**An experimental study of chondrule formation interacting with the surrouding gas under the nebular conditions of reducing and $10^{-3}$ bars.** N. Imae[1] and H. Isobe[2], [1]National Institute of Polar Research, Tachikawa, Tokyo 190-8518, Japan. e-mail: imae@nipr.ac.jp. [2]Kumamoto University, Chuo-ku, Kumamoto 860-8555, Japan.

**Introduction:**

So far, experiments on chondrule formation have been carried out mainly under the 1 atmospheric pressure, and the consideration for the precursor materials and their compositions have not been satisfactory [e.g., 1]. In the present study, the experiments on chondrule formation were carried out under the nebular pressures (mainly $10^{-3}$ bars) of the hydrogen gas dominant reduced conditions, and the chondritic precursors with various Fe# were used, since there may be many kinds of precursors of chondrules. Additional consideration was the role of the Si-rich gas during the heating. Under the reducing and low-pressure conditions, the interaction with the surrounding gas becomes significant. The interaction is important because the interaction with gas during the chondrule formation has been strongly suggested from the oxygen isotopic analyses of primitive chondrules [e.g., 2].

**Experiments:**

Starting materials for the present experiments have been revised and the number of the experimental runs has been much added from the presentation at the present symposium last year [3]. The main revision is to use the sintered pellets with various chondrite and chondritic samples (Table 1). Experimental conditions were focused on the reproduction of porphyritic chondrules, which is the majority especially of carbonaceous chondrites: peak temperatures mainly of 1250-1550°C, oxygen fugacities of IW-3 to IW-4, and cooling rates of 64-10000°C/h.

The polished thin sections of the run products were examined using an electron probe micro analyzer (JXA-8200) on the condition of focused beam for minerals of olivines and pyroxenes, defocused beam for mesostasis glass (5-10 μm), and broad beam for bulk composition of each charge (100 μm). The chondrules of three primitive chondrites (Y-81020 CO3.0, Y-793495 CR2, and NWA 1465 anomalous C) were also examined similarly for the comparison.

**Results and discussion:**

Olivines and pyroxenes were common minerals crystallized from the melt of the starting materials. However, their compositions and modes, and the species of pyroxenes were systematically different among them and depending on the experimental conditions. Large and euhedral shaped low-Ca clinopyroxenes crystallized from the runs with Si-rich gas source (Fig. 1b, 1d, 1f), but low-Ca pyroxenes were smaller or absent from the runs without Si-rich gas source (Fig. 1a, 1c, 1e). The Fe#s of olivines and pyroxenes at the higher peak temperatures (more than 1450°C) and lower cooling rates (100°C/h) were significantly lower than those of the lower peak temperatures (less than 1400°C) (Figs. 2 and 3). The starting materials (S2SP, S3SP, and S5SP) of the reduced mixtures were more refractory than those of the oxidized mixtures (A3SP, A4SP, NWSP), with the difference of ~50°C for liquidus temperatures.

The compositional variations are much wider for A3SP and A4SP (Fe#=0-40) than the others. Orthoenstatites (CaO=1-2 wt%) and high-Ca pyroxenes from A3SP, A4SP, NWSP, and S5SP were common but absent from S2SP and S3SP, which are enriched in the Al/Ca ratio. The abundances of orthoenstatites from slower cooling rates of 100°C/h are higher than those of faster cooling rates, and those from the condition without Si-rich gas source are also higher than those with Si-rich gas.

The significant decrease of the iron content was recognized from higher peak temperatures and slower cooling rates. This is not only by the absorption to the Pt or Mo wire used for holding the charge, but rather vaporization of iron during the heating. As the result of the vaporization of iron, the ratios of the other elemental contents increased. Especially for the $SiO_2$ content, ~10wt% increased without Si-rich gas source. While, additionally ~5wt% $SiO_2$ increases with Si-rich gas source (thus ~15wt% in total), which is consistent with the theoretical estimation based on the collision theory.

**Comparison with primitive chondrules and the implication to the evolution of chondrules:**

The compositions of olivines and low-Ca pyroxenes from the peak temperature more than 1450°C and the cooling rate of 100°C/h are in the compositional range observed from type I chondrules of Y-81020 except of the almost pure forsterites which should be direct condensates from nebula gas. This is irrespective of the prepared starting materials. The ferroan olivines and low-Ca pyroxenes corresponding to those of type II chondrules occurred from the lower peak temperatures and rapid cooling rates. Especially rounded olivines poikilitically enclosed in enstatite form under the condition of Si-rich gas source, suggesting the similar condition in the solar nebula.

The increase of Si content due to the evaporation of iron content during the chondrule formation is enhanced on the Si-rich gas existing condition. Thus this may bring the chemical evolution of chondrules into Si-rich. Chondrule may evolve to Si-rich through the chondrule formation such as type IA to IB and II to IB.


**References:**

[1] Tsuchiyama A., et al. (1980) *Earth Planet. Sci. Lett.*, 48, 155-165. [2] Chaussidon M., et al. (2008) *GCA*, 72, 1924-1938. [3] Imae N. and Isobe H. (2013) *Antarctic Meteorites* XXXVI, 36-37.


Table. 1. The number of runs for each starting materials.

| Starting materials | Abbreviation of the starting material | Without Si-rich gas source | With Si-rich gas source |
|---|---|---|---|
| Fragment of the Allende CV3 chondrite | | 18 | 5 |
| Sintered pellet of the powder of the Allende CV3 chondrite | A3SP, A4SP | 5 | 3 |
| Sintered pellet of the powder of the NWA1465 anomalous C chondrite | NWSP | 7 | 8 |
| Sintered pellet of the powder of the two kinds of reduced chondritic composition | S2SP, S3SP | 7 | 8 |
| Sintered pellet of the powder of reduced chondritic composition | S5SP | 3 | 3 |

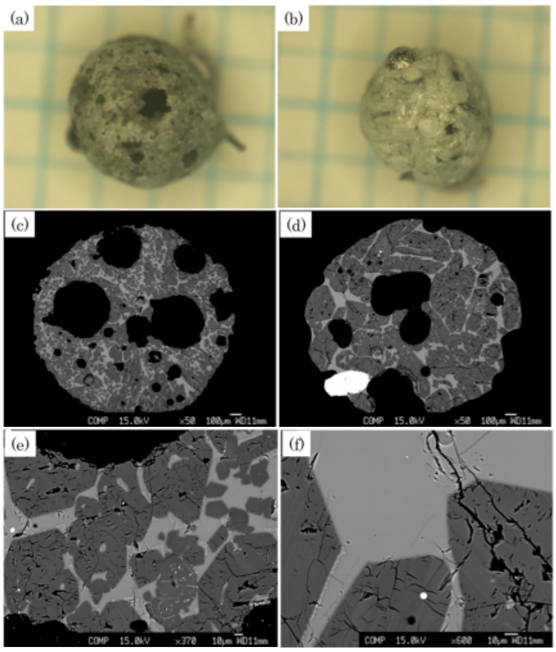

Fig. 1. Photographs of representative run products. Left column [(a), (c), (e)] = NWNS-7. $En_{96\text{-}97}$. $En_{50}Wo_{48}$. Right column [(b), (d), (f)] = NWS-7. $En_{98}$. The NW in the run number denotes the starting material of NWSP, NS the condition without Si-rich gas source, and S with Si-rich gas source.

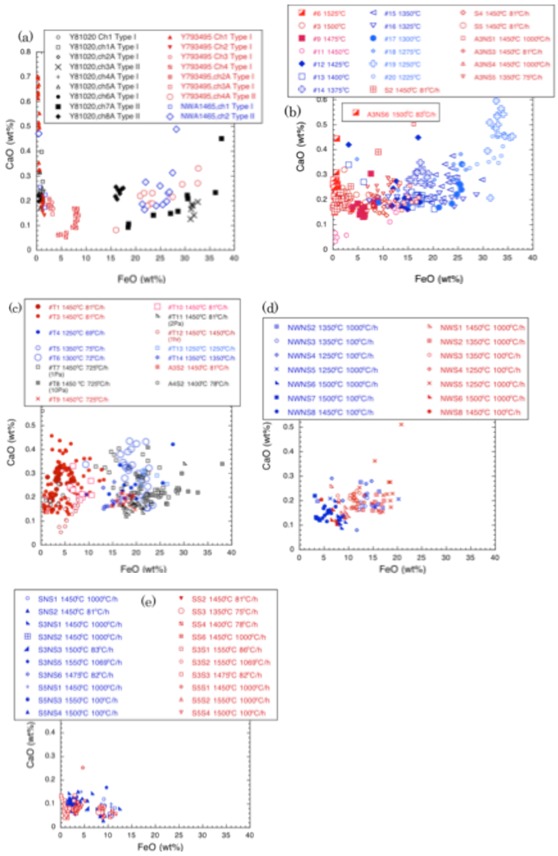

Fig. 2. (a)-(e). Compositions of olivines.

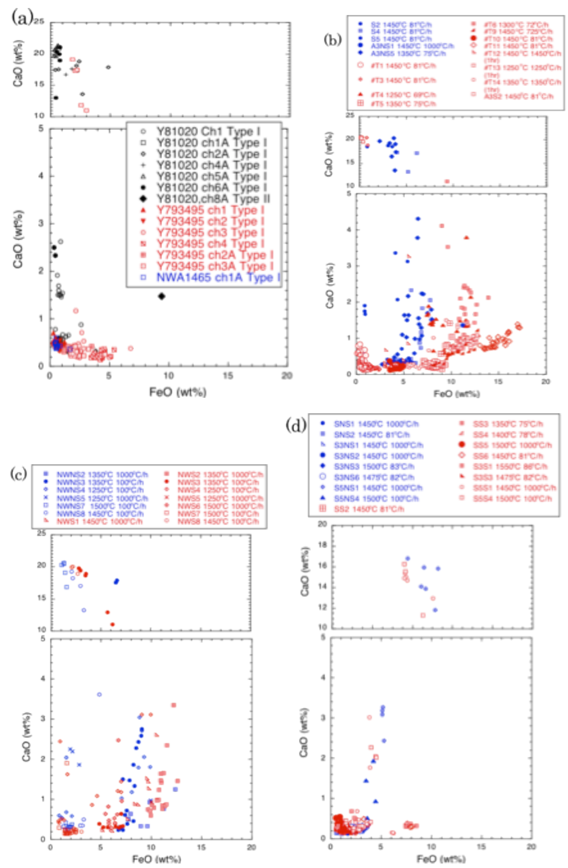

Fig. 3. (a)-(d). Compositions of low-Ca pyroxenes.