A NEW EVALUATION OF PALLASITE COOLING RATES. E. R. Harju[1] A. E. Rubin[2], and J. T. Wasson[1,2], [1]Department of Earth and Space Sciences, University of California, Los Angeles, CA 90095-1567, [2]Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA, 90095-1567.

Introduction: Metal compositions in the main-group pallasites (PMG) are closely related to those in IIIAB iron meteorites and especially the high-Au, low-Ir extreme of the IIIABs [1]. Oxygen isotope compositions in PMG (e.g., in chromite) cannot be resolved from those in IIIAB irons [2]. Thus, the common view is that the PMG formed at the core-mantle boundary in the IIIAB asteroid, perhaps by the impact mixing of crushed mantle olivine with residual liquid derived from nearly complete core crystallization. However, Yang et al. [3] recently argued that the PMG could not be from the same parent body as the IIIAB irons because their metallographic cooling rates (MCR) indicated that the PMG cooling rate was an order of magnitude lower.

Many factors affect the taenite compositional profiles that are modeled in cooling-rate calculations. This investigation was initiated to examine whether nearness to olivine affected taenite Ni profiles. We therefore investigated three PMG (Seymchan, Brenham, and Glorieta Mountain) with relatively large silicate-free metal areas. Each section was free of olivine for one or more centimeters in all directions.

We chose the narrowest lamellae orientations to reduce the need for large corrections due to the obliquity of the cut and focused our study on narrow taenite lamellae to minimize the effects of differences in conditions at high temperatures.

Several methods are used to determine cooling rates in iron meteorites. The commonly used approach is to plot the central Ni content of γ (taenite) lamellae against the halfwidth and to compare these with numerical models. At high temperatures γ was the only stable phase; cooling brought the system into the α+γ field and the Widmanstätten pattern started to form with kamacite bands nucleating in four planes oriented as the four faces of an octahedron.

Cooling-rate models include the assumption that α nucleates and grows within a single γ crystal, with the studied γ being a remnant of the original high-temperature crystal. Dimensions of the lamellae above and below the plane of the section are assumed to be semi-infinite. We questioned whether these models could be used on pallasites that contain olivine inclusions located as near as 1 mm from the studied γ lamellae.

Experimental: The Fe and Ni contents of three profiles across 10 taenite bands in each of the three meteorites were measured using the UCLA JEOL electron microprobe (EMP). Lamellae were chosen with halfwidths less than 20 µm. Both primary and secondary (in coarse plessite) lamellae were measured. These γ-lamellae were chosen to have α bands $\geq$50 µm in half thickness on both sides. We followed the common practice of plotting the central Ni content of a lamella against the taenite halfwidth.

We discovered that lamellar widths 3 µm and lower show more scatter than wider lamellae. In some of these bands the taenite lamellae are discontinuous (i.e., partially resorbed) thus diffusion may not be limited to directions perpendicular to the planar surface of the lamellae. Such three dimensional effects that result in high Ni contents are not taken into account in cooling rate models.

It is important to obtain an accurate halfwidth for the lamellae. We therefore applied corrections to the measured halfwidths to account for geometry. Three to four taenite orientations can be seen in the samples. The narrowest sets are all close to (within 20° of) perpendicularity and require quite small corrections. In Brenham three orientations form equilateral triangles and thus have the dihedral angle of 109.5° and need a 6% correction. Seymchan lamellae are oriented in three directions; the narrowest set of bands required a 1% reduction. The other two sets were divided by factors of 1.05 and 1.27. The measured lamellae in Glorieta Mountain required 5% reductions.

Schreibersite inclusions are present in all sections and show that, at low temperatures the metal was saturated in P (and thus P effects on diffusion coefficients were the same in all PMG). During cooling the Ni/(Ni+Fe) of schreibersite increased; this removed Ni and added Fe to the nearby metal and increased the rate of the resorption of taenite. Those taenite lamellae that contained small schreibersite inclusions were observed to be either discontinuous at the inclusion or to decrease in width near the inclusion.

A major consideration in obtaining cooling rates from central Ni concentrations is the effect of shock-induced defects on the compositions of the bands. Seymchan, Brenham, and Glorieta Mountain all display evidence of shock shearing followed by annealing. Discontinuous, jagged, and curved bands are present in each PMG studied. Because the discontinuous bands are not always associated with visible inclusions, we suspect that shearing enhanced this resorption/reprecipitation process. Brenham has areas of parallel bands near areas of bands that are not straight, but instead consist of segments with slightly different orientations, apparently a reflection of deformation. Many taenites wax and wane in width along the strike of the lamella. Taenite in Glorieta Mountain has "thorns" or "spurs" indicating that, during recrystallization, taenite grew in other octahedral directions.

Results: Plotting our observations of taenite central Ni contents against halfwidth (Fig. 1) yields trends with negative slopes similar to IIIAB irons plotted in our companion abstract [4], but central Ni contents in PMG are higher by approximately 80 mg/g Ni. We distinguished between lamellae adjacent to primary (first generation) kamacite and those in coarse plessite fields adjacent to kamacite formed at lower temperatures. Each meteorite has its own symbol and primary and secondary bands are distinguished by different colors. In Seymchan and Brenham there is no appreciable difference in the trends between the primary and secondary lamellae, an indication that narrow lamellae are not strongly affected by their early history. The Glorieta points average ~10 mg/g higher than those in the other PMG and three profiles across one secondary lamella with width ~3.3 mm (Fig. 1) plot ~30 mg/g higher than the trend through other Glorieta data.

The trends defined by the secondary lamellae in Seymchan and Brenham are the same or marginally lower than those of the primary points. If the anomalously high Glorieta points are neglected, the secondary and primary data are unresolvable.

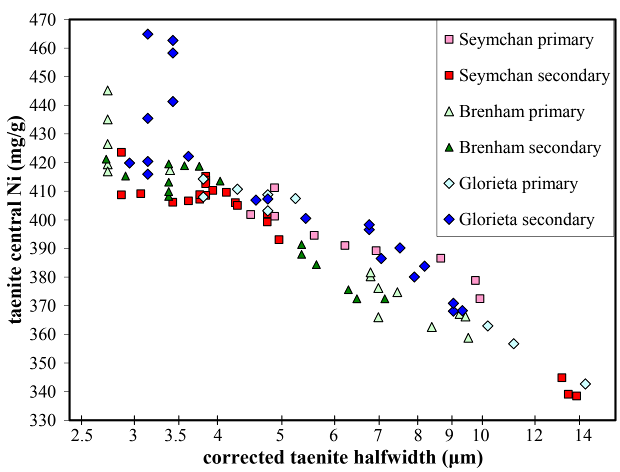

Figure 1. Central Ni content vs. corrected taenite halfwidth for each PMG.

Discussion: Our EMP studies of PMG taenite lamellae confirm those of [3]; at the same halfwidth, the central Ni contents of taenite lamellae are appreciably more Ni rich than those in IIIAB irons.

One possibility is that the PMG really cooled at a rate 20× lower than the IIIAB irons [3]. However, it seems possible that this is part of the poorly understood problem that metallic bodies give systematically low cooling rates in stony irons; published cooling rates for mesosiderites are extremely low, ≤0.2 K/Ma [5], 30-100× lower than reported in PMG [3]. PMG should have cooling rates similar to IIIAB irons, their close compositional relatives. Mesosiderites have basaltic silicates that only form near the surfaces of asteroids, and should have cooled much faster. We have therefore considered possible scenarios that could lead to erroneously low metallographic cooling rates in PMG.

We mentioned that each of the PMG shows evidence of impact damage followed by annealing. Impact creation of defects and cracks can lead to more rapid diffusion into the interiors of regions that were massive before the impact event. This process can lead to both artificially high (if no α nucleates) and low (if α nucleates) taenite central Ni contents.

Summary: Compositions of narrow taenite lamella in three PMG with olivine-free areas were studied using an EMP. Plotting central Ni content versus halfwidth for PMG taenite lamellae yields a similar slope, but much higher central Ni contents compared to IIIAB irons. This may be due to the PMG having cooled at a 20x lower rate, but other factors, such as shock effects, may also be influencing the metal compositions.

References: [1] Wasson J. T. and Choi B. G. (2003) *GCA, 66,* 3079-3096. [2] Clayton R. N. and Mayeda T. K. (1996) *GCA, 60,* 1999-2017. [3] Yang, J. et al. (2010) *GCA, 74,* 4471-4492. [4] Wasson J. T. and Hoppe P. (2011) *LPS XLII,* Abstract #2452. [5] Hopfe W. D. and Goldstein J. I (2001) *MPS, 36,* 135-154.