Comment on "On the lower limit of chondrule cooling rates: The significance of iron loss in

dynamic crystallization experiments" by S. Weinbruch, et al.

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Lofgren (1989) and the further analysis of Lofgren's 1989 experiments by Jones and Lofgren (1993) established that cooling rates as slow as 5°C/hr produced analog textures and major and minor element zoning profiles in minerals, implying that a lower limit on chondrule cooling rates may be approximately 5°C/hr. These results, however, are in conflict with those reported by Radomsky and Hewins (1990). In their paper, Radomsky and Hewins (1990) established a lower limit on chondrule cooling rates of 100°C/hr, a factor of 20 higher than that suggested by Jones and Lofgren (1993). The higher cooling rates suggested by Radomsky and Hewins (1990) have gained considerable favor within the meteoritic community largely because it appears more consistent with the preservation of Na in chondrules, which tends to volatilize at the slower cooling rates. In their study, however, Radomsky and Hewins (1990) did not use Pt hang wires that were coated or saturated with Fe. The lack of such techniques likely facilitated Fe loss from their experimental chondrules to the hang wire during formation (Jones and Lofgren, 1993). The effect of Fe loss could produce an inaccurate determination of cooling rates since these rates are largely determined by the Mg-Fe distributions in individual crystals.

In a quest to more accurately determine the lower limit on cooling rates and to determine in more detail the effects of Fe loss from a molten sample to Pt wire loops, Weinbruch et al. (1998) have explored this issue experimentally and reevaluated the findings of Radomsky and Hewins (1990) in light of their new results. We applaud Weinbruch et al. (1998) for undertaking this issue and for asserting that the lower limit for chondrule cooling rates is ambiguous. The basic conclusions of their paper are an important contribution to our understanding of how experimental techniques can affect established constraints on chondrule formation and are thus of interest to a wide audience. We do believe, however, that their methodology produces results that provide inappropriate impressions of the applicability of their study to chondrule formation

The experimental protocol used by Weinbruch et al. (1998) is significantly different from that employed in previous studies. These variances have the potential for increasing the amount of Fe loss to Pt compared to the standard experimental protocol used in other laboratories. In particular, we will address the following issues: (1) diameter of the Pt hanging wire, (2) sample size, and (3) heating and cooling profile.

Diameter of the Pt hanging wire. Weinbruch et al. (1998) state that "Two wires (0.35 mm in diameter) were twisted together and formed into a loop." We will give them the benefit of the doubt and assume that they twisted two wires together, then separated them at the ends and formed a loop, so that the hanging wire in contact with the sample consisted of a single loop of 0.35 mm Pt wire. If, however, Weinbruch et al. (1998) actually fashioned their loop out of twisted wire it would effectively double the volume of Pt adjacent to the sample, further enhancing Fe loss.

The diameter of their wire is significantly thicker than that used in previous work. Radomsky and Hewins (1990), Lofgren and Russell (1986), Lofgren (1989), and Jones and Lofgren (1993) used 0.20 mm diameter Pt wire. The cross-sectional area of 0.35 mm Pt wire is more than three times greater than that of a 0.20 mm Pt wire (0.0962 mm^2 vs. 0.0314 mm^2). The larger surface area in contact with the sample facilitates greater Fe loss from the sample at a more rapid rate than experiments utilizing smaller diameter Pt wire (Presnall and Brenner, 1974; Donaldson et al., 1975). We believe that Weinbruch et al. (1998) should have used a single strand of 0.20 mm diameter Pt wire if their goal was to compare the effect of Fe loss on the results of previous studies such as Radomsky and Hewins (1990).

Sample size. Weinbruch et al. (1998) used a sample size of 10 mg, compared to the 100 mg used in the experiments of Radomsky and Hewins (1990). The majority of chondrule

approximately one mm^3 of sample per mm^2 of Pt compared to 8.4 mm^3 sample per mm^2 of Pt for Radomsky and Hewins (1990) and others.

Heating and cooling profile. Both an increased amount of time and an increase in temperature will increase the diffusion rate of Fe in both the melt and the Pt wire (e.g., Johannes and Bode, 1978). Experimental runs by Lofgren, Hewins, and co-workers are generally performed by bringing the furnace to the maximum run temperature for the experiment before inserting the room temperature sample into the hot furnace. The sample is held at the maximum run temperature for a specified period of time before commencing cooling. Thus the factors that affect the Fe loss to the Pt wire include the amount of time it takes for the cold sample assembly to reach the maximum temperature, the length of time the sample is held at maximum temperature, and the absolute value of the maximum temperature. Fe loss to the Pt wire increases when any of these values is increased.

In addition, the lower the quench temperature and the slower the cooling rate, the longer the sample remains at a temperature where there is a potential for Fe loss to the Pt wire to occur. Therefore, decreasing the quench temperature and/or cooling rate will increase Fe loss. This effect is likely to be minor compared to other factors, and will diminish as temperature decreases and the amount of crystallization in the sample increases.

Instead of placing the sample in the furnace at the maximum run temperature, Weinbruch et al. (1998) placed the sample in the furnace at 800°C and heated at 20°C/min (1200°C/hr) to 1450°C followed by heating at 5°C/min (300°C/hr) to the run temperature of 1500°C. These experimental conditions were chosen to follow the heating path as closely as possible to the calorimeter experiments. The samples were held at 1500°C for 30 minutes and then cooled at 10 or 100°C/hr to 1000°C. Although not clearly stated, the implication from Radomsky and Hewins

Weinbruch et al. (1998) found different results depending on whether the Fe crucible, Pt wire, or presaturated Pt wire was used to hold the sample. Similar results were found by Lofgren et al. (1979) for a lunar basalt composition, with additional quantification of the effects of the sample holding technique on nucleation and phase chemistry. These authors confirmed by INAA analysis that no Fe was lost to presaturated Pt loops in experiments cooled at 4°C/hr. A small amount of Fe loss was found in the 2°C/hr experiment.

The loss of Fe to the wire, severe using the pure Pt, but still significant with the pre-saturated Fe-Pt alloy wire loop, has the potential to significantly change the liquidus of the melt in contact with the wire and therefore change the crystallization behavior of the melt. Fe loss increases the SiO_2 content of the remaining melt relative to $MgO + FeO$ and therefore stabilizes pyroxene relative to olivine. Furthermore, because the Fe content of the melts in each of the different kinds of experiments is changing, it cannot be assumed that the melt temperature is the same for each experiment because the liquidus of the starting material changes as the Fe content changes. The number of nuclei in a sample is the main factor controlling the texture. A change in the liquidus temperature can cause a significant change in the number of nucleation sites present for a specified run temperature.

Since the proportion of the iron in the samples of Weinbruch et al. (1998) is greater than in previous experiments it would follow that the change in mineralogy, after accounting for Fe loss, would also be greater. This is indeed the case, as the increase in the SiO_2 content of the melt is significant enough to stabilize tridymite. It is interesting to note that tridymite formed in experiments using the presaturated Pt loops, suggesting that the presaturation step (22 hr at 1462°C with an fO_2 of IW - 0.16) was not adequate for the final run conditions, which were at a higher temperature, lower fO_2, and, for the 10°C/hr experiments, were in the furnace above the

and Hewins (1990) who concluded that chondrules formed at cooling rates of 100°C/hr or faster. However, as Weinbruch et al. (1998) note, the experiments of Jones and Lofgren (1993) yielded a cooling rates as low as 2 to 5°C/hr for porphyritic olivine chondrules. It should be stressed that Jones and Lofgren (1993) did mitigate Fe loss to the Pt wire by plating the loops with Fe prior to the experiment.

Weinbruch et al. (1998) state: "If cooling rates are to be derived from comparison of synthetic analogues and natural chondrules, Fe loss during the experiment has to be avoided completely." The bulk compositions of natural chondrules, however, have an extremely wide range of FeO content, ranging from nearly Fe free in the enstatite chondrites to ~53 wt. % FeO rich chondrules from ordinary chondrites (Connolly et al., in press).

Given these factors, the conclusion of Weinbruch et al. (1988) that "chondrule cooling rates cannot be constrained precisely from such experiments" is not reflective of the complete body of experimental data on chondrule cooling rates currently available and should only include those experiments that did not account for Fe loss to Pt.

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