MELT SEGREGATION IN PLANETARY INTERIORS: EVIDENCE FROM THE BRENHAM PALLASITE

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Abstract: New constraints on the formation history of the Brenham pallasite are provided through textural examination and the analysis of wetting angles between coexisting olivine and Fe-Ni metal. The estimated wetting angle of 94° is used to calculate a value of interfacial energy for metal/olivine interfaces of 0.660+/-0.260 joules/m^2, and to predict that formation of a connected network of metallic melt would require over 20% melt fraction.

Introduction: In pallasites, the aggregate of closely packed olivine grains penetrated by a connected network of metallic melt may record a process of segregation of silicates and metal from an originally chondritic source. The purpose of this report is to assess the contribution of interfacial energy between olivine and Fe-Ni metal to the texture observed in the Brenham pallasite, sample 425b from Harvard University. The Brenham pallasite is a large meteorite, samples of which have been studied extensively by previous workers, who have found evidence for subsolidus chemical equilibration between the olivine and the Fe-Ni metal [1], which supports the idea that textural equilibrium has been reached.

Data: Metal/olivine wetting angles θ, defined by the two metal/olivine interfaces at cusps formed by adjacent olivine grains (fig 1a), were measured using a protractor on a video screen attached to a Nikon SMZ-2T reflected light microscope. Frequency distribution plots (solid) of the wetting angles are given in figure 2. Also shown on the graphs are theoretical plots (dashed) of distributions of apparent angles measured at arbitrary orientations relative to given true angles [2]. For each graph, the degree to which data approximates theoretical distributions was assessed in terms of a chi-squared value, and only the best fit is shown.

Wetting angle measurements comprise two populations, distinguished by the presence or absence of a fine filling of metal or troilite between the olivine grains which meet at the cusp. A population of 25 angles represents cusps at which the olivine/olivine grain boundary was free of any non-silicate filling. A plot of these angles (fig 2a) closely matches a theoretical distribution for a true angle of 94°. This value is comparable to an experimentally determined 92° wetting angle for Fe-sulfide melt with olivine [3].

A plot of the second population, for the 42 angles at which the olivine/olivine grain boundary was filled with non-silicates, is given in figure 2b. The theoretical distribution for a single true angle of 83° comes closest to matching it, but the fit is not good, suggesting local textural disequilibrium. Each olivine/olivine grain boundary has been replaced by two non-silcate/olivine interfaces, giving a total of four interfaces which meet at the cusp (fig 1b). These interfaces occur as two pairs of connected interfaces. Each pair is unconnected to the other and therefore is independent in terms of interfacial forces. In theory, interfacial forces at a simple intersection of two non-facetted interfaces are balanced only if they meet at 180°. Any smaller angle will be unstable, resulting in the tendency for it to become rounded as a means of approaching 180° (figure 1d). The second population of angles thus may have originated as wetting angles like those in the first poplulation, but after the intrusion of a non-silicate phase between the olivine grains, rounding may have begun to modify the shape of the cusps, and so may explain the fact that the approximate angle in the second population is 10° smaller than in the first (fig 1c). The preservation of relatively distinct angles, however, suggests that the grain-boundary-filling and rounding processes occurred at low temperatures with insufficient time to allow local interfacial equilibrium to be achieved. Because of this, the filled grain boundaries represent an exception to the overall chemical and textural equilibrium, likely to be due to a late-stage mechanical process after which complete re-equilibration did not occur.

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Conclusions: The estimated wetting angle $\theta = 94°$, for olivine/olivine cusps wetted by Fe-Ni metal, can be used to calculate the interfacial energy $\gamma_{metal/olivine}$ for olivine/metal interfaces, using the expression $\gamma_{olivine/olivine}=2\gamma_{metal/olivine}\cos\theta$ and the value of $\gamma_{olivine/olivine}=0.900+/-0.350$ joules/m^2 [4]. The result is $\gamma_{metal/olivine}=0.660+/-0.260$ joules/m^2. This value contrasts with 0.500+/-0.200 joules/m^2 for basalt/olivine interfaces [4]. The wetting angle of 94° in the pallasite would be predicted to inhibit the formation of a connected network of Fe-Ni melt at small melt fractions [5], but extrapolation of the plot provided in [5] suggests that at over 20% melt, a network could form to permit the flow of Fe-Ni melt, and thus enhance segregation processes. Fine non-silicate fillings between olivine grains probably represent a late-stage process, which occurred after the olivine and Fe-Ni metal had segregated from chondritic material, and reached equilibrium at subsolidus conditions.

References: [1] Buseck (1977) GCA 41:711-740; [2] Jurewicz and Jurewicz (1986) JGR 78:7581-7588; [3] Jurewicz SR and Jones JH (1993) LPSC XXIV:743-744; [4] Cooper and Kohlstedt (1982) in Akimoto S. and Manghnani M.H, eds, High-Pressure Research in Geophysics. Advances in Earth and Planetary Science 2. Center for Academic Publications, Tokyo, Japan; [5] vonBargen and Waff (1986) JGR 91:9261-9276.

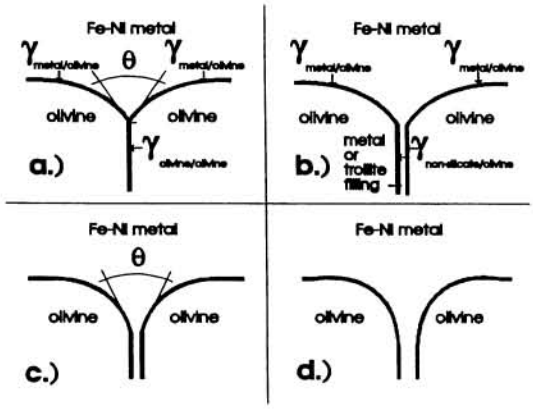

figure 1. Wetting angles and the effect of rounding

figure 2a

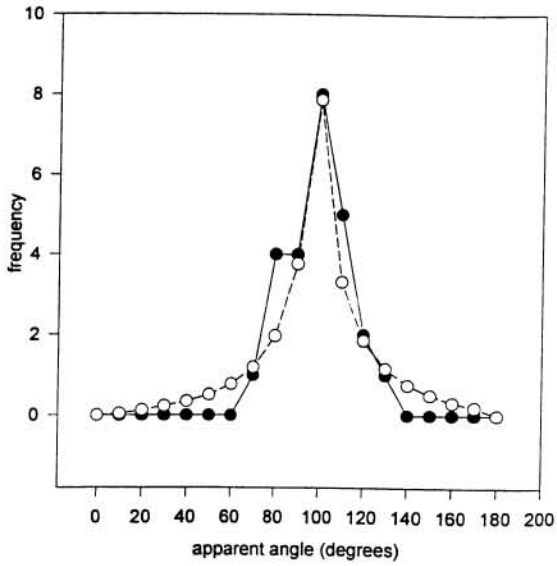

figure 2b