

**VERIFICATION OF A MODEL TO CALCULATE COOLING RATES IN OLIVINE BY CONSIDERATION OF FE-MG DIFFUSION AND OLIVINE CRYSTAL GROWTH.** M. Miyamoto<sup>1</sup>, R. H. Jones<sup>2</sup>, E. Koizumi<sup>1</sup> and T. Mikouchi<sup>1</sup>, <sup>1</sup>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)), <sup>2</sup>Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM87131.

**Introduction:** We developed a model to analyze chemical zoning in olivine on the basis of Fe-Mg interdiffusion during olivine crystal growth to obtain the cooling rate (or burial depth) of parent rock [e.g., 1]. In this abstract, we verify this model by using Fe-Mg zoning in olivine produced by dynamic crystallization experiments of Jones and Lofgren [2]. They reported Fe-Mg chemical zoning in olivine for the bulk chemical composition like a porphyritic chondrule of Semarkona (LL3.0) at 2 °C/h, 5 °C/h and 100 °C/h cooling experiments.

**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 and during this process diffusional modification takes place by Fe-Mg interdiffusion. Namely, we compute diffusional modification for Fe-Mg chemical zoning produced by the fractional crystallization in the growing olivine crystal.

Crystallization of olivine starts at temperature  $T_S$  and olivine grows until temperature  $T_E$  as temperature decreases. Diffusional modification for Fe-Mg zoning formed by fractional crystallization also takes place during crystal growth and continue until closure temperature ( $T_F$ ) of Fe-Mg diffusion, which is usually lower than  $T_E$ .

We assume that crystal growth of olivine is parabolic [e.g., 3], 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 for closed-system fractional crystallization. The partition coefficient of Fe/Mg between olivine and melt is 0.30.

We compute diffusional modification of the Fe-Mg zoning by numerically solving the diffusion equation using the Fe-Mg diffusion coefficient in olivine reported by Misener [4] with oxygen-fugacity dependence. There are approximately two orders of magnitude variations among the Fe-Mg interdiffusion coefficients reported previously. Miyamoto et al. [5] evaluated the Fe-Mg diffusion coefficients of olivine reported in several studies in the literature by employing the experimentally produced chemical zoning pattern and concluded that the profile calculated by using the Fe-Mg diffusion coefficient

reported by Misener [4] with oxygen-fugacity dependence gives the best-fit to the observed zoning profile.

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

**Experiments:** Jones and Lofgren [2] experimentally produced porphyritic olivine textures by dynamic crystallization of bulk chemical composition like a porphyritic chondrule of Semarkona (LL3.0) and reported Fe-Mg zoning profiles of olivine for continuously cooled at 2 °C/h from 1525 °C to 985 °C, 5 °C/h from 1550 °C to 1015 °C, and 100 °C/h from 1525 °C to 1200 °C. We used these experimentally produced profiles for verification of our model, that is, we calculated the cooling rate by using our model to obtain the best-fit profile to the experimentally produced zoning profile. We estimated the temperature ( $T_E$ ) at which olivine crystallization terminates by using the MELTS program [6] for the bulk chemical composition. Although the result is approximately 1200 °C, we employed  $T_E$  of 1150 °C considering supercooling.  $T_S$  is 1525 °C, 1550 °C, and 1525 °C, and  $T_F$  is 985 °C, 1015 °C, and 1200 °C for 2 °C/h, 5 °C/h, and 100 °C/h cooling, respectively. These values are the same as those for dynamic crystallization experiments by Jones and Lofgren [2]. The experiments were carried out at  $\log fO_2 = IW-0.5$ : this is the oxygen fugacity we assumed in the model.

**Results and Discussion:** Figure 1 shows the results. Open circles show the zoning profiles produced by dynamic crystallization experiments reported by Jones and Lofgren [2] and solid curves show the calculated profiles. The best-fit cooling rates obtained by our model calculation are 2.4 °C/h for 2 °C/h cooling experiment, 5.6 °C/h for the 5 °C/h cooling experiment and 120 °C/h for 100 °C/h cooling experiment. The calculated zoning profiles are in good agreement with the experimentally produced profiles. These results mean that the Fe-Mg interdiffusion coefficient reported by Misener [4]

with oxygen-fugacity dependence [5] is relatively accurate. Our model to estimate the cooling rate on the basis of Fe-Mg zoning is valid.

The initial Fa ( $=\text{Fe}/(\text{Mg}+\text{Fe})$ , mol%) concentrations in the bulk liquid calculated by our model are 10, 13, and 17 mol% for 2 °C/h, 5 °C/h, and 100 °C/h cooling experiments, respectively. For comparison, the molar Fe/(Mg+Fe) of the starting material for dynamic crystallization experiments was 16 mol%.

The fractions of liquid remaining calculated are 54%, 40%, and 33% for 2 °C/h, 5 °C/h, and 100 °C/h cooling experiments, respectively.

**References:** [1] Miyamoto M. et al. (1999) *Lunar and Planetary Science XXX*, Abstract #1323 (CD-ROM). [2] Jones R. H. and Lofgren G. E. (1993) *Meteoritics*, 28, 213-221. [3] Elwell D. and Scheel H. J. (1975) *Crystal Growth from High-Temperature Solutions*, 634 pp, Academic Press Inc. London. [4] Misener, D. J., (1974) in *Geochemical Transport and Kinetics*, ed. by A. W. Hofmann et al., Carnegie Inst. Washington, Publ. 634. [5] Miyamoto M. et al. (2002) *Antarct. Meteorite Res.*, 15, 143-151. [6] Ghiorso, M. and Sack, R. (1995) *Contrib. Mineral Petrol.*, 119, 197-212.

Fig. 1. Comparison of the calculated zoning profiles (solid curves) with the observed zoning profiles (open circles) produced by dynamic crystallization experiments by Jones and Lofgren [2]. (a) 2 °C/h, (b) 5 °C/h, and (c) 100 °C/h cooling experiments. Solid curves show the best-fit to the observed profiles and numbers show the best-fit cooling rates. The calculated cooling rate is in good agreement with the experimental cooling rate.

