Micro-Raman spectroscopic analysis of darkened olivine in Martian meteorites.

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Introduction:

It is known that some Martian meteorites contain darkened olivine called as "brown olivine" as reported by [e.g. 1,2]. According to their studies such darkening is induced by the formation of iron nano-particles in olivine during shock events. We reported that Martian meteorites with brown olivine tend to contain no high-pressure minerals although they seem to have been subjected to strong shock pressure and high temperature [3]. Although the P-T condition of a strong shock event is often estimated by using the presence of high pressure minerals [e.g. 4], it is difficult to reveal the shock history of such meteorites without high-pressure minerals. On the other hand, brown olivine has potential to provide us information of the shock event by revealing their formation conditions.

Samples and Methods:

In this study we analyzed thin sections of five shergottites (LAR 06319, NWA 1950, NWA 1068, RBT 04261, and Tissint) that were analyzed in detail in our previous study [3]. Most olivine grains in NWA 1950 and LAR 06319 are brown to black in color ("brown olivine") while most olivine grains in NWA 1068 and RBT 04261 show yellowish to slightly yellowish color (though some olivine grains adjacent to shock melt are brownish). Tissint contains slightly brownish colored olivine whereas most olivine grains are almost colorless.

Raman spectra of "brown olivine" in NWA 1950 are previously reported by [2,5] and it is known that there are extra peaks around 670 cm^{-1} and 750 cm^{-1} that are not found in normal olivine. However, Raman spectra of colored olivine in other Martian meteorites have not been reported before. Therefore, in this study, micro-Raman analysis (JASCO NRS-1000 at National Institute of Polar Research, Tokyo) is performed focusing on such various colored olivine in each meteorite in order to reveal relationships between "brown olivine" and the other colored olivine.

Results:

Olivine in LAR 06319 and NWA 1950 is heterogeneously darkened (Fig. 1) and olivine adjacent to shock melt vein in LAR 06319 is partially molten (become colorless). Raman spectra are obtained at both brown and colorless areas and Fig. 2 shows those spectra. Raman spectra of yellowish olivine and brownish olivine in NWA 1068 and RBT 04262 are also shown in Fig. 2. Regarding Tissint, Raman spectra of colorless olivine and brownish olivine (in particular lamellar texture reported by [3]: Fig. 3) is obtained and shown in Fig. 2.

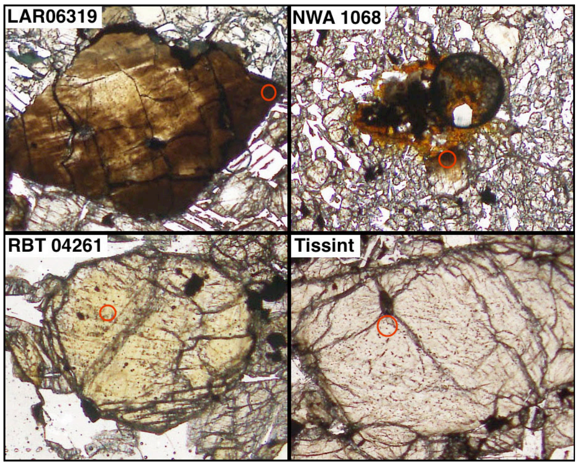

Fig. 1 Optical photomicrographs of colored olivine in shergottites ("brown olivine" in LAR 06319, brownish olivine adjacent to shock melt in NWA 1068, yellowish olivine in RBT 04261 and colorless olivine in Tissint). Width of each image is 1 mm and red circles show the points where Raman spectra were obtained.

Raman spectrum of brown olivine in NWA 1950 and LAR 06319 shows extra peaks at 690 cm^{-1} and around 640-680 cm^{-1}, respectively, similar to the reported ones [2,5] (Fig. 2). However, the other reported extra peak at around 750 cm^{-1} is not observed in these meteorites. Brownish olivine in NWA 1068 and lamellar texture in Tissint also have the extra peak around 670 cm^{-1} although brownish olivine in RBT 04261 does not seem to have that peak. Yellowish olivine in NWA 1068 and RBT 04261 shows no extra peaks compared to that of the colorless olivine in Tissint, which is almost identical to that of an ordinary olivine.

Discussion:

Our previous study [3] suggested that "brown olivine" formed with transformation of olivine to their high-pressure phases by a strong shock event (high pressure and temperature). In such a shock event, high-pressure phases may be no longer present because the temperature is still high enough after decompression to induce back-transformation of high-pressure phases. Observation of thin sections supports this idea because "brown olivine" shows a lamellar texture indicating the transformation of olivine. Furthermore their heterogeneous darkening needs rapid Fe diffusion attained by transformation to high-pressure phases although they are back-transformed and not able to be recognized by EBSD analysis (see in detail [3]). Our previous study

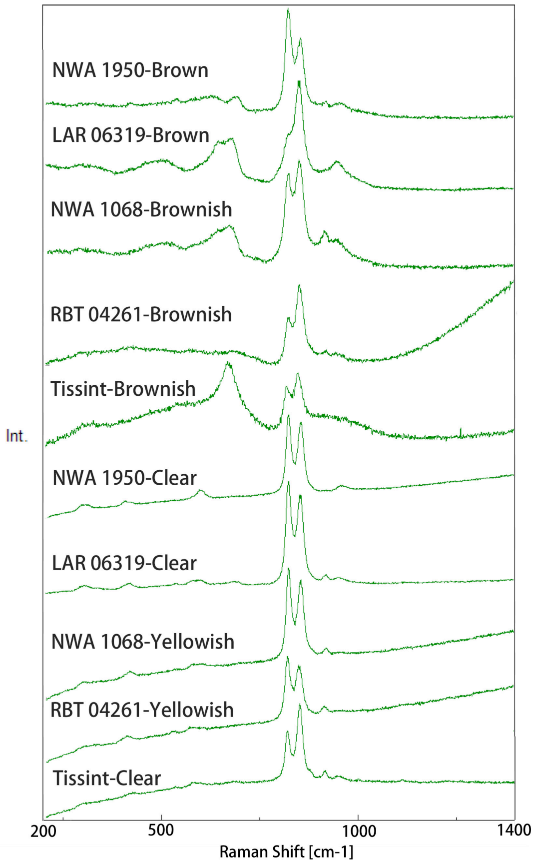

Fig. 2 Raman spectra of each colored and colorless olivine. There are extra peaks around 640-690 cm^{-1} in brown and brownish olivine, while peaks at 850 and 820 cm^{-1} are the characteristic peaks of ordinary olivine.

also reported that brownish olivine adjacent to shock melt shows identical features to those of "brown olivine" and this indicates that brownish and "brown olivine" have similar formation processes and conditions. In this study, similar extra Raman peaks are found in "brown olivine" and brownish olivine in NWA 1068 and Tissint (lamellar texture), supporting the above idea. These extra peaks indicate that extra atomic linkages are formed in olivine [2,5] and these peaks may be derived from high-pressure phases. In addition the lamellar texture showing the extra peak strongly supports the occurrence of transformation because olivine high-pressure phases are often found as lamellae in highly shocked meteorites [e.g., 6, 7]. While their formation processes may be similar to each other, yellowish olivine shows no extra peaks and this implies that their coloring process is different from that of "brown olivine". Their coloring processes needs further investigation.

If "brown olivine" and brownish olivine have identical formation processes, brownish olivine has information of a formation condition of "brown olivine" because brownish olivine is only found around shock melt veins where temperature should be the highest in each meteorite. Then, it is expected that the darkening processes of "brown olivine" need

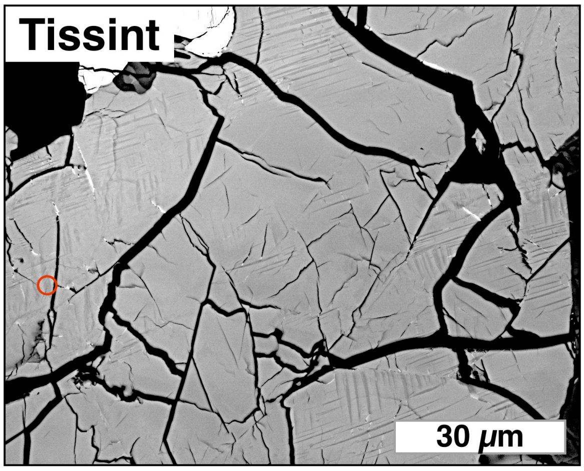

Fig. 3 BSE image of lamellar texture in brownish olivine in Tissint. The red circle shows a point where Raman spectrum is obtained.

high temperature and pressure similar to those around shock melt inducing transformation and also need high and/or long post-shock temperature inducing incomplete back-transformation which leaves extra peaks in Raman spectra of olivine.

Conclusion:

In this study, Raman spectra of various colored olivine in shergottites are obtained and it reveals that "brown olivine", brownish olivine adjacent to shock melt and lamellar texture in brownish olivine have extra peaks around 640-690 cm^{-1}, indicating similar formation processes which occurred with transformation to high-pressure phases. This result supports our previous study [3]. On the other hand, yellowish olivine found in Martian meteorites seems to have different coloring processes (including a possibility of a weathering on the Earth). Therefore, "brown olivine" may have formed under high pressure and temperature with subsequent transformation of olivine to their high-pressure phases, similar to the condition around shock melts.

References:

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