MAXIMUM TEMPERATURE OF PARENT-BODY THERMAL METAMORPHISM FOR ALH77299 (H3.7) CHONDRITE BY ANALYZING FE-MG ZONING OF OLIVINE. M. Miyamoto[1] and H. Kaiden[2], [1]Space and Planetary Science, Graduate School of Science, University of Tokyo, Hongo, Tokyo 113-0033, Japan, miyamoto@eps.s.u-tokyo.ac.jp, [2]National Institute of Polar Research, Midori-cho, Tachikawa, Tokyo 190-8518, Japan.

Introduction: Ordinary chondrites show the metamorphic sequence that formed in their parent bodies [e.g., 1]. As evidence to support this idea, chemical zoning profiles of olivine and pyroxene change gradually among different petrologic types [e.g., 2]. Since chemical zoning in minerals provides information on their thermal metamorphism, we applied Fe-Mg chemical zoning of olivine to estimating the maximum temperature of thermal metamorphism in the parent body of ALH77299 (H3.7) ordinary chondrite and compared the results with those of Yamato791717 (CO3.6) carbonaceous chondrite reported in [3]. The method employed is similar to that in previous studies [e.g., 4], that is, by solving the diffusion equation to calculate the best-fit zoning profile to the observed one, because chemical zoning is mainly controlled by atomic diffusion and atomic partition.

We determined the maximum temperature of parent-body thermal metamorphism by calculating the cooling rate or burial depth for different maximum temperatures of (1) linear cooling, (2) nonlinear cooling in a sheet, and (3) nonlinear cooling in ^{26}Al heated parent body.

Procedures and Results:

Thermal metamorphism: Linear cooling. We applied the diffusional modification model developed by [4] to calculating the zoning profile, corresponding to thermal metamorphism. The primary zoning profile formed by closed-system fractional crystallization (Rayleigh equation; solid curve in Fig. 1) is modified by Fe-Mg interdiffusion to obtain the best fit to the observed profile (open circles). The comparison was made by the residuals of least squares fitting.

We calculated the linear cooling rate from a maximum temperature to obtain the best fit. Fig. 2 compares the best-fit profiles among different maximum temperatures and Table 1 shows the least squares residuals. The results are different in the curvature of the calculated profile (Fig. 2), shown by the least-squares residuals in Table 1. The result for the maximum temperature of 600 ^{o}C shows the best fit. Table 2 shows the results for Y791717 (CO3.6) by similar calculations [3] and the maximum temperature of 600 ^{o}C also shows the best fit.

Thermal metamorphism in parent body: Burial depth in sheet (nonlinear cooling). We calculated the burial depth in the parent body as cooling from different maximum temperatures of sheet. In this case, cooling is nonlinear. We assumed the sheet having the rock-like thermal diffusivity of 0.004 cm^2/s and ambient temperature of 200K. We calculated the best-fit burial depth for each maximum temperature. The residuals for different maximum temperatures are shown in Tables 1 and 2. The maximum temperature of 600 ^{o}C shows the best fit like the linear cooling case.

Thermal metamorphism in parent body: Burial depth in ^{26}Al heated body. We calculated the best-fit burial depth in the ^{26}Al heated parent body. The model used is similar to that proposed by [5]. The radius of parent body is 85 km. The best-fit burial depth is 6.5 km for ALH77299 (H3.7) and 5.5 km for Y791717 (CO3.6).

Diffusion coefficient. Fe-Mg interdiffusion coefficient in olivine is a function of the Fe-concentration, oxygen fugacity, and temperature. We used the Fe-Mg diffusion coefficient in olivine reported by [6] with oxygen-fugacity dependence [7] as

$$D_{Fe} = 0.03163 \times 10^{-2} (f_{O2})^{1/6}(0.41+0.0112C_{Fe}) \exp[(-39.27+0.0905C_{Fe})/RT]$$

where D_{Fe} is the Fe-Mg interdiffusion coefficient in cm^2/s, f_{O2} is oxygen fugacity in atm. C_{Fe} is the Fa (= 100x Fe/(Mg+Fe), mole%) component, R is the gas constant in kcal mol^{-1} K^{-1} and T is temperature in K.

Discussion:

The maximum temperature of metamorphism to give the best fit is about 600 ^{o}C for both linear cooling and nonlinear cooling in a sheet (Table 1 and 2). The thermal metamorphic temperature previously proposed for type 3 chondrites is 400 – 600 ^{o}C [e.g., 1, 2]. Our results are consistent with this temperature range.

The best-fit burial depth of about 6 km for ^{26}Al heated body is deeper than those proposed by [5], where the range of burial depth for type 3 is 0 - 2.5 km for H and L chondrites. This value was, however, based on the assumption of the fall fraction of type 3 chondrites [5].

The difference in the curvature of calculated profiles is mainly caused by Fe-concentration dependency of the Fe-Mg interdiffusion coefficient in olivine. The Fe-Mg diffusion coefficient is a function of Fe-concentration of olivine, oxygen fugacity, and temperature. Oxygen fugacity is also a function of temperature.

Our study suggests that the detailed analysis of the Fe-Mg zoning profile gives some constraints on thermal metamorphism of meteorites.

References: [1] Kimura M. et al. (2008) *Meteorit-*

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Table 1. Cooling rates and depths for different maximum temperatures of thermal metamorphism in the parent body for ALH77299 (H3.7) chondrite. The best-fit profile is given for the maximum temperature of 600 °C by the smallest value of least squares residuals (boldface).

Maximum temperature °C	Linear cooling rate	LSQ Residual	Depth*	LSQ Residual
900 -	11 °C/yr	4.178	20 m	4.309
800 -	0.92 °C/yr	3.778	66 m	3.878
700 -	0.046 °C/yr	3.463	270 m	3.523
650 -	8100 °C/myr	3.362	620 m	3.398
600 -	**1100 °C/myr**	**3.317**	**1.6 km**	**3.326**
550 -	140 °C/myr	3.351	4.3 km	3.328
500 -	12 °C/myr	3.493	14 km	3.434
450 -	0.78 °C/myr	3.781	52 km	3.682
400 -	0.033 °C/myr	4.273	234 km	4.128
^{26}Al heated body			6.5 km	3.403

* assumed rock-like thermal diffusivity of 0.004 cm^2/s

Table 2. Cooling rates and depths for different maximum temperatures of thermal metamorphism in the parent body for Yamato791717 (CO3.6) chondrite. The best-fit profile is given for the maximum temperature of 600 °C

Maximum temperature °C	Linear cooling rate	LSQ Residual	Depth*	LSQ Residual
900 -	140 °C/yr	17.178	5.8 m	17.398
800 -	12 °C/yr	16.385	18 m	16.534
700 -	0.67 °C/yr	15.81	72 m	15.867
650 -	0.12 °C/yr	15.663	160 m	15.663
600 -	**0.019 °C/myr**	**15.653**	**389 m**	**15.589**
550 -	2400 °C/myr	15.835	1.1 km	15.696
500 -	220 °C/myr	16.272	3.2 km	16.054
400 -	0.73 °C/myr	18.357	51 km	17.944
^{26}Al heated body			5.5 km	16.678

* assumed rock-like thermal diffusivity of 0.004 cm^2/s

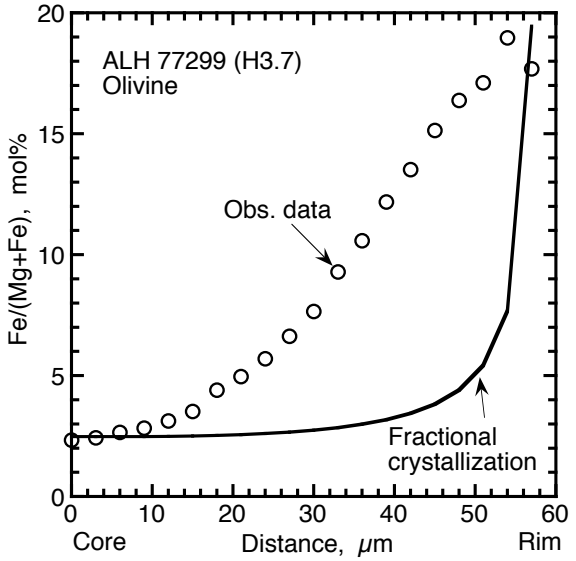

Fig. 1. The zoning profile calculated by closed-system fractional crystallization (solid curve). Liquid remaining is 6%. Open circles are the observed profile.

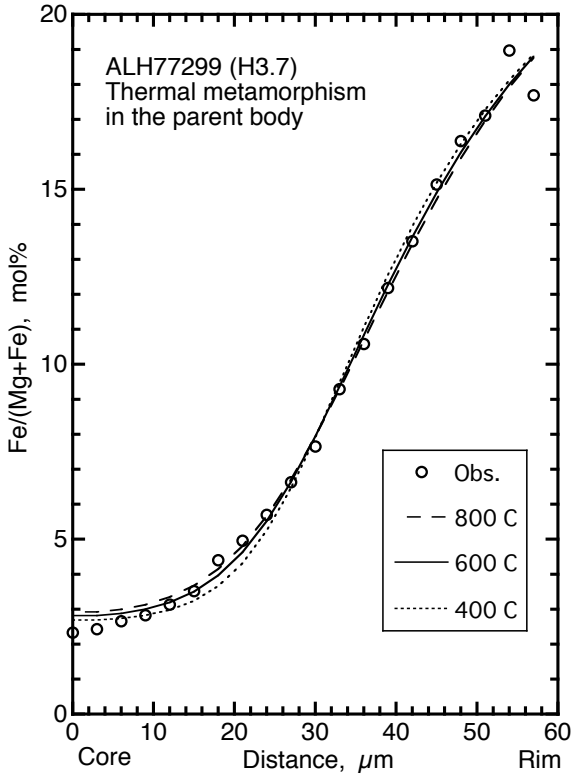

Fig. 2. Comparison of diffusional modification for the primary zoning formed by fractional crystallization (solid cure in Fig. 1) among different maximum temperatures. Cooling from 600 °C gives the best fit. See Table 1. Open circles are the same as those in Fig.1.