FAST COOLING HISTORY OF THE CHASSIGNY MARTIAN METEORITE. A. Monkawa, T. Mikouchi, E. Koizumi, J. Chokai, M. Miyamoto, Dept. of Earth and Planet. Science, Graduate School of Science, University of Tokyo, Hongo, Tokyo 113-0033, Japan (monkawa@eps.s.u-tokyo.ac.jp).

Introduction: The Chassigny martian meteorite is a dunite with rare poikilitic Ca-poor pyroxenes containing lamellae of exsolved Ca-rich pyroxene [1]. It has a modal composition of 90% olivine, 5% pyroxene, 2% feldspar, and 1.4 % chromite along with minor and trace phases such as sulfides, Fe-Ti oxides, and chlorapatite. The anhedral to subhedral olivine grains averaging 1.5 mm long are commonly in close contact with each other and occasionally form 120º triple junctions. Olivine is compositionally homogeneous in major elements throughout the samples having an average forsterite content of 68 mol% [2]. Olivine usually includes euhedral chromite grains and rounded magmatic inclusions as large as 200 µm in diameter. Some of these inclusions contain Ti-rich amphibole (kaersutite) associated with pyroxenes, chlorapatite, troilite, chromite, pentlandite and alkali feldspar-rich glass [3].

Floran et al. [3] reported that the single poikilitic pyroxene grain in one of the Chassigny sections they studied consisted of a high-Ca host that had fine exsolution lamellae of orthopyroxene on the [001] plane. Wadhwa and Crozaz [1] also reported exsolution-free augite, which is present around high-Ca pyroxene having exsolution lamellae and exsolution-free low-Ca pyroxene.

We observed Chassigny pyroxene grains to estimate its cooling history from the width of pyroxene lamellae. We also paid attention to minor element zoning of olivine which could also give us information on cooling rate. By combining these results, we estimated the cooling history of Chassigny, which is believed to have a martian mantle origin [4].

EBSD analysis: EBSD analysis is used to provide crystallographic and phase information on micro sized crystalline materials. EBSD analysis was performed with FEG-SEM on condition that the accelerating voltage of the incident beam was 20 kV, and the beam current was 1-2 nA. The collection semiangle of the EBSD detector was ~37.5º. The specimens were coated with amorphous carbon to maintain electrical conductivity. The specimens were tilted by ~70º from the horizontal toward the phosphor screen (the detector) using a specimen mount. The calculated patterns for these minerals were obtained by using the Structure Factor Calculation computer program.

Pyroxene mineralogy: Poikilitic pyroxene occupies ~5% of Chassigny. Pyroxene grains consist of a high-Ca and low-Ca pyroxene pair both having exsolution lamellae (Fig. 1). Low-Ca pyroxene areas have plate-like exsolution lamellae of augite with composition planes close to (001). The host of this low-Ca pyroxene was identified as pigeonite by using EBSD analysis (Fig. 2). A thickness of the augite lamellae is 0.5-1.5 µm and the mean width is 1 µm (Fig. 3a). The intervals of lamellae are about 1.5-2 µm. These relatively coarse lamellae belong to the type of exsolution lamellae that are most probably formed by a process of nucleation and growth [6]. The high-Ca pyroxene area has finer exsolution lamellae (10-50 nm) of low-Ca pyroxene. They are sets of “001” low-Ca pyroxene (pigeonite) lamellae with a thickness between 50 and 100 nm and have mutual distances between about 0.5 and 1 µm (Fig. 3b). The host of this high-Ca pyroxene was identified as augite by using EBSD analysis. The equilibrium temperature for two pyroxene areas estimated by two pyroxenes geothermometer (augite-pigeonite) [5] indicates ~1150 °C.

Discussion: We estimated a cooling rate of Chassigny from the width of pyroxene lamellae. The thickness of augite exsolution lamellae in pigeonite is generally a function of cooling rate. The mean width of Chassigny augite exsolution lamellae in the pigeonite is 1 µm. This width was compared with the width (~0.25 µm) of augite exsolution lamellae in the Zagami pigeonite [7, 8]. Brearley et al. [7] estimated that Zagami pigeonite may have cooled at ~175 ºC/yr (~0.02 ºC/hr) through the temperature range of 1100–950 ºC. Based on this cooling rate, they suggested either that Zagami originates from a lava flow significantly thicker than 10 m or that comes from a shallow intrusive body such as a sill or dyke.The width of the Chassigny augite exsolution lamellae is slightly thicker than that of the Zagami augite exsolution lamellae. From the comparison of these augite lamellae, a cooling rate of Chassigny seems to have been slightly slower than that of Zagami. Based on the schematic TTT diagram of Nord et al. [9], the Chassigny pigeonite may have cooled at least a factor of 4-5 slower through the temperature interval of 1100-950°C, which suggests that the Chassigny pigeonite may have cooled at 35-43 ºC/yr (~0.004-0.005 ºC/hr). This estimated cooling rate corresponds to the burial depths of about 15 m.

Although olivine in Chassingy is homogeneous in the Fe/Mg ratio, CaO contents show slight decrease from the core (0.3 wt%) to the rim (0.1 wt%). The CaO content in olivine containing a magmatic inclusion also decreases toward the magmatic inclusion. We estimated cooling rate of Chassigny by using this Ca zoning of olivine. The decrease of Ca towards the rim shows that Ca in Chassigny olivine was absorbed into the residual melt. Chassigny olivines preserve such a Ca zoning profile because the host magma has cooled before Chassigny olivine reaches equilibrium with the residual melt. By assuming that Chassigny olivine was originally homogeneous and then it was modified by atomic diffusion due to contact with the surrounding residual melt, cooling rates of Chassigny olivine could be calculated by employing a method similar to Miyamoto et al. [10]. Although we assumed that initial composition was homogeneous, this assumption is not critical to our estimate of cooling rates. We employed the olivine Ca diffusion rate of Jurewicz and Watson [11]. We calculated diffusion profiles for cooling over the temperature ranges of 1150–650 ºC. The cooling rate of 28 ºC/yr gives the best-fit to the observed Ca zoning profile of the Chassigny olivine. This estimated cooling rate is nearly identical to the cooling rate estimated by the pyroxene exsolution and corresponds to the burial depths of about 15 m.

Thus, pyroxene exsolution feature and chemical zoning of olivine in Chassigny suggest fast cooling history of this dunite meteorite. Although the location of the initial olivine crystallization is unclear, the final solidification of Chassigny seems to have occurred near the surface of the Mars.

References: [1] Wadhwa M. W. and Crozaz G. (1997) *GCA* 90, 1151-1154. [2] Prinz M. (1974) *Meteoritics,* 9, 393-394. [3] Floran R. J. et al. (1978) *GCA,* 42, 1213-1229. [4] Nekvasil H. et al. (2003) *Sixth Internatl. Conf. on Mars*, #3041. [5] Lindsley D. H. (1983) *Am. Min*., 68, 477-493. [6] Müller W. F. et al. (1993) *GCA,* 57, 4311-4322. [7] Brearley A. (1991) *LPS XXII,* 135-136. [8] Mikouchi T. et al. (1999) *EPSL,* 173, 235-256. [9] Nord G. L. et al. (1975) *LPS VI*, 601-603. [10] Miyamoto M. et al. (1986) *JGR,* 91, 12804-12816. [11] Jurewicz A. J. G. and Watson. E. (1988) *Contrib. Mineral. Petrol.,* 99, 186-201.

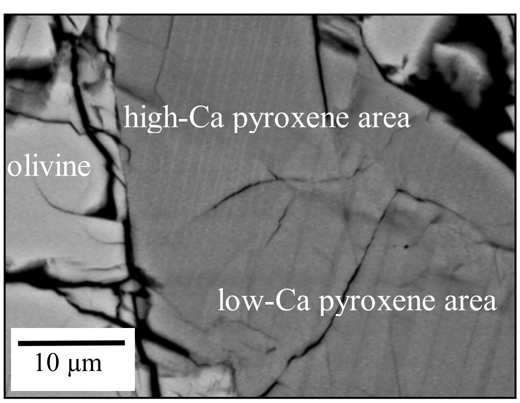

Fig. 1. High-Ca and low-Ca pyroxenes pair having exsolution lamellae, respectively.

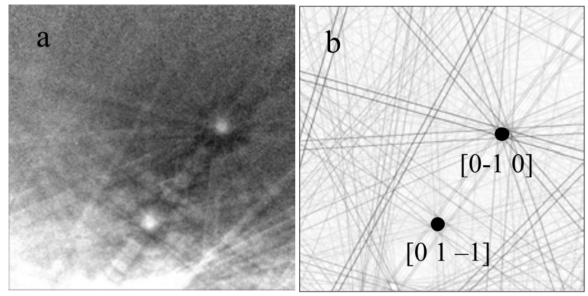

Fig. 2. (a) Observed and (b) calculated EBSD patterns of the pigeonite matrix in low Ca pyroxene having exsolution lamellae.

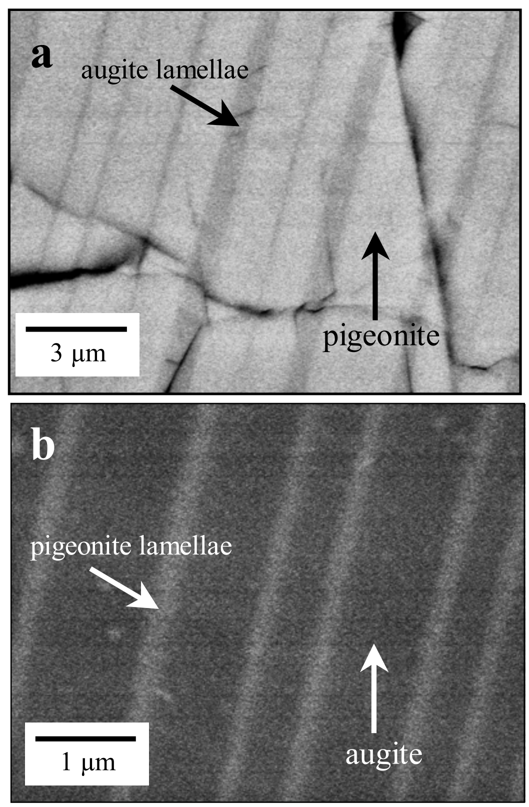

Fig. 3. (a) Augite lamellae in pigeonite matrix, (b) pigeonite lamellae in augite matrix.