CONSTRAINTS ON COOLING HISTORIES OF ORDINARY CHONDRITES AS INFERRED FROM CHEMICAL ZONING OF PORPHYRITIC OLIVINE

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Porphyritic olivines in type 3 ordinary chondrites (ALHA 77278 (LL3) and ALHA 77299 (H3)) show various types of Mg-Fe and Ca zonings (1). Some porphyritic olivines show wide Mg-Fe and CaO variations, whereas some porphyritic olivines show homogenized texture of no zonings. Equilibrated textures in types 4, 5, and 6 ordinary chondrites are generally thought to be produced by thermal metamorphism. We studied the conditions of thermal metamorphism necessary to produce homogenized olivines by numerically solving the diffusion equation by using Mg-Fe and Ca zoning profiles of zoned porphyritic olivines in type 3 ordinary chondrites as initial values. Details of calculations are given in (1).

Initial cooling: We calculated cooling rates needed to homogenize chemical zoning for different sizes of olivines from initial temperatures 1600, 1500, and 1400°C to 1000°C (linear cooling), to study whether primary chemical zoning of olivines can be preserved during initial cooling after formation of chondrules (Fig. 1). In Fig. 1, olivines are not homogenized under the conditions in the upper right domain bordered by dashed line. Olivines are homogenized in the lower left domain bordered by solid line. The domain between the solid and dashed lines is transitional. Numbers show initial temperatures (°C). Bars on the figure show the range of cooling rates used in crystallization experiments that produced porphyritic olivines (2).

For porphyritic olivine of the typical size of 100 μm, Mg-Fe zoning is homogenized during initial cooling if cooling rates are slower than about 50°C/hr. Fig. 1 shows that olivines of larger than 10 μm in size keep Ca zoning if cooling rates are faster than 10°C/hr. Lofgren and Russell (1986)(3) suggested that porphyritic textures can form at cooling rates in excess of 100 °C/hr on the basis of systematic crystallization experiments. Almost all olivines can keep Mg-Fe zoning in the range of the cooling rates. In chondrules of type 3 ordinary chondrites, some olivines of a few tens of micrometers in size keep Mg-Fe zoning. The results of calculations and crystallization experiments are consistent with the observation that some porphyritic olivines keep Mg-Fe and Ca zonings. In order to form porphyritic olivines, cooling from just below the liquidus at moderately high rates is preferable to cooling from above the liquidus at low rates.

Thermal metamorphism: We examined the conditions of diffusional homogenization of zoned olivines during thermal metamorphism that would produce petrologic types of ordinary chondrites. We calculated cooling rates needed to homogenize different sizes of zoned olivines from maximum metamorphic temperatures 900, 700, and 400°C to 100°C (linear cooling)(Fig. 2). Bars on the figure show the range of cooling rates obtained by Fe-Ni data (4). In types 5-6, Mg-Fe zoning of olivine is homogenized and Ca zoning is almost homogenized. If metamorphic temperatures are higher than 700°C for types 5 and 6 (5), Mg-Fe zoning is homogenized at cooling rates slower than about 1°C/yr, and Ca zoning is homogenized at cooling rates slower than about $100°C/10^6$yr. Because cooling rates of $2\text{-}400°C/10^6$yr are proposed for types 5-6 on the basis of Fe-Ni data (4), our results are consistent with homogenized olivines in types 5-6. In order that Mg-Fe zoning of olivines in type 3 chondrites may survive thermal metamorphism, cooling rates faster than about $1°C/10^6$yr are needed for metamorphic temperature of 400°C (5). Although this result is broadly consistent with cooling rates of

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0.2-2°C/10^6yr obtained by Fe-Ni data for type 3, the range of cooling rates by Fe-Ni data seems to be too slow, because metamorphic temperature proposed ranges from 400 to 600°C (5).

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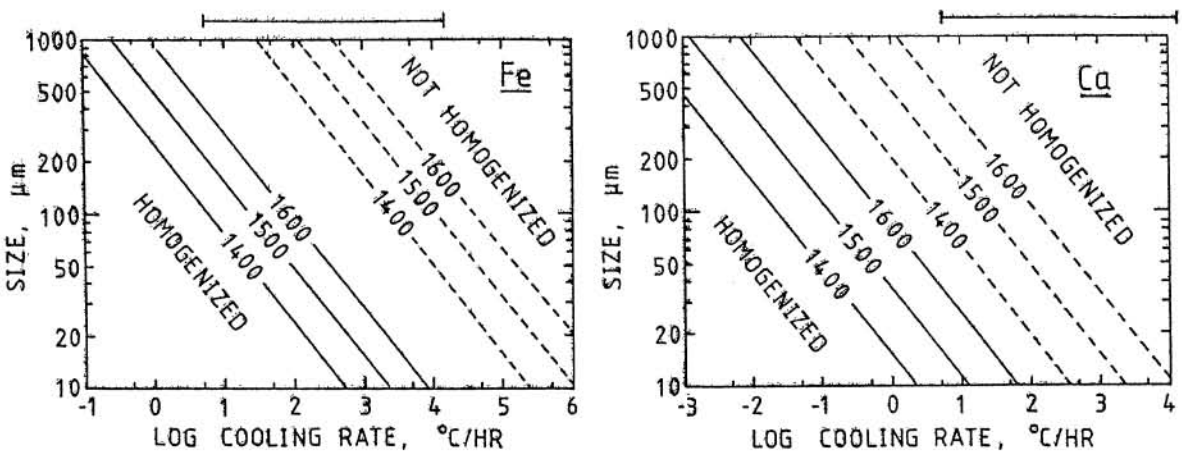

Fig. 1. Size of olivine vs. cooling rate (°C/hr) from initial temperatures 1600, 1500, and 1400°C for homogenization of Mg-Fe and Ca zonings. Bars show the range of cooling rates in crystallization experiments that produced porphyritic olivines.

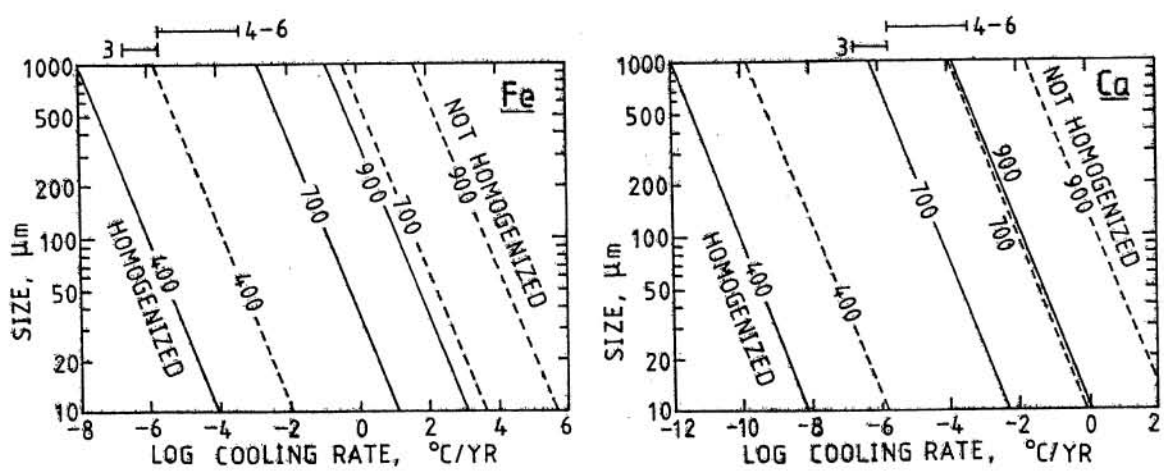

Fig. 2. Size of olivine vs. cooling rate (°C/yr) from initial temperatures 900, 700, and 400°C for homogenization of Mg-Fe and Ca zonings. Bars show the range of cooling rates obtained by Fe-Ni data for type 3 and types 4-6 ordinary chondrites.