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A Synthesis of Instrumental Analytical Techniques for Examination of the Thermal History of Pallasite Meteorites

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Pallasites are a unique group of meteorites consisting of a mixture of approximately equal proportions of olivine grains in a matrix of Fe-Ni metal. These meteorites provide physical samples of the interior of a differentiated planetary body. As such, they provide direct geochemical clues to planetary differentiation processes. In this study, one large collaborative effort is undertaken to analyze a suite of 14 main-group pallasite specimens by several different instrumental analytical techniques in an attempt to provide a comprehensive picture of formation processes, temperatures and timescales. The suite of specimens chosen come from both the main group pallasites and the Eagle Station trio, and encompass a range of fayalite composition and of olivine shape and distribution.

Samples have been optically imaged and then mapped EDS using a JEOL JSM-6500F field-emission SEM equipped with an Oxford X-Max 80 mm^2 silicon drift detector to determine major element composition and distribution. The Oxford AZtec software allows large-format montaged mapping so that the entire specimen can be mapped to the same scale. Smaller region EDS mapping highlights minor mineral phases and the interfaces between the mineral grains and the metal phases. These maps quantitatively verify the mineral phases present and the Fe/Mg ratio of the olivine phase and the Fe/Ni ratio of the metal phase. Electron microprobe WDS analyses of mineral phases are being done on a JEOL 8900 to verify major and minor element composition in regions of interest. These analyses also highlight areas that are targeted for focused ion beam (FIB) analysis. The FIB is used to examine the interface between olivine and metal and create a 3-D reconstruction. Nano-scale phases are then highlighted for future TEM preparation.

Between the SEM and microprobe results, areas were highlighted for mass spectrometry analysis. Several samples were analyzed with laser ablation ICPMS for trace element content. Pallasites can provide information about highly-siderophile elements (HSE) present in both mantle and core of differentiated bodies. Many differentiated planetary bodies show enrichment in HSE concentration in their mantle relative to their core. Our study indicates that both HSE concentrations and the O-isotope fractionation share a common trend with iron III-AB meteorites. The HSE concentrations are also comparable to Mars and the Angrite parent body.

In addition, diffusion profiles are being obtained in the microprobe for both the metal and olivine phases, which indicate the cooling rates of these meteorites. The iron metal region contains regions of taenite interlaced with kamacite, in which Ni zonation and diffusion has traditionally been used to determine the metallographic cooling rate within the taenite [1]. More recently, zonation of the olivine rim has been used to determine cooling rates [2], however these indicate a much faster cooling rate than that estimated by the metallic rates. This study aims to examine diffusion in both phases to better

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understand the cooling rate. A field emission microprobe can access a finer resolution of the linear Ni/Fe concentration variation at the boundary of the taenite than can be seen with conventional microprobe. This sloped region has been confirmed by STEM measurements (Yang et al, 2010). A preliminary study (Armstrong et al, 2013) utilizing a field emission microprobe demonstrated the feasibility of this approach.

The temperature of formation for pallasites is an important constraint on understanding their origin. The olivine was mixed with molten metal (which has a lower melting point than olivine), but the exact temperature at which this happened is not known. If the equilibration temperature can be constrained, the formation history and parent bodies can possibly be elucidated. Iron isotope fractionation between the metal and the olivine is being explored in both high pressure and temperature experiments and extra-terrestrial samples using laser ablation MC-ICPMS. This will give a tracer of the last equilibration temperature and provide a thermometer for pallasite formation. This temperature can be compared to the cooling rates determined by diffusion.

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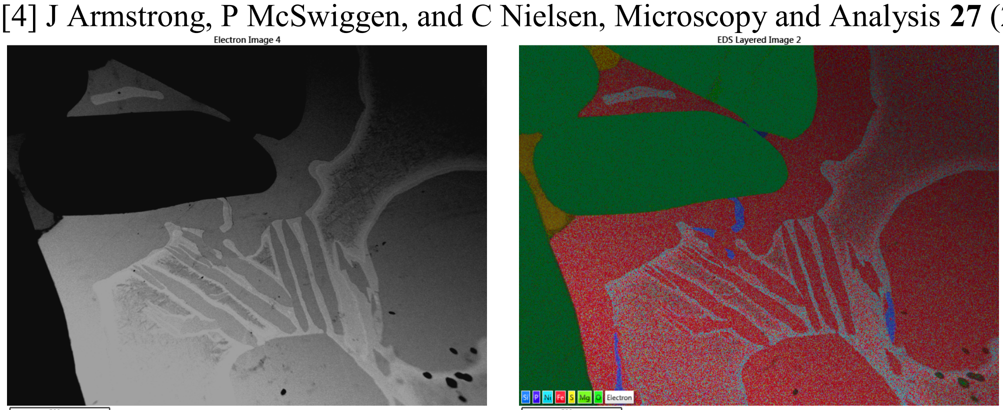

Figure 1: (a) Backscattered image of Giroux pallasite and (b) EDS map of the same region.

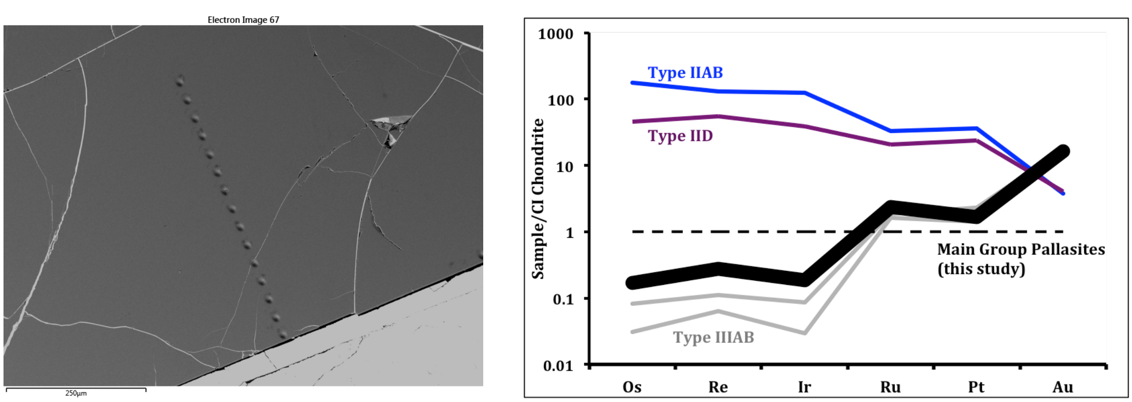

Figure 2: (a) Backscattered image of Brenham pallasite showing the LA-ICPMS pits and (b) graph showing the HSE and Au concentrations determined by LA-ICPMS in this study compared to three different classifications of iron meteorites.

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