N94-16400

MORE ON THE COOLING HISTORY OF ANGRITE LEW 86010. G. McKay (SN4 NASA-JSC, Houston, TX,77058), T. Ogawa (Dept. of Pure and Applied Sci., Univ. of Tokyo, Komaba, Tokyo 153, Japan), M. Miyamoto and H. Takeda, Mineralogical Inst., Faculty of Sci., Univ. of Tokyo, Hongo, Tokyo 113, Japan)

Introduction. Antarctic angrite LEW 86010 has many chemical and mineralogical characteristics which suggest it is closely related to Angra dos Reis (ADOR) [e.g., 1-5]. However, these meteorites have had very different thermal histories. Olivines and pyroxenes in ADOR are nearly homogeneous [6], suggesting very slow cooling or extensive subsolidus equilibration. In contrast, LEW 86010 pyroxenes are extensively zoned in both major and trace elements [2-4], while olivines are nearly homogeneous, suggesting that cooling of this sample was slow enough to homogenize olivines, but too fast to homogenize pyroxenes.

In an earlier study [7], we used Ca diffusion gradients associated with exsolution lamellae of kirschsteinite in LEW 86010 olivines [1-5] to estimate the cooling rate of this sample. We obtained cooling rates of a few x .01°C/yr, corresponding to a burial depth of ~10^2 m under solid rock (thermal diffusivity = 0.004 cm^2/s), or ~10 m under regolith material (10^{-5} cm^2/s). Unfortunately, this calculation was very sensitive to the assumed temperature of initial exsolution, which we approximated from the estimated initial olivine bulk Ca content, and also to the extrapolated values for the Ca diffusion coefficient (D_{Ca}).

This abstract reports new cooling rate estimates obtained using a refined approach that includes the initial temperature of exsolution as one of the fitted parameters. The purpose of our new calculations is (1) to reduce uncertainties in cooling rate due to uncertainties in bulk olivine Ca content and initial exsolution temperature, (2) to investigate the effects of using different values for D_{Ca}, and (3) to determine how well constrained the cooling rate is for any particular Ca diffusion coefficient.

Method. For kirschsteinite lamellae in olivine in the LEW 86010 angrite, we computed both the width of the lamellae and the compositional gradients between the kirschsteinite and host olivine for various cooling conditions and compared them to profiles measured by electron microprobe. The method is similar to that in our previous studies [7,8], and is analogous to that developed by [9]. As the temperature goes down, olivine begins to exsolve kirschsteinite when the bulk olivine content meets the solvus function. Kirschsteinite lamellae grow as time passes and temperature falls. We used the solvus function reported by [10] to relate the initial exsolution temperature to olivine Ca content. We used D_{Ca} values extrapolated to $T<1000°C$ from experimental values for $T>1100°C$ [11,12]. We assume that the initial Ca concentration is uniform and that cooling is monotonic.

The difference from our earlier calculations [7] is that we now include the initial CaO content as a parameter to be fit. The initial Ca content determines the temperature of onset of exsolution, one of the major sources of cooling rate uncertainty in our previous estimate of the LEW 86010 cooling rate.

An important remaining uncertainty in the calculation is the value of D_{Ca} as a function of temperature over the cooling interval. We used experimentally measured diffusion coefficients for Ca in olivine parallel to the *c* direction from Morioka [11] and Jurewicz and Watson [12]. These measurements were made for temperatures ≥ 1100°C. To extrapolate to lower temperatures, we used two different values for the activation energy (E_a): 25 kcal/mole, based on experimental data for Fe-Mg diffusion in olivine [13] and Ca diffusion in pyroxene [14]; and 42 kcal/mole, the value observed at $T>1100°C$ by Jurewicz and Watson[12].

Results and Discussion. Cooling rates yielding model zoning profiles most closely matching observed profiles for a series of diffusion coefficient values are given in Table 1. Regardless of which diffusion coefficient is used, the best-fit value for initial Ca is ~8 mol %, or ~1.7x higher than the value in our earlier calculations. The earlier value was the concentration measured midway between kirschsteinite lamellae, under the assumption that Ca diffusion had not extended that far into the host olivine. The new calculations suggest that this assumption was not valid. The higher initial Ca concentration obtained by our new fitting procedures yields higher initial exsolution temperatures, and hence higher cooling rates than we estimated in our earlier study (Table 1 and [7]). These cooling rates correspond to burial depths of ~ 15-170 m of rock or ~ 1-10 m of regolith, depending on D_{Ca}.

Table 1. Best-fit cooling rates for various Ca diffusion coefficients (D_{Ca}) and activation energies (E_a).

D_{Ca} @ 1100°C (cm^2/s)	E_a (kcal/mol)	Rate (°C/yr)
1.098×10^{-14} [12]	25^1	0.35
1.434×10^{-11} [13]	42^2	10.
"	25^1	50.

Notes:
1. From pyroxene (see text).
2. Observed at T>1100 [12].

The robustness of our cooling rate solutions is illustrated in Figures 1 and 2. Figure 1 compares the observed Ca profile with model profiles for several cooling rates above and below the best-fit cooling rate. The best-fit rate (0.35°C/yr for D_{Ca} and E_a from line 1, Table 1) gives an obviously better fit to the observed data, particularly the width of the lamella, than rates twice or half as fast.

Figure 2 compares the observed profile with best-fit model profiles for several values of bulk Ca content, and provides an indication of how well our fitting method constrains the initial Ca content, and thus the temperature at the onset of exsolution. Different Ca contents yield different profiles in the host olivine, but no significant difference in lamella width. The observed profile is asymmetrical in the low-Ca phase, and best matches the profile for the 2x faster rate on one side, and for the 2x slower rate on the other. Despite the asymmetry, the observed profile is clearly a better match to the model profile for optimum Ca content than to those for initial Ca contents yielding cooling rates 1/5 and 5 times as high, and a marginally better match than those for rates of 1/2 and 2x. We infer a ~ 2x uncertainty in cooling rate resulting from uncertainty in the Ca fit.

The largest remaining uncertainty in calculating the cooling rate for LEW 86010 is the diffusion rate of Ca in olivine. The discrepancy of > 100x between 1100°C values reported by Morioka [11] and Jurewicz and Watson [12] results in an uncertainty of > 100x in the cooling rate. Further significant refinement of the cooling rate will probably require additional experiments to measure Ca diffusion.

Despite the uncertainties in diffusion rate, we obtain burial depths of a few tens of meters or less, assuming LEW 86010 was covered by material with the thermal diffusivity of solid rock. A physical setting corresponding to this burial depth might be at the bottom of a fairly thick lava flow. Lower limits correspond to about a meter of material with the insulating properties of regolith.

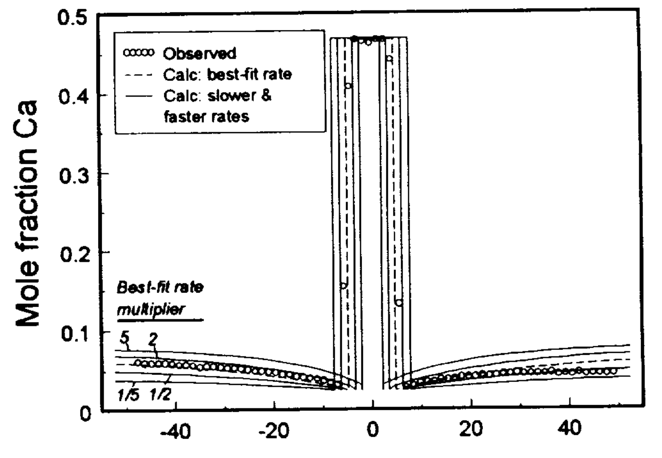

Figure 1. Observed and computed Ca zoning profiles in olivine adjacent to kirschsteinite lamella. Profiles are computed for a cooling rate that best fits observed profile (0.35°C/yr), plus rates of 5x, 2x, 1/2x, and 1/5x the best-fit rate.

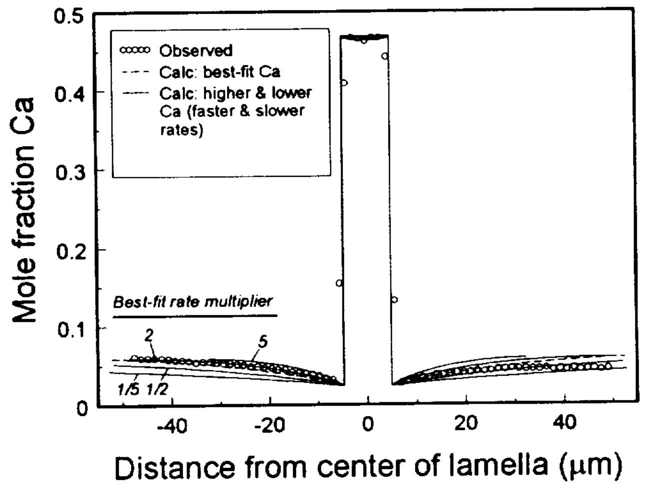

Figure 2. Observed and computed profiles. Profiles are computed for the optimum Ca content (8.0 mol %) and best-fit cooling rate (0.35°C/yr), and for Ca contents (11.4, 9.3, 7.1 and 6.1 mol %) that give best-fit cooling rates of 5x, 2x, 1/2x, and 1/5x the best rate for optimum Ca.

References: [1] Mason (1987) Antarctic Meteorite Newsletter 10, no. 2. [2] McKay et al. (1988) Lunar and Planetary Science XIX, 762. [3] Prinz et al. (1988) Lunar and Planetary Science XIX, 949. [4] Crozaz et al. (1988) Lunar and Planetary Science XIX, 231. [5] Mittlefehldt et al. (1989) Lunar and Planetary Science XX, 701. [6] Prinz et al. (1977) EPSL 35, 317. [7] McKay, Miyamoto, and Takeda (1989) Meteoritics, 24, 302. [8] Miyamoto et al. (1986) J. Geophys. Res. 91, 11804. [9] Goldstein and Short (1967) Geochim. et Cosmochim. Acta 31, 1001. [10] Davidson and Mukhopadhyay (1984) Contr. Min. Pet. 86, 256. [11] Morioka (1981) Geochim. et Cosmochim. Acta 45, 1573. [12] Jurewicz and Watson (1988), Contr. Min. Pet. 99, 186. [13] Buening and Buseck (1973) JGR 78, 6852. [14] Fujino, Naohara, and Momoi (1990) EOS 71, 943.