

THERMAL HISTORY OF THE LODRANITE YAMATO 74357: CONSTRAINTS FROM COMPOSITIONAL ZONING AND FE-MG ORDERING.

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Introduction: Lodranites are a group of primitive achondrites that are closely related to acapulcoites, but are more coarse-grained (average mafic mineral size $\sim 500\text{-}600\mu\text{m}$) and depleted in plagioclase and troilite [1, 2]. These mineralogical differences are the results of different degrees of melting. Reconstruction of the thermal histories of primitive achondrites has been a subject of interest towards the understanding of planetary processes [e.g. 2, 3, 4, 5]. To this end, we have undertaken a detailed study of the cooling history of the lodranite Yamato74357 on the basis of the compositional properties of its minerals at two different scales: (a) compositional zoning within individual grains and (b) Fe²⁺-Mg ordering in orthopyroxenes.

Compositional zoning: Yamato74357 is a coarse-grained aggregate of olivine and orthopyroxene ($\sim 90\%$ in vol.) with an average grain size of $\sim 580\mu\text{m}$ [2], and minor amounts of troilite, metal, diopside, and chromite. Fe-Mg compositional zoning was measured in a spinel grain included in a large grain of olivine (Fig. 1).

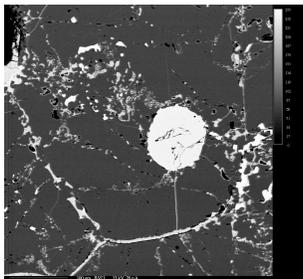


Figure 1: Backscattered image of the spinel grain ($\sim 100\mu\text{m}$ across) enclosed in the olivine.

The olivine grain is homogeneous and has the same composition as in the large mass of matrix grains. Thus, despite the fact that $D(\text{Fe-Mg})_{\text{olivine}} < D(\text{Fe,Mg})_{\text{spinel}}$ [6, 7], we assume that olivine behaved as a homogeneous infinite reservoir. Here we

envision that rapid diffusion was mediated through the grain boundaries of olivine, and only a very small near surface domain of a number of olivine grains had participated in Fe-Mg exchange with spinel. However, the composition of these domains remained effectively fixed due their relatively large volume compared to that of the small spinel grain. The initial temperature was assumed to be $\sim 1000^\circ\text{C}$ [8] and the cooling rate was assumed to be constant. The Fe-Mg interdiffusion coefficient, ($D_{\text{Fe-Mg}}$), in spinel used in this work is a modified version of the data of Liermann and Ganguly [7], accounting for the effect of Cr on $D_{\text{(Fe-Mg)}}$ [9]. The successful modeling of the compositional profiles in the ol-sp couple, corresponding to a cooling rate of $\sim 7^\circ/100\text{ yr}$ between 1000°C and 540°C , is illustrated in Fig. 2.

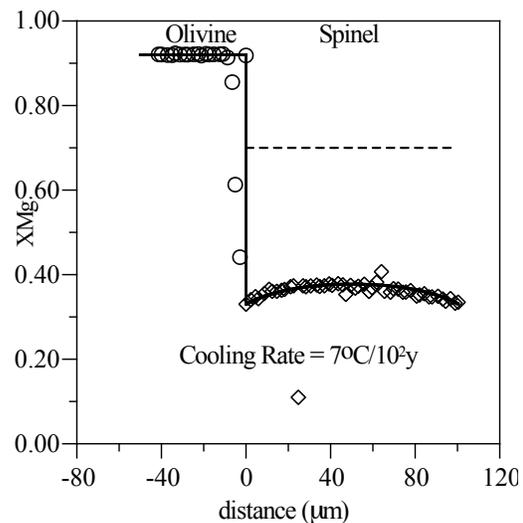


Figure 2: Observed (circles and diamonds) and modeled (solid lines) compositional profile in Ol-Sp couple. The dotted line represents the calculated initial composition of spinel at 1000°C .

Fe-Mg ordering in orthopyroxenes: Fe²⁺ and Mg fractionate between the two non-equivalent crystallographic sites, M1 and M2 of orthopyroxenes, with M2 being the preferred site for Fe²⁺. In this study, we have determined the ordering states of one opx crystal from the Yamato74357 sample by single crystal structure refinement. The X-ray data were collected on a Bruker SMART1000 diffractometer with CCD area detector. Ordering state was determined on the basis on ~12000 non-equivalent reflections using the structure refinement program Rfine95 [10], and imposing the bulk chemical constraints. The bulk composition was determined with a very high precision on the basis of ~80 spot analyses in an electron microprobe, and mathematically projected on the crystal-chemically constrained surface to determine the statistically most probable composition subject to the crystal-chemical constraints [11]. The site atomic fractions of Fe²⁺ and Mg were determined with a precision of 0.001.

Discussion: The cooling rate calculated from the compositional zoning of spinel is in excellent agreement with that calculated from Fe-Mg ordering state of orthopyroxene. Thus, we have a well constrained cooling rate of ~ 6-7 °C/100 yr between 1000 and 500 °C for the Lodranite Yamato74357. This inferred cooling rate is, however, an order of magnitude slower than that calculated by Myamoto and Takeda [8] on the basis of Fe-Mg zoning in orthopyroxene. This difference might be due to the choice of diffusion data. In fact, the data used by them were not directly measured for orthopyroxene, but inferred to be similar to the preliminary Fe-Mg diffusion in clinopyroxene of Fujino et al. [14]. As pointed in previous works [1, 2, 5, 8], the cooling history of lodranites might be quite complex. The rapid cooling rate of 60C/102yr below 1000oC could be due to fragmentation of the parent body [1] or cooling under a regolith/megaregolith blanket.

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