COMPARATIVE COOLING RATES OF NAKHLITES AS INFERRED FROM IRON-MAGNESIUM AND CALCIUM ZONING OF OLIVINES. T. Mikouchi and M. Miyamoto, Dept. of Earth and Planetary Science, Graduate School of Science, University of Tokyo, Hongo, Tokyo 113-0033, Japan. (mikouchi@eps.s.u-tokyo.ac.jp)

Introduction: The four nakhlite meteorites (Nakhla, Lafayette, Governador Valadares, and the recently discovered NWA817), are olivine-bearing Martian clinopyroxenites. They are cumulate rocks closely related to each other and have undergone various degrees of late-magmatic and subsolidus atomic diffusion [1]. In this abstract, we report cooling rate calculations of nakhlite olivines by analyzing Fe-Mg and Ca zoning profiles, and discuss their geological settings.

Olivine and Augite in Nakhlites: The disequilibrium core compositions in Fe-Mg between olivine and augite have been argued for the previously known nakhlites (Nakhla, Lafayette, and Governador Valadares) [1,2]. Augite in these nakhlites has an nearly identical core composition (~$En_{39}Wo_{39}$). In contrast, the olivine cores are all too Fe-rich (Nakhla: Fa_{58}, Governador Valadares: Fa_{60}, Lafayette: Fa_{67}). This inconsistency can be explained by faster atomic diffusion rates of Fe-Mg in olivine than pyroxene [1]. That is, olivine compositions were largely modified by atomic diffusion and olivine cores do not preserve their initial compositions. However, slower Fe-Mg diffusion rates in pyroxenes did not alter their initial core compositions. In the newly discovered nakhlite, NWA817, olivine (Fa_{54}) and augite ($En_{39}Wo_{39}$) cores are nearly in Fe-Mg equilibrium [3]. Therefore, it would be reasonable to consider that the original olivine compositions of all nakhlites were homogeneous (Fa_{54}) and the present zoning profiles were products of atomic diffusion by different degree. The observed Ca zoning profiles of olivines show decrease towards the rims except for Lafayette. Fractional crystallization produces increase of Ca as crystal grows. Therefore, we suggest that Ca decrease at the rims is also product of atomic diffusion. The initial CaO content was assumed to be 0.54 wt% that is the homogeneous core composition of the NWA817 olivine.

Cooling Rate Calculations: We computed the Fa and Ca zoning profiles at various cooling rates from 1100 °C to 700 °C after we assumed that initial olivine compositions are homogeneous (Fa_{54}, CaO: 0.54 wt%). We revised the Fe-Mg diffusion rate of [4] by dependence of fO_2 and Fe/Mg ratios of olivine [5]. In this calculation, we set fO_2 at the QFM buffer that is the estimated redox condition of nakhlites [6]. Ca diffusion data are from [7]. Olivine may have started cooling from higher temperature than 1100 °C. In that case, olivine should have experienced faster cooling rates than the result obtained for the 1100-700 °C temperature range.

Results: Fig. 1 shows the observed and calculated zoning profiles of olivines in four nakhlites. NWA817 has the most magnesian and Ca-rich composition in the core and zoned towards the Fe-rich, Ca-poor rims. These zoning profiles give the best fits for the cooling rates of 2.2 °C/hr for Fa and 0.5 °C/hr for Ca, respectively. Olivines in Nakhla and Governador Valadares preserve chemical zoning, but their core compositions are different from those in NWA817. For the Nakhla olivine, 0.04 °C/hr cooling increases the core composition from Fa_{54} to Fa_{57} and the calculated profile generally agrees with the observed one. The cooling rate of 0.0005~0.001 °C/hr is the best fit for the Ca zoning of Nakhla olivine. Similarly, 0.085 °C/hr and 0.01 °C/hr cooling give the best fits for the Fa and Ca zoning of Governador Valadares olivine, respectively. Because the Lafayette olivine is homogeneous in both Fa and Ca, we calculated cooling rates necessary to rehomogenize the initially Fa-poor and Ca-rich compositions. The obtained cooling rates for Fa and Ca are 0.015 °C/hr and 0.001 °C/hr, respectively.

Discussion and Conclusion: Nakhlites have nearly identical crystallization and cosmic-ray exposure ages [8]. Therefore, it is likely that they formed in the same igneous body and ejected by the same impact event. The obtained cooling rates correspond to the burial depths ranging from 0.5 to 30 m (Fig. 1). It is evident that NWA817 has the fastest cooling rate (burial depth: 0.5~2 m), suggesting crystallization near the surface. In contrast, the homogeneous Ca content of Lafayette olivine requires slower cooling than 0.001 °C/hr (burial depth: 30 m). It is most likely that Nakhla and Governador Valadares have the intermediate cooling rates. However, they show large differences in the obtained cooling rates between Fa and Ca (Fig. 1). Fa gives 50 times faster cooling rate than Ca for Nakhla. This may be due to uncertainty in Fa and Ca diffusion rates in olivine [5]. The other possibility is that these nakhlites originally had different olivine compositions. Irregular Ca zoning pattern, especially in Nakhla [1,2], may suggest more complex crystallization history. Nevertheless, our cooling estimates, employing originally uniform olivine compositions of NWA817, are comparable to [9] that proposed the minimum thickness of the lava flow of 20 m. Thus, this study further supports that nakhlites formed at different locations (burial depths) of the same cooling cumulate pile.

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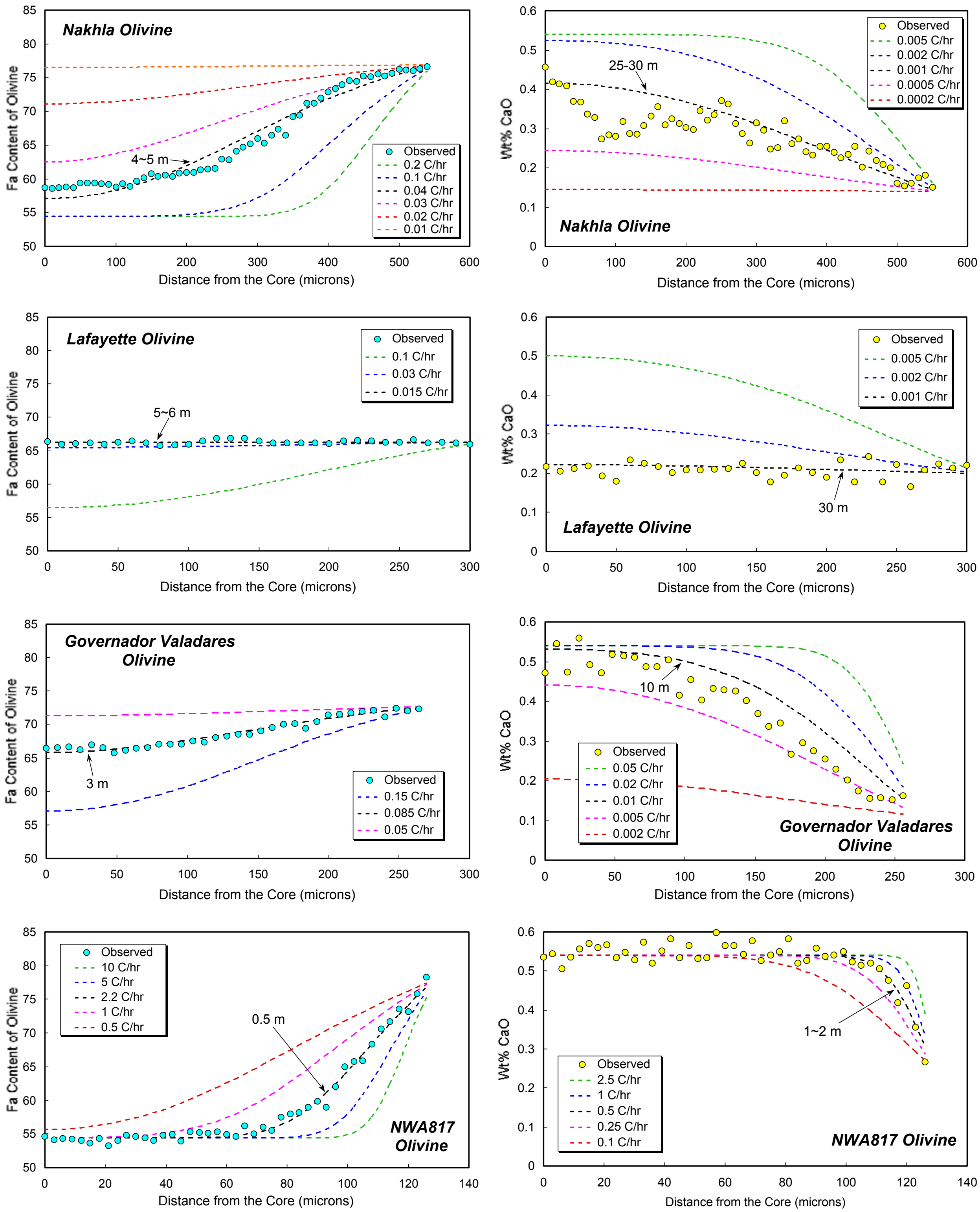

Fig. 1. Observed (colored circles) and calculated zoning profiles (dashed lines) of Fa and Ca contents in olivines from four nakhlite meteorites (Nakhla, Lafayette, Governador Valadares, and NWA817). The arrows indicate the profiles giving the best-fit cooling rates and their burial depths are also shown.