COOLING RATES AND METAL-OLIVINE IRON ISOTOPE FRACTIONATIONS IN PALLASITES

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Introduction: Pallasites are traditionally thought to be remnants of core-mantle boundary materials of differentiated planetesimals. Recent studies have challenged this view and suggested instead that pallasites may have an impact origin [1, 2]. In this latter scenario, metal was mixed with olivine crystals at high temperature and rapidly cooled until it was covered by a thick blanket of regolith. This allowed slow cooling (<100s of °C/Myr) to below 700 °C to allow kamacite nucleation. Studying the extent to which olivine and metal equilibrated could provide insights to the formation of pallasites. Several lines of observation suggest that olivine and metal may not be in equilibrium: 1) diffusion calcuations for elemental zoning patterns in olivine suggest cooling rates that are 6 orders of magnitude faster than the metallographic cooling rates [3], and 2) iron isotopes suggested apparent equilibration temperatures that are too low, down to 300 °C [4]. Here, we re-evaluate these observations following new diffusion calculations and re-measuring the iron isotopic compositions of metal and olivine in 11 main-group pallasites.

Samples: The Mg-Fe concentration profiles reported in [3] (Esquel and Imilac) were remodeled assuming a lower starting temperature, 700 °C. We also microdrilled the metal and silicate phases in 11 main-group pallasites (Imilac, Brenham, Thiel Mountains, Mount Vernon, Brahin, Springwater, Giroux, Krasnojarsk, Fukang, Esquel, Seymchan) in order to analyze the iron isotope compositions.

Methods and Results: Diffusion calculations were performed using explicit numerical methods incorporating a Mg-Fe diffusivity that varies as a function of temperature, using the formulation provided by [5]. The starting temperature is assumed to be 700 °C and cooling is assumed to be linear to 600 °C. Using a cooling rate of ~100 °C/Myr, we are able to reproduce the Mg-Fe profiles reported in [3]. This is in stark contrast to the cooling rate of ~100 °C/yr obtained in that study. This discrepancy can be explained by the much higher initial temperature used in Miyamoto's calculation (1100 °C). At lower temperatures, diffusion kinetics are much slower, thus requiring slower cooling rates to generate the same chemical profiles.

Pallasite thick sections were obtained from the Smithsonian Institution and the Royal Ontario Museum. X-ray maps were produced for each sample, and areas in the kamacite displaying homogenous Fe-Ni were microdrilled for isotopic analyses. These areas were targetted because large kinetic Fe-Ni isotope fractionations are known to occur during diffusion-limited growth of kamacite [6]. However, homogenous Fe-Ni regions of kamacite sample Fe isotope compositions that are very close to the bulk metal values [6]. As a result, we are confident that our metal fractions do not posses a significant contribution from kinetic isotope effects or impurity from other phases. Olivines adjacent to the analyzed metal spot were also microdrilled for iron isotopic analyses.

Disscusion: The elemental zoning profiles in [3] cannot be produced by a slow monotonic cooling from a high initial temperature. There are thus likely to be multiple stages of cooling in the pallasite parent bodies. In contrast to previous studies, we consistently find small isotope fractionations between metal and olivine (0.06 ± 0.10 ‰ in $\Delta^{56/54}Fe_{metal-olivine}$; error represents 2SD of the 11 analyses) that support equilibration temperatures several hundred degrees higher than 300 °C. Determination of final equilibration temperatures based on iron isotope exchange between metal and olivine await laboratory experimental studies that are currently ongoing.

References:
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