HIGH TEMPERATURE SHOCK EXPERIMENT OF SAN CARLOS OLIVINE: IMPLICATIONS FOR THE FORMATION OF NANO-PARTICLES IN OLIVINE FROM MARTIAN METEORITES. T. Kurihara[1], T. Mikouchi[1], A. Yamaguchi[2], T. Sekine[3], and M. Miyamoto[1], [1]Dept. of Earth and Planetary Science, Graduate School of Science, University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0033, JAPAN[1], [2]National Institute of Polar Research, Tachikawa, Tokyo 190-8518, JAPAN, [3]Natiolal Institute for Materials Science, Tsukuba, Ibaraki 305-0044, JAPAN (E-mail: kurihar@eps.s.u-tokyo.ac.jp).

Introduction: Recent TEM studies revealed that Fe-Ni metal nano-particles are responsible for the dark "brown" color of olivine in the NWA2737 chassignite, which is interpreted to have formed by reduction of olivine due to heavy shock events [1,2]. Similar brown color olivine is fairly common among Martian meteorites especially in shergottites, and thus widespread presence of Fe-Ni metal nano-particles in these olivine grains can be expected. Indeed, our previous study revealed the presence of Fe-Ni metal nano-particles in several Martian meteorites (NWA2737, ALH77005 and Y000097) [3]. These Fe-Ni nano-particles have a significant effect of darkning of their host crystals . We also discovered magnetite nano-particles in other Martian meteorites (Dhofar 019, LEW88516 and LAR06319) [3-5]. These magnetite nano-particles are similar to Fe-Ni metal nano-particles in morphology and size, and probably responsible for brown color of olivine. There has been suggested that Fe-Ni nano-particles have formed by reduction of Fe^{2+} in olivine crystal during heavy shock [1,2]. In contrast, the formation of magnetite requires oxidation of Fe^{2+} in olivine crystal in contrast to the formation of Fe-Ni metal. In our previous shock experiments, we showed that magnetite nano-particles could be produced at the shock higher than 40 GPa under atmospheric condition [6]. When the olivine was mixed with graphite, Fe-Ni metal was instead formed at similar shock pressure [6]. Thus, in these experiments, difference of atmospheric condition could be a major factor controling the redox state. However, it is unlikely to suppose large difference of oxygen fugacity during shock of Martian meteorites because they crystallized under similar conditions (e.g., burial depth, crystallization age). Thus, temperature difference during shock could be another possible factor. The iron-wüstite (IW) buffer curve is a function of temperature. At a given oxygen fugacity (fO_2), it is more reducing when the temperature is higher. Magnetite nano-particles would be formed when temperature increased moderately. When temperature increase was significant and fO_2 during the shock was below the IW buffer, Fe-Ni nano-particles would be formed. To test this hypothesis, we performed shock experiments of olivine preheated at different temperature.

Experimental Methods: The shock-recovery experiments were performed using a single stage 30 mm-bore propellant gun to generate shock waves by hypervelocity impact at the National Institute for Materials Science, Tsukuba. We prepared powder (100-200 μm) of San Carlos (Fo_{89}) olivine for starting material. The olivine powder was set into a stainless-steel container and shocked by a 2-4 mm-thick Cu plate, bedded at the front of a polyethylene sabot. These experimental condition was similar to our previous experiment [6]. However, we adopted stainless-steel instead of Cu for container material because of higher intensity demand. To reduce direct contact between stainless-steel and sample, Cu powder was bedded under and over the sample. Preheat temperature was set at 400 and 800 °C. Shock pressure was set at 40 GPa. For comparison, we also performed shock experiment without preheating. The sample chamber was evacuated to 200 Pa before each shot. The peak pressure was estimated by the impedance match method using the measured impact velocity. Details of shock experimental procedures are similar to [7]. The recovered samples were observed by TEM (JEOL JEM2010) with EDS.

Results: Nano-particles were observed in olivines from preheated samples at 400 and 800 °C (Fig. 1). Typical sizes of these particles were 5 to 20 nm in diameter. EDS shows that these particles are enriched in Fe (Fig. 2). These particles contain small amount of Ni. The electron diffraction patterns show that they are Fe metal (Fig. 3).

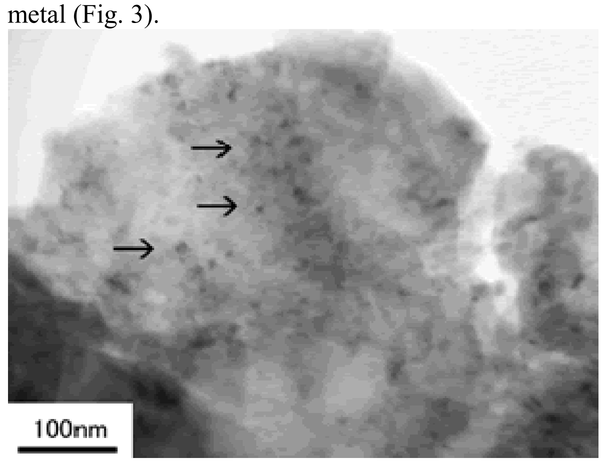

Fig. 1 TEM image of shocked olivine (40 GPa) preheated at 400 °C. Nano-particles are indicated by arrows).

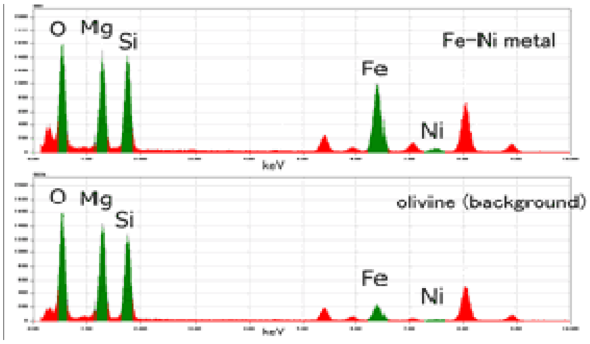

Fig. 2 TEM-EDS data of the shocked olivine (40 GPa) preheated at 800 °C. Above: Nano-particle. Below: host olivine.

Fig. 3 Electron diffraction pattern of a nano-particle in shocked olivine (40 GPa) preheated at 400 °C. It shows that the particle is a Fe-Ni metal.

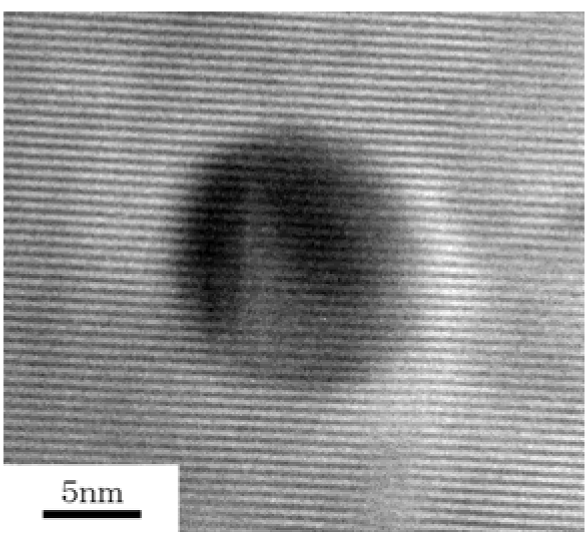

Fig. 4 High resolution TEM image of a Fe-Ni metal nano-particle in shocked olivine (40 GPa) preheated at 800 °C.

Nano-particles are directly contacted with olivine and no other phases were observed between them (Fig. 4). Indeed the electron diffraction patterns of olivine adjacent to the nano-particles show sharp crystalline spots. The absence of surrounding secondary phase is a common feature of Fe-Ni and magnetite nano-particles in both experimentally shocked olivine and Martian meteorites [1-6].

Discussion and Conclusion: In our previous shock experiments, magnetite nano-particles were produced at the peak shock pressure higher than 40 GPa. Fe-Ni nano-particles were formed only under relatively reducing condition. However, in this study, we could produce Fe-Ni metal nano-paricles instead of magnetite nano-particles by preheating olivine before shock. Thus, temperature difference during shock might control the formation of Fe-rich nano-particles either Fe-Ni metal or magnetite.

The formation of metal phase near the Martian surface is unlikely since estimated fO_2 of Martian meteorites is ranging from IW+2 to QFM. However, the IW buffer curve is in inverse proportion to temperature and the temeprature increase of a few hundred degrees would be enough to cross the IW buffer curve. As in the case for space weathering [8,9], the formation of Fe-Ni and magnetite nano-particles not only results in optical color change of olivine, but also affects infra-red spectrum pattern. No olivine absorption peak near the 1.1 µm can be observed in Fe-Ni nano particles-bearing olivine. If broad distribution of nano-particles in olivine is assumed on the surface of Mars, the present remote sensing data are strongly affected by the existence of nano-particles [10]. Furthermore, nano-phase Fe particles can be a magnetic carrier of the meteorites, and is significant for their magnetic studies [11].

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