THERMAL HISTORY AND ORIGIN OF THE MAIN GROUP PALLASITES. J. Yang[1], J. I. Goldstein[1] and E. R. D. Scott[2], [1]Dept. of Mechanical and Industrial Engineering, University of Massachusetts, Amherst, MA 01003, USA, jiyang@ecs.umass.edu, [2]Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, Honolulu, HI 96822, USA.

Introduction: The origin of the pallasites, mixtures of Fe-Ni metal and olivine, and their parent bodies is not well established. The main group of pallasites which are thought to come from one parent body may have formed 1) near the surface [1,2], 2) close to the center [3,4], 3) at the metal-olivine contact zones of isolated metal pods [5], or 4) at core-mantle boundaries [6, 7]. In the latter case, the IIIAB irons have been proposed as the metal associated with such a boundary. Our metallographic studies of the cloudy zone in the main group pallasites suggest a new origin, viz., from a range of depths within a metal-poor parent body, and that the main group pallasites and IIIAB irons are from separate parent bodies [8]. Here we report new data based on an investigation of the cloudy zone and tetrataenite rim microstructures and preliminary measurements of metallographic cooling rates which give insight into the origin of the main group pallasites.

Techniques: Metal regions of 20 main group pallasites were prepared by standard metallographic procedures for various analyses such as compositional analysis using the electron probe microanalyser (EPMA), crystal orientation measurements using electron backscatter diffraction techniques (EBSD), and microstructure analysis using the light optical microscope (LOM) and scanning electron microscope (SEM).

Results: *Metallic microstructure of pallasites*. A variety of microstructures are observed in the metallic regions of the taenite after etching with nital (2 vol % nitric acid in ethyl alcohol), including a characteristic Widmanstatten pattern in > 2cm wide metal regions and plessitic metal regions which are surrounded by kamacite bordering olivine. Tetrataenite and cloudy zone microstructures are observed at high magnification in the taenite regions bordering kamacite (Fig. 1).

Polycrystals. EBSD measurements of metal in pallasites show that the taenite is polycrystalline and each crystal may not solidify from the same metal pool or reservoir. Olivine-free regions of Brenham have meter-sized taenite crystals. On the other hand, the presence of cooler olivine probably promoted nucleation of taenite crystals.

Tetrataenite and cloudy zone measurements. We measured the width of the tetrataenite zone and the high-Ni particle size of the cloudy zone (Fig. 1) in 20 main group pallasites. The width of the tetrataenite zone was measured and corrected for orientation with respect to the growing kamacite. The orientation correction is obtained by measuring the crystal orientation of the taenite and kamacite phases using EBSD. After correction, the tetrataenite zone bandwidth in 20 main group pallasites varies from 1370 nm to 2550 nm, with a 1 standard deviation of 5-20% of the bandwidth measurement. The high-Ni particle size in the cloudy zone varies from 91 nm to 188 nm. The tetrataenite width and the size of the high-Ni particles in the cloudy zone are well correlated and increase with decreasing cooling rate. However, both cooling rate parameters are not correlated with the bulk metal concentration (e.g. Au, Ni, Ga, and Ir) of the pallasite.

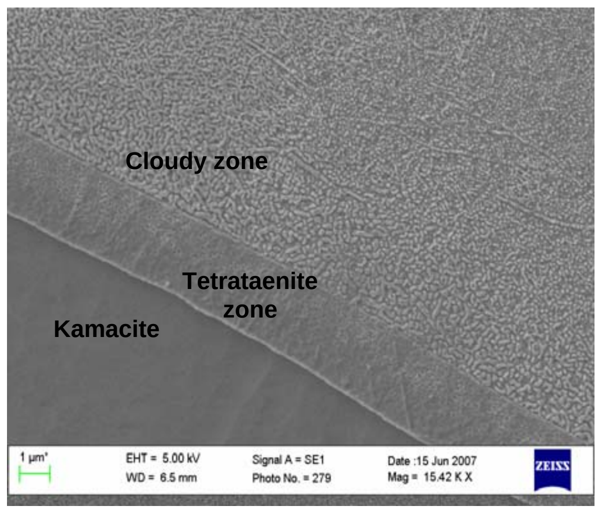

Fig. 1 SEM image of the kamacite-taenite border in the Argonia pallasite showing kamacite, tetrataenite and the cloudy zone.

Cooling rates of the main group pallasites. Preliminary results for the measurement of the metallographic cooling rates of 5 main group pallasites, using the Wood method yield cooling rates in the range 2-10 K/Myr at temperatures between 600 and 400 C. These cooling rates are significantly slower than the cooling rates determined for the IIIAB irons [9]. The size of the high-Ni particles can be used to derive cooling rates at low temperature. Using the relationship between high-Ni particle size and cooling rate [10], the cooling rates at low temperatures (~300 C) vary from 1.7 to 10 K/Myr, about a factor of ~5. No correlation is observed between the Ni content of the metal and the metallographic or cloudy zone cooling rates.

Discussion: Our studies of the dimensions of the high-Ni particles in cloudy taenite and the width of the adjacent tetrataenite zone clearly show 1) that the main group pallasites were not associated with the IIIAB irons as the latter have much faster cooling rates, and 2) that main group pallasites did not cool through ~300°C with identical cooling rates. The factor of ~5 variation implies that MG pallasites cooled in various environments that were thermally isolated. This means that they did not form at a core-mantle interface, which is consistent with the lack of associated iron meteorites. Although the ingredients of the MG pallasites presumably formed in a traditional body that differentiated into core and mantle, they did not cool in such a body. Some kind of impact produced a secondary body composed mainly of fractured olivine mantle with isolated metal-rich pallasitic zones spread over a range of depths.

Fractional crystallization: Even though main-group pallasites did not cool in the vicinity of IIIAB irons, the chemically evolved nature of the metal (generally sub-chondritic Ir/Ni) means that this metal is largely derived from the residual liquid from a core that had largely (~80%) fractionally crystallized prior to metal-olivine mixing. The chemical diversity of the metal in MG pallasites, the cooling rate variations, and the taenite polycrystallinity all point towards a secondary body in which isolated regions of molten metal experienced limited fractional crystallization. We attribute the limited extent of fractional crystallization to the ubiquitous presence of relatively cool olivine that triggered pervasive nucleation of crystalline metal and the growth of polycrystalline taenite. The dimensions of the metal-bearing pallasite regions appear to have been much less than the range of burial depths of these regions, possibly sub-kilometer or tens of meters in size. Such a body could produce MG pallasites with similar metal compositions but very different cooling rates, as observed.

The lowest cooling rate of 2 K/Myr that we derived for MG pallasites from the cloudy taenite dimensions provides a constraint on the size of the secondary body. If the body consisted of 2/3 silicate and 1/3 metal and lacked a regolith it would have been at least 400 km in radius, assuming the slowest cooled pallasites were at the center. But with regolith and a higher silicate/metal ratio, the minimum radius drops to 50 km or less.

Impact mixing. Given that the primary body had a core that had extensively crystallized within 50-100 Myr of accretion, we infer that it was smaller or possibly comparable in size to Vesta. Two kinds of impacts can be envisaged: catastrophic disruption by a smaller body, or hit-and-run collision with a larger protoplanet that converted the smaller body into a string of bodies with diverse metal-silicate ratios [11, 12]. In any case the impact appears to have ruptured the core of the primary body allowing a secondary body to form from great globs of molten metal and much larger volumes of fractured olivine mantle which was mostly much cooler. Asphaug (priv. comm.) notes that the products of the protoplanetary bodies would have spin rates close to their maximum limits and that this would have reduced the degree of gravitational separation of molten metal and silicate. Although the O isotopic data are consistent with a single parent body for the MG pallasites [13,14], multiple bodies cannot be excluded, especially as a protoplanetary impact can generate a string of bodies with identical O isotopic compositions.

.

References: [1] Mittlefehldt D. W. (1980) *Earth & Planet. Sci. Letts., 51*, 29-40. [2] Davis A. M. and Olsen E. J. (1991) *Nature, 353,* 637-640. [3] Wahl W. (1965) *GCA, 29*, 177-181. [4] Buseck P. R. and Goldstein J. I. (1968) *Science, 159*, 300-302. [5] Urey H. C. (1956) *The Astrophy. J., 124,* 623-637. [6] Scott E. R. D. (1977) *Mineral. Mag., 41*, 265-72. [7] Wasson J. T. and Choi B.-G. (2003) *Geochim. Cosmochim. Acta, 67*, 3079-3096. [8] Yang J. et al. (2007) *Meteoritics & Planet. Sci., 42,* A168. [9] Yang J. and Goldstein J. I. (2006) *Geochim. Cosmochim. Acta, 70*, 3197-3215. [10] Yang J. et al. (2007) *Nature, 446*, 888-891. [11] Asphaug E. et al. (2006). *Nature, 439*, 155-160. [12] Scott E. R. D. (2007) *LPS XXXVIII*, Abstract #2284. [13] Clayton R. N. and Mayeda T. K. (1996) *Geochim. Cosmochim. Acta, 60*, 1999-2017. [14] Greenwood R. C. et al. (2006). *Science, 313*, 1763-1765.