PALLASITES: OLIVINE-METAL TEXTURES, METAL COMPOSITIONS, MINOR PHASES, ORIGINS, AND INSIGHTS INTO PROCESSES AT CORE-MANTLE BOUNDARIES OF ASTEROIDS. 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)

Main group pallasites: Formation models for main-group (MG) pallasites must account for their remarkably diverse compositions of Fe-Ni metal and olivine (Fa 11-19), morphology of olivines—predominantly rounded (like Brenham) or fragmental (Table 1, Fig. 1), and minor phases—phosphates, chromite and P-rich olivine.

Iridium. Iridium concentrations in metal in main group pallasites (as in most groups of iron meteorites) vary by a factor of 500 and are inversely correlated with Ni and Au showing that the metal was derived from a molten core that fractionally crystallized [1, 2].

Metal-olivine boundaries. Pallasites with fragmental cm-sized olivine crystals like Admire (Fig. 1a) commonly show regions where tiny olivine fragments 0.1-0.5 mm in size in metallic Fe,Ni have grown together to develop rounded textures like those of cm-sized olivines in pallasites like Brenham [3, 4]. Thus, rounded olivine textures formed by grain boundary migration reducing the high-energy surface area between olivine and metal, increasing the contact area between touching olivines, and rounding olivine crystals [3]. Rounded olivines did not form by partially resorbing angular crystals in silicate melt [5, 12]. Solferino et al. [6] found that olivine grain growth is orders of magnitude faster in molten Fe-S metal than in solid metal [3] and that Brenham-like textures (Fig. 1c) can be generated experimentally from mixtures of olivine powder and molten Fe-S. They calculated that Brenham-like textures could form in molten metal on timescales appropriate to asteroidal thermal models. Given the uniform metallographic cooling rates of MG pallasites [10], sub-mm olivines in fragmental olivine pallasites were probably rounded in solid Fe-Ni after rapid crystallization of metal, whereas Brenham-like pallasites equilibrated texturally in liquid metal. This explains the lack of intermediate degrees of rounding.

Precursor olivines. Some characteristics of Brenham-like pallasites are difficult to reconcile with formation from fragmental-olivine pallasites. The uniformity of the metal-olivine proportions and olivine grain size in Brenham-like pallasites are unique and quite unlike fragmental olivine pallasites. The latter typically contain highly variable proportions of metal and olivine and a wide range of olivine grain sizes with olivine aggregates up to many cm across. Aggregates this big are absent in Brenham-like pallasites. Many olivine aggregates in pallasites with angular olivines are not simply mantle fragments, as previously claimed [3], but actually contain a few vol.% of metal grains with rounded concave surfaces next to olivine (Fig. 1b). Thus, macro-rounding in Brenham-like pallasites *preceded* the formation of the olivine fragments observed in Seymchan, Esquel and other pallasites.

Tarduno et al. [7] assumed that rounded olivines form from fragmental olivines and envisaged that core metallic melt from an impacting body was injected into the upper mantle of a ~200-kilometer-radius protoplanet and mixed with olivine mantle fragments prior to slow cooling in a magnetic field. However, this model does not account for the features of Brenham-like pallasites listed above, the MG pallasites with high Ir contents, and the presence of olivine aggregates with rounded metal-olivine boundaries inside pallasites with fragmental olivine (Fig. 1b).

Formation of pallasites: Figure 2 shows a simple model that allows rounding before fragmentation. Olivine crystals accumulate at the core mantle-boundary and are submerged in molten metal by the weight of the growing olivine mantle above [8-10]. Olivine-metal boundaries migrate to form a connected network of Brenham-like olivine through which molten metal flows (zone 3 in Fig. 2c). Outside the pallasitic layer, olivine crystals are deformed and melts squeezed out to form dunite (zone 1) [8]. Between these two zones there is a transition zone with metal-poor, Brenham-like textures (zone 2).

Fragmental olivine pallasites formed when olivine in zones 1 and 2 was broken and molten metal was injected and rapidly solidified. Most pallasites have 0.1-0.01 ppm Ir (low and very low in Table 1) and probably formed after ~80% of the core had crystallized and the body was disrupted [1, 2, 10]. Pallasites with 1-5 ppm Ir formed at the core-mantle boundary during the earliest stages of core crystallization, generally as a result of impacts or tectonic forces that fragmented zones 1-3 and injected molten metal. Pavlodar (pallasite) has high Ir and rounded olivines so these must have formed before the core crystallized significantly.

Sharp boundaries between decimeter-sized olivine-free metal regions and regions with normal pallasitic textures in Brenham, Glorieta Mtn., and Seymchan suggest that molten metal began to solidify quickly on broken olivine surfaces. Rare pallasites with mixed rounded and planar-faced olivines like Molong [3] and Rawlinna 001 [11] probably formed by gentle disaggregation of zone 2 or 3 material, rather than by mixing of olivines from different regions.

Minor phases. Tiny grains of P-rich olivine and phosphates formed in some pallasites from trapped silicate melt that was enriched in P from molten metal via redox reactions [12-14]. Phosphoran olivine occurs in five MG pallasites [12, 13], which all have low Ir concentrations (≤0.1 ppm), probably because fractional crystallization causes P contents to increase with decreasing Ir, aiding P enrichment of silicate melt. Four of the five pallasites contain rounded olivines [12, 14]. Trapped silicate melt in these pallasites would have communicated readily with residual molten metal during core crystallization.

Further discussion: Olivines that accumulated at the core-mantle boundary (Fig. 2a) had a complex history judging from heterogeneous enrichments of Cr, Al, Ti [15], and may have formed by partial melting [5, 16]. Conceivably, the olivines were derived from a prior olivine mantle that fragmented cleanly along grain boundaries during tidal stresses in a hit-and-run impact [17]. In any case, the layered structure in Fig. 2c provides a good basis for understanding the full range of Ir contents, olivine shapes, and the distribution of minor phases in pallasites.

Four pallasites in the main group [18] have Fa 16-19 olivine (cf. Fa 11-13), very low Ir, and high Ni and Co in metal indicative of oxidation of Fe [2]. They also contain rounded olivines and farringtonite, $Mg_3(PO_4)_2$: 4 vol.% in Springwater [11] which encloses olivine. High Fa contents may have resulted from farringtonite formation by oxidation of P dissolved in molten metal via reaction 2 in [19]. Brenham lacks farringtonite [20] but has massive chromite ~10 cm across [21] that probably formed in a similar way by oxidation of Cr dissolved in molten metal.

Table 1. Main group pallasites subdivided according to Ir content of metal and olivine shape.

Ir (ppm)	Rounded olivines	Fragmental olivines
High 0.7-5	Pavlodar (pallasite) *(3)*	Finmarken *(1)* Marjalahti *(1)* Seymchan *(2)*
Low 0.1-0.3	Krasnojarsk *(3)* Thiel Mtns *(3)*	Mt. Vernon *(1)* Dora (pal.) *(1)*
Very low 0.01-0.1	Brenham *(3)* Springwater *(3)*	Admire *(1)* Esquel *(2)*

Number in italics shows inferred source zone of olivine aggregates (See Fig. 2.)

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Fig. 1. Pallasite textures. Top-to-bottom: a) Mantle dunite in fragmental olivine matrix in Admire. b) Olivine aggregate containing rounded olivines in fragmental olivine matrix (lower left) in Seymchan. L. Labenne. c) Rounded olivine texture in Brenham. Monnig Collection. Widths: a, 15 cm; b, 6.4 cm; c, 9 cm.

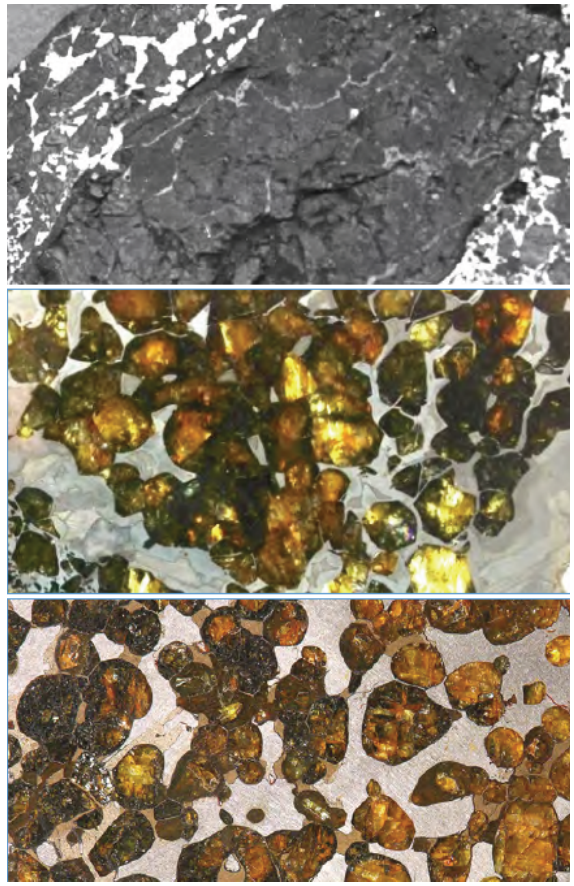

Fig. 2. Cartoon showing how dunite mantle (zone 1) and Brenham-like olivine (zone 3) may form at the core-mantle boundary. Zone 2 is a metal-poor Brenham-like region. Fig. 1a-1c show olivines from zones 1-3, respectively.