

VERIFICATION OF A MODEL TO CALCULATE COOLING RATES IN OLIVINE BY CONSIDERATION OF FE-MG DIFFUSION AND OLIVINE CRYSTAL GROWTH, II. 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).

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] have verified this model by using Fe-Mg zoning in olivine produced by dynamic crystallization experiments of Jones and Lofgren [3] and reported that cooling rates calculated by this model for the experimentally produced zoning profiles are in good agreement with cooling rates of the experiments. In this abstract, we further verify this model by using zoning profiles experimentally produced by dynamic crystallization for Martian and lunar meteorite compositions.

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. Namely, we compute diffusional modification for Fe-Mg zoning produced by 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 (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, which is usually lower than the temperature T_E at which olivine crystal growth stops.

We assume that crystal growth of olivine is parabolic [e.g., 4], 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.

We compute diffusional modification of the Fe-Mg zoning by numerically solving the diffusion equation by using the Fe-Mg diffusion coefficient in olivine reported by Misener [5] with oxygen-fugacity dependence [6].

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 experimentally produced zoning profile. We compared the calculated cooling rate with the cooling rate of the dynamic crystallization experiment that produced the observed zoning profile.

Experiments: Koizumi et al. [7,8] performed dynamic crystallization experiments of the Y980459 Martian meteorite and the LAP02205 lunar meteorite to better understand their cooling histories and conditions. Synthetic glass having a similar composition to the bulk composition of Y980459 was cooled from 1460 °C to 1000 °C at the rate of 2.5 °C/h (Fig. 2a). Synthetic glass similar to LAP02205 was cooled from 1160 °C to 1000 °C at the rate of 2.5 °C/h (Fig. 2b) or 20 °C/h (Fig. 2c). We used these experimentally produced profiles for verification of our model, that is, we calculated the cooling rate by our model to obtain the best-fit profile to the experimentally produced zoning profile.

We estimated the temperature (T_S) at which olivine crystallization starts and the temperature (T_E) at which olivine crystallization terminates by using the MELTS program [9] for each bulk chemical composition. The results are: T_S of 1450 °C and T_E of 1190 °C for Y980459, and T_S of 1140 °C and T_E of 1050 °C for LAP02205. We employed closure temperature (T_F) of 1000 °C that is the same as that of dynamic crystallization. The experiments were carried out at $\log f_{O_2} = IW+1.0$ for Y980459 and at $\log f_{O_2} = IW-1.0$ for LAP02205: these are the oxygen fugacities we assumed in the model calculation.

Results and Discussion: Fig. 2 shows the results. Open circles show zoning profiles produced by dynamic crystallization experiments by Koizumi et al. [7,8] and solid curves show the calculated profiles. The best-fit cooling rate calculated by our model is 4.7 °C/h for the 2.5 °C/h cooling experiment of Y980459 (Fig. 2a). The best-fit cooling rates for LAP0205 are 3.9 °C/h for the 2.5 °C/h experiment (Fig. 2b) and 22 °C/h for the 20 °C/h experiment (Fig. 2c). These calculated cooling rates are in good agreement with those of experiments. Table 1 shows the results of the calculated cooling rates for different T_S and T_E for comparison.

The initial Fa ($=\text{Fe}/(\text{Mg}+\text{Fe})$, mol%) concentration (C_0) in the bulk liquid calculated by our model is 22 mol% for Y980459. The calculated core composition of the final zoning profile shown in Fig. 2a is 27 mol%. This difference in composition is caused by Fe-Mg diffusion mainly during crystal growth. The initial Fa concentration calculated for LAP02205 are 47 and 50 mol% for 2.5 °C/hr and 20 °C/hr of cooling experiments, respectively.

The fractions of liquid remaining calculated by our model are 10% for Y980459, 3%, and 13% for 2.5 °C/h and 20 °C/h experiments of LAP02205, respectively. These values are broadly consistent with those of experimental results.

Conclusions: The results of this study and Miyamoto et al. [2] mean that (1) our model to estimate the cooling rate on the basis of Fe-Mg zoning considering olivine crystal growth is valid for different bulk chemical compositions and for the wide range of the Fa component and (2) the Fe-Mg interdiffusion coefficient reported by Misener [5] with oxygen-fugacity dependence [6] is relatively accurate.

References: [1] Miyamoto M. et al. (1999) *LPS XXX*, Abstract #1323. [2] Miyamoto M. et al. (2005) *LPS XXXV*, Abstract #1610. [3] Jones R. H. and Lofgren G. E. (1993) *Meteoritics*, 28, 213-221. [4] Elwell D. and Scheel H. J. (1975) *Crystal Growth from High-Temperature Solutions*, 634 pp, Academic Press Inc. London. [5] Misener, D. J. (1974) in *Geochemical Transport and Kinetics*, ed. A. W. Hofmann et al., Carnegie Inst. Washington, Publ. 634. [6] Miyamoto M. et al. (2002) *Antarct. Meteorite Res.*, 15, 143-151. [7] Koizumi E. et al. (2004) *LPS XXXV*, Abstract #1494. [8] Koizumi E. et al. (2005) *Meteoritics & Planet. Sci.*, 40, A85. [9] Ghiorso, M. and Sack, R. (1995) *Contrib. Mineral Petrol.*, 119, 197-212.

Table 1	T_S	T_E	T_F	Coolig rate
Y98 2.5 °C/hr	1450 °C	1190	1000	4.7 °C/hr
	1450	1150	1000	2.7
	1400	1190	1000	4.8
	1400	1150	1000	2.8
LAP 2.5 °C/hr	1140	1050	1000	3.9
	1140	1000	1000	0.7
LAP 20 °C/hr	1140	1050	1000	22.5
	1140	1000	1000	22.2

Fig. 2. Comparison of calculated zoning profiles (solid curves) with observed zoning profiles (open circles) (a) 2.5 °C/h of Y980459, (b) 2.5 °C/h and (c) 20 °C/h of LAP02205 cooling experiments.

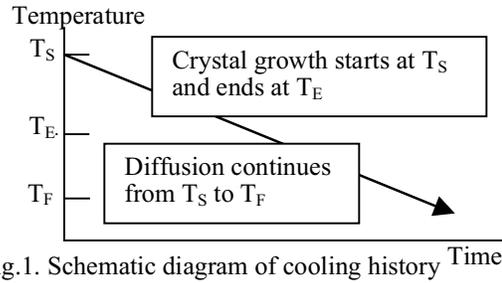


Fig.1. Schematic diagram of cooling history

