IMPACT ORIGINS FOR PALLASITES. Edward R. D. Scott, Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Manoa, Honolulu, Hawai'i 96822, USA (escott@hawaii.edu).

Introduction: Although pallasites are certainly mixtures of core and mantle material, links between specific groups of irons and pallasites are tenuous suggesting that they may come from different parent bodies. In this case, pallasites may have formed not at core-mantle boundaries as widely inferred, but from impact-generated mixtures of core and mantle materials. If irons and stony-irons are derived from differentiated protoplanetary projectiles that were eviscerated in hit-and-run collisions, as Asphaug et al. [1] suggest, pallasites may be coming from secondary bodies that contained relatively small amounts of molten metallic core material.

IIIAB irons and Main-group pallasites: The IIIAB irons and main group pallasites, which are the largest groups of irons and pallasites, are generally considered to be derived from the same parent body. The bulk composition of the metal in main group pallasites is a plausible match for the evolved melt after ~80% of the IIIAB core crystallized [2, 3] and their oxygen isotopic compositions are similar [4]. However, the connection is not robust because the O isotopic and metal compositions of MG pallasites are shared by many other meteorite types, and the metal is rather heterogeneous. Yang and Goldstein [5] question the connection between MG pallasites and IIIAB irons because the cooling rates of the IIIAB irons and the MG pallasites are significantly different. Although cooling rates for pallasites are rather uncertain, taenite edge compositions suggest that pallasites cooled through 700-500°C at ~2-4°C/Myr [6, 7], 10-100 × slower than IIIAB irons [5]. In addition, cloudy taenite microstructures in MG pallasites are 3 × larger than those of IIIAB irons (170±20 vs. 54±10 nm; ref. 7) suggesting that at 300°C, pallasites cooled ~15 × slower than IIIAB irons. (The plot relating cloudy taenite particle size to Widmanstatten-based cooling rate has been updated by Yang et al. [8].) The faster cooling rates of the IIIAB irons, which were supposedly buried more deeply than the mantling pallasites, together with the 60 My younger Re-Os age of the pallasites [9] suggest that the MG pallasites were not located at the core-mantle boundary of the IIIAB iron parent body during slow cooling. Thus, these meteorites may well come from separate parent bodies.

Are any irons coming from pallasite parent bodies? If the IIIAB irons and MG pallasites are derived from separate bodies, as suggested above, it is possible that few if any irons come from the seven sampled pallasite parent bodies (four for the pyroxene-bearing pallasites [10], Milton [11], and the Eagle Station and MG groups). Oxygen isotopic and metal compositions suggest that the pyroxene pallasites, Vermillion and Y 7451, and the Eagle Station pallasites are unrelated to any ungrouped irons. The ungrouped Milton pallasite may be linked to the South Byron trio of irons [11, 12], but additional data are needed to test this connection.

Formation of pallasites: Two mechanisms for pallasite formation have been proposed. Wood [13] inferred from the rounded olivine textures that pallasites formed from equilibrium processes that allowed intercumulus silicate liquid to be replaced by molten metal. Scott [14] inferred from the rounded olivine microstructures in pallasites with large angular olivines that fragments of mantle olivine were mixed with molten metal from cores by impacts and then annealed to diverse degrees. Scott and Taylor [15] invoked both mechanisms. If pallasites and irons come from quite different sets of bodies, as suggested above, pallasites may not have formed at core-mantle interfaces and should be considered more as core-mantle mixtures formed by impacts.

Greenwood et al. [16] reach similar conclusions and also invoke Asphaugian giant impacts [1] for making pallasites but they base their conclusion on the fast cooling rates at high temperatures of 10^{-2} to 10^{2} °C/yr inferred by Tomiyama and Huss [17] from zoning profiles of Ca, Cr, and Co in olivine. However, these cooling rates are model-dependent, as Tomiyama and Huss note, as they assume that olivine zoning profiles were established at 1100-800°C. The absence of sulfide nodules and the dimensions of the parent taenite crystals in olivine-poor Brenham samples (>50 cm) suggest that cooling rates during metal crystallization were low enough to ensure that secondary dendrite arm spacings exceeded ~50 cm. The relationship between dendrite arm spacing and cooling rate [18] suggests that in this case cooling rates during metal crystallization were $<10^{-3}$ °C/yr—consistent with the conclusion of Ito and Ganguly [19] that Omolon cooled at ~20-40°C/Myr at ~1000°C. Thus pallasite cooling rates do not require giant impacts.

Composition of MG pallasite metal: The wide range of Ir concentrations in the metal of MG pallasites (0.01-6 μg/g; ref. 3) shows that the MG metal was fractionally crystallized. In addition, the low mean Ir concentration requires that early-formed, Ir-rich metal was poorly sampled. Since ungrouped irons have not been associated with MG pallasites, it is possible that the Ir-rich pallasites, like the S-rich pallasites and the metal-free mantle material were generally weak and are poorly represented in meteorite collections. Two possible mechanisms may have ensured that pallasites with early crystallized metal were relatively weak. First, metal crystals may have preferentially nucleated in cooler regions with high olivine/metal ratios, assuming that mantle olivine was slightly cooler that the core metal when mixed. Second, continued post-impact mixing of metal and silicate may have generated more intimate mixtures of metal and silicate that produced well-armored pallasites. The spread of MG metal compositions from a single fractional crystallization compositional trajectory may have resulted from the creation of numerous isolated metallic reservoirs in a single body.

The MG pallasites may be atypical in having fractionally crystallized metal as the pyroxene pallasites, Vermillion and Y 8451, the Eagle Station pallasites [3], and the ungrouped pallasite, Milton [11] all have metal with relatively high concentrations of Ir (2-50 μg/g). This suggests that the metal in their parent bodies did not fractionally crystallize so efficiently as the metal in the MG pallasite parent body.

Nature of impacts that mixed mantle and core material: Mixing of small amounts of core metal with olivine mantle may have resulted from large impacts between asteroids. However, Asphaug et al. [1] infer that irons and stony-irons come from bodies that formed during glancing impacts between Moon-to-Mars-sized protoplanets. Such collisions may have converted differentiated projectiles into chains of differentiated bodies with diverse metal-silicate ratios. Pallasites may be derived solely from bodies formed in such collisions that were comprised of fractured olivine mantle material inundated with smaller volumes of molten core metal. Thus pallasite parent bodies may lack large volumes of olivine-free metal capable of supplying iron meteorites. Irons may come from bodies in which metal and silicate separated prior to crystallization. The IVA irons appear to be an exception, but they trapped pyroxene-silica inclusions, not olivine. Pallasites should be added to the list of meteorites that experienced early major impacts: ureilites, mesosiderites, the Shallowater aubrite [20], and the IVA irons [8]. In the case of MG pallasites, ^{53}Mn-^{53}Cr isotope systematics suggest that olivine-metal mixing occurred <10 Myr after chondrule formation [21].

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