

**A WIDE RANGE OF THE COOLING RATE OF TYPE II PORPHYRITIC OLIVINE CHONDRULES IN SEMARKONA (LL3.0).** M. Miyamoto, E. Koizumi and T. Mikouchi, Space and Planetary Science, Graduate School of Science, University of Tokyo, Hongo, Tokyo 113-0033, Japan ([miyamoto@eps.s.u-tokyo.ac.jp](mailto:miyamoto@eps.s.u-tokyo.ac.jp)).

**Introduction:** We developed a model to calculate the cooling rate of olivine by analyzing chemical zoning on the basis of Fe-Mg interdiffusion during olivine crystal growth [e.g., 1]. Miyamoto et al. [2, 3] have verified this model by using Fe-Mg zoning in olivine produced by dynamic crystallization experiments of Jones and Lofgren [4] and Koizumi et al. [5] and reported that the cooling rates calculated by this model give a good agreement with those of the experiments. In this abstract, we applied the model to calculating the cooling rate of olivines in several different type II porphyritic olivine chondrules in Semarkona (LL3.0). We found that porphyritic olivine chondrules in Semarkona show a wide range of the cooling rate.

**Model:** We consider that Fe-Mg chemical zoning in olivine forms basically on the basis of the closed-system fractional crystallization as olivine crystal grows in the high temperature range. We calculated an Fe-Mg zoning profile by using the Rayleigh equation. The equation is  $C_L/C_0 = F^{K_D-1}$ , where  $C_0$  and  $C_L$  are the initial concentration in the bulk liquid and the concentration in the observed liquid, respectively.  $K_D$  is the distribution coefficient (0.30), and  $F$  is the fraction of liquid remaining. The primary zoning profile that formed by fractional crystallization is modified by Fe-Mg interdiffusion during crystal growth in the high temperature range. Namely, we compute diffusional modification for Fe-Mg zoning produced by fractional crystallization in the growing olivine crystal by numerically solving the diffusion equation. We used the Fe-Mg diffusion coefficient in olivine reported by Misener [6] with oxygen-fugacity dependence [7]. The oxygen fugacity used in the model calculation is  $\log fO_2 = IW-0.5$ .

**Olivine crystal growth:** We assume that crystal growth of olivine is parabolic [e.g., 8], that is,  $dR/dt$  is proportional to  $1/R$ , where  $R$  is the radius of crystal and  $t$  is time. As the crystal grows, Fe-Mg zoning forms in accordance with the Rayleigh equation.

**Estimation of  $T_S$  and  $T_E$ :** Crystallization of olivine starts at temperature  $T_S$  and olivine grows until temperature  $T_E$  as temperature decreases (Fig. 1). Diffusional modification of Fe-Mg zoning formed by fractional crystallization takes place during crystal growth and continues until closure temperature ( $T_F$ ) of Fe-Mg interdiffusion at which Fe-Mg interdiffusion essentially ceases.  $T_F$  is usually lower than the temperature  $T_E$  at which olivine crystal growth stops. We estimated  $T_S$  and  $T_E$  by using MELTS [9] for the bulk chemical

composition of Semarkona chondrule [10] under the conditions that equilibrium or fractionate solids option of MELTS. The difference in  $T_S$  does not significantly affect the calculated cooling rate, whereas  $T_E$  affects the result: 100 °C of difference in  $T_E$  gives 3-4 times difference in the cooling rate. We employed closure temperature ( $T_F$ ) of 900 °C.

**Procedures:** We determined three unknown parameters, the cooling rate, initial concentration for fractional crystallization ( $C_0$ ), and fraction of liquid remaining ( $F$ ) by employing the non-linear least squares method (Simplex method) to fit the computed zoning profile to the observed zoning.

**Results and discussion:** Fig. 2 shows the results for olivines in different porphyritic olivine chondrules. Open circles show zoning profiles measured by electron microprobe and solid curves show the calculated profiles. The best-fit cooling rates calculated by our model are 4.5, 5.3, 11, 120, and 1100 °C/h for olivines in several porphyritic olivine chondrules. The calculated values of the fraction of liquid remaining are 15, 46, 10, 16, and 13%, respectively. The observed values of the fraction of liquid remaining reported by Jones [10] for Semarkona chondrules range from 15 to 37%. Our calculated results are broadly consistent with the observed values.  $T_S$  and  $T_E$  estimated by MELTS are shown in Fig. 2 for each olivine.

According to the summary by Hewins [11] for the relation between the cooling rate and texture of experimentally reproduced chondrules, porphyritic olivine chondrules can be experimentally reproduced at the cooling rate of 10-2000 °C/h. Our calculation results (4.5-1100 °C/h) are broadly consistent with the experimental results. Our results suggest that porphyritic olivine chondrules actually formed at a wide variety of the cooling rate, although experimental results only show the possibility of the cooling rate at which porphyritic olivine chondrule forms.

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**References:** [1] Miyamoto M. et al. (1999) *LPS XXX*, Abstract #1323. [2] Miyamoto M. et al. (2005) *LPS XXXVI*, Abstract #1610. [3] Miyamoto M. et al. (2006) *LPS XXXVII*, Abstract #1538. [4] Jones R. H. and Lofgren G. E. (1993) *Meteoritics*, 28, 213-221. [5] Koizumi E. et al. (2004) *LPS XXXV*, Abstract #1494. [6] Misener, D. J. (1974) in *Geochemical Transport and Kinetics*, ed. A. W. Hofmann et al., Carnegie Inst. Washington, Publ. 634. [7] Miyamoto M. et al. (2002)

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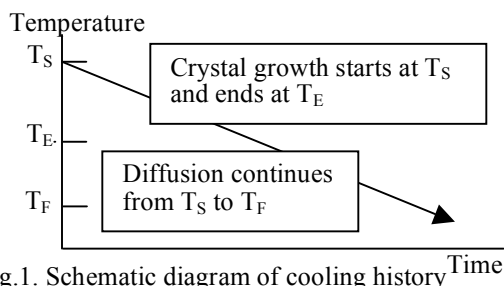


Fig. 1. Schematic diagram of cooling history

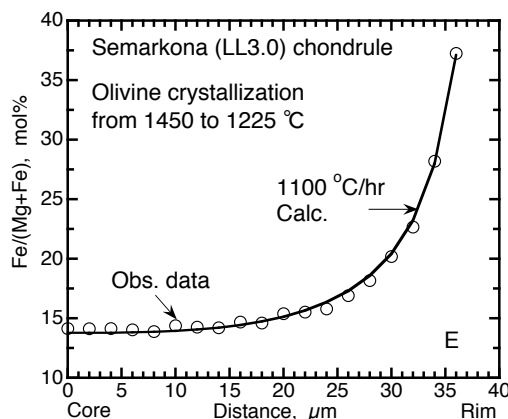
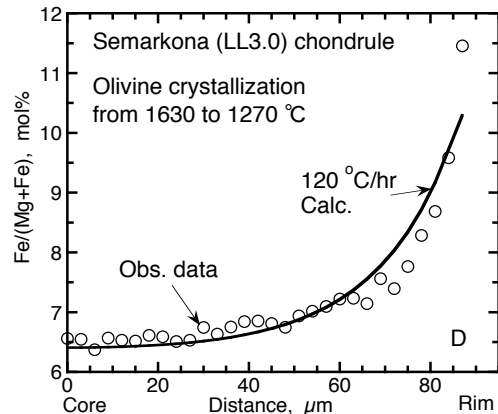
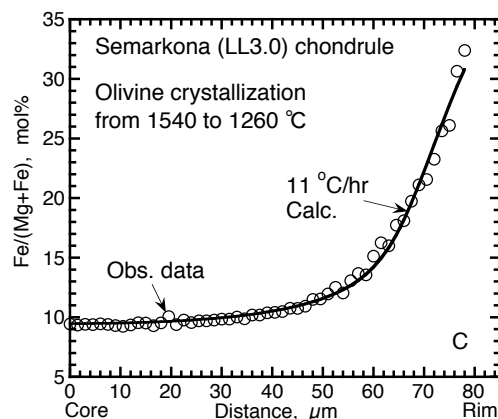
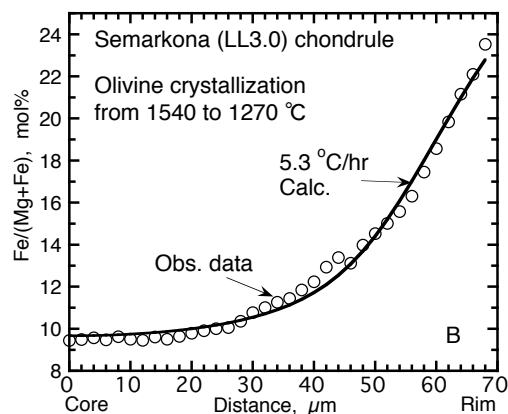
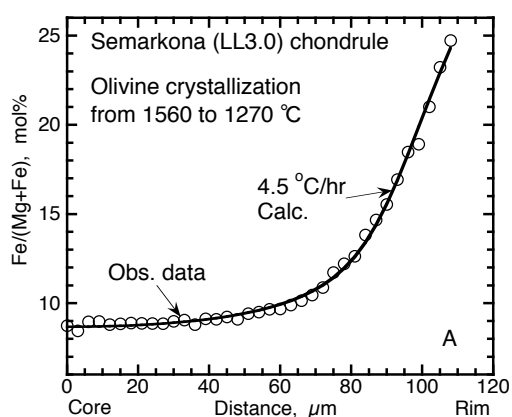


Fig. 2. Calculated zoning profiles (solid curves) and observed zoning profiles (open circles) for olivines in Semarkona (LL3.0) type II porphyritic olivine chondrules. A-E show different chondrules. Solid curves show the best-fit to the observed profiles and numbers on curves show the best-fit cooling rates calculated by our model.