brown olivine in Martian meteorites. Then, this study discusses whether olivine darkening is unique on Mars or common in a highly strong shock event, and then suggests the importance of nano-particles in olivine for a remote sensing research.

Sample and Methods: In this study, Dhofar 307 lunar anorthisitic impact melt breccia is observed. This meteorite is considered to be paired with the Dhofar 303 meteorites group. Reddish olivine is found in troctolitic clast and as isolated mineral fragments. We observed them by FE-SEM and Raman spectroscopy at NiPR and analyzed its Fe valence by synchrotron (SR) micro-XANES at Photon Factory (PF), KEK, Tsukuba.

Results: Dhofar 307 consists of abundant clasts, and isolated mineral fragments (various size ranges) with anorthisitic impact glass. Rims of anorthisitic clasts are devitrified by high-temperature and olivine often shows planar deformation fracture and wavy extinction. Unfortunately, this meteorite is severely weathered on the Earth because there are abundant carbonate veins. Olivine reddening occurs in a troctolitic clast and isolated large mineral fragments, however, most small olivine fragments in matrices are not colored. Although the forsterite contents of all olivine grains show bimodal distribution [7], there is no relationship between chemical compositions and degrees of coloration. Reddish olivine is heterogeneously colored and colored areas have less smooth surfaces compared to colorless areas in SEM observation. The surfaces of strongly red colored areas seem to be rusted, while a weakly reddened areas show scratch-like trails with weak preferential crystallographic orientation. Raman analyses of reddish olivine show no extra peaks which are reported in brown olivine, however, peaks of hematite is remarkable. SR Fe micro-XANES indicates the presence of high ratios of Fe^{3+} and this may be also derived from hematite.

Discussion and Conclusion: This study reveals that reddish olivine rarely shows the features of brown olivine found in Martian meteorites. Raman and SR micro-XANES analyses clarify the presence of hematite in reddish areas although hematite grains are not observed in SEM observation. Considering the previous study, the color of reddish olivine is certainly derived from hematite nano-particles. Because Dhofar 307 shows strong terrestrial weathering, these hematites may be formed by the weathering on the Earth. However, because there are many non-weathered olivine grains, there is a possibility that the reddish areas are weaker against weathering compared to the other olivine for some reasons. For example, scratch-like trails in weakly reddened areas may have been similar areas to brown olivine. Such areas achieve rapid atomic diffusion because of disordered crystal structure with iron nano-particles formed by a shock event and therefore become weak against weathering. Then, the formation of iron nano-particles easily explains the formation of hematite nano-particles by its weathering on the Earth. This indicates that the phenomena similar to olivine darkening in Martian meteorites may occur on the other celestial bodies such as Moon. It is reported that brown olivine with nano-particles changes their reflectance spectra and magnetic susceptibility [1,8]. If nano-particles are widely formed in olivine by strong shock events on such bodies, we may overlook the presence of olivine inside and around large craters on the remote sensing data. Therefore, we need to pay attention to this possibility not only on Mars but also the other large bodies such as Moon and Vesta.

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