

CAN PORPHYRITIC CHONDRULES FORM IN PLANETARY EMBRYO BOW SHOCKS? A. M. Perez¹, S. J. Desch¹, D. L. Schrader¹, and C. B. Till¹, ¹School of Earth and Space Exploration, Arizona State University, P.O. Box 871404, Tempe, AZ 85287-1404, alexandra.m.perez@asu.edu

Introduction: Chondrules, mm-sized igneous inclusions that comprise up to 80% of the mass of chondritic meteorites, are a key to understanding the history of the Solar System and the formation of terrestrial planets. Chondrules formed in the first few Myr of the Solar System's history [e.g., 1], during its protoplanetary disk phase, and so understanding the energetic event(s) that melted chondrules is key to using meteoritic data to constrain astrophysical models of the disk. Once igneous textures were recognized in chondrules, formation models suggesting a melting event were sought to understand planetary formation [2]. However despite their long-standing importance, an overarching mechanism for chondrule formation mechanism has not been established.

Chondritic textures are the result of melting and crystallization and depend on several parameters. Figure 1 shows the textures reproduced experimentally at various cooling rates. The three most common chondrule textures are: (1) barred, (2) radiating, and (3) porphyritic. Porphyritic textures are the most common and make up approximately 82 to 99% of all chondrules in a given chondrite group [3], so chondrule formation models must be able to explain these textures in particular. Porphyritic textures are defined as phenocrysts ($> 40 \mu\text{m}$) of olivine and/or pyroxene in a fine grain mesostasis. Important parameters that control chondrule textures include chemical composition, peak temperature, duration of heating, and precursor grain size. Any formation model must therefore be able to predict these parameters.

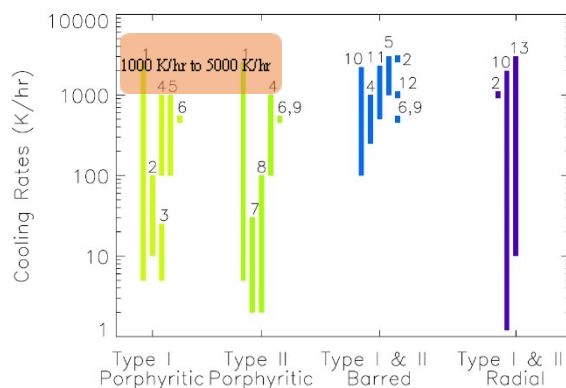


Figure 1. Cooling rates that have been experimentally shown to reproduce various chondrule textures [4]. The orange shaded region overlaying the figure shows the cooling rates of interest in this research.

Proposed models of chondrule formation include formation in planetesimal impacts, by nebular lighting, by large-scale (spiral density wave) shocks, and by bow shocks around planetary embryos. All of these models are broadly consistent with the experimental constraints that suggest chondrule precursors were heated above their liquidus in a time span of minutes and then cooled over hours while freely floating in the nebula [5]. The last model, and the model being tested here, is the planetary embryo bow shock model [6,7]. Embryos $>1000 \text{ km}$ in size are known to have existed in the nebula during chondrule formation [8], and if they were cast onto eccentric orbits, their shock fronts could melt chondrules. The atmospheres of these embryos may also have contained high partial pressures of Na vapor, which the chondrules were exposed to [9]. This model robustly predicts cooling rates of 3000 K/hr or more, and it is not clear whether or not these are consistent with the dominant porphyritic textures.

Passage through bow shocks around planetary embryos [6] offers the best match to multiple chondrule properties, but is not widely considered a viable model because it predicts chondrules cooled at rates between 3000-5000 K/hr [6,7], whereas the predominant chondrule textures, porphyritic, have only been reproduced (so far) by cooling rates up to 2500-3000 K/hr. If porphyritic textures are reproduced by cooling rates $> 3000 \text{ K/hr}$, the planetary embryo bow shock model would be consistent with all known chondrule properties, validating it as a chondrule formation mechanism. This would represent a profound paradigm shift: rather than chondrules being the building blocks of planets, chondrule formation would have to be considered a secondary consequence of planet formation. Therefore we have conducted experiments to test whether cooling rates $>3000 \text{ K/hr}$ can yield chondrules with porphyritic textures.

Approach: For our experiments, we have created chondrule analogs by melting mixtures of the minerals San Carlos Olivine, Dog Lake Diopside, and Amelia Albite (Table 1). For the experiments, a 60 mg pellet of the minerals created with a binding agent are placed in a Pt basket suspended from a thermocouple inside a 1-atmospheric vertical gas mixing furnace located at the Experimental Petrology and Igneous process Center (EPIC) at ASU. We are currently investigating the role of grain size in the chondrule precursor and preliminary work has been conducted using a mixture of a fine grain powder of diopside and albite, as well as

larger grain size fractions of olivine to represent of seed nuclei. Future experiments will use starting material that is more homogenous in terms of grain size

Table 1. EPMA analysis of precursor material. Precision is 1% for major elements.

Oxide	San Carlos Olivine (wt %)	Amelia Albite (wt %)	Dog Lake Diopside (wt %)	Analog (wt%)
SiO ₂	40.89	68.55	55.52	48.70
TiO ₂	n.a.	n.a.	0.04	0.01
Al ₂ O ₃	n.a.	20.09	0.03	3.02
FeO	9.07	n.a.	0.75	5.63
Cr ₂ O ₃	0.02	n.a.	n.a.	0.01
MnO	0.12	n.a.	0.07	0.09
MgO	50.26	n.a.	18.50	34.78
CaO	0.07	0.46	26.04	6.62
Na ₂ O	n.a.	11.69	0.06	1.77
K ₂ O	0.01	0.12	n.a.	0.02
TOTAL	100.44	100.91	101.01	100.65

Preliminary Results: Heating durations of 1, 5, 10, 15, and 20 minutes have been investigated, as well as peak temperatures ranging from 1400°C to 1550°C. Initial work has been conducted to serve as a benchmark to produce porphyritic textures consistent with the results of [2,10,11]. Once these results have been achieved, we will conduct experiments at cooling rates consistent with the planetary bow shock model.

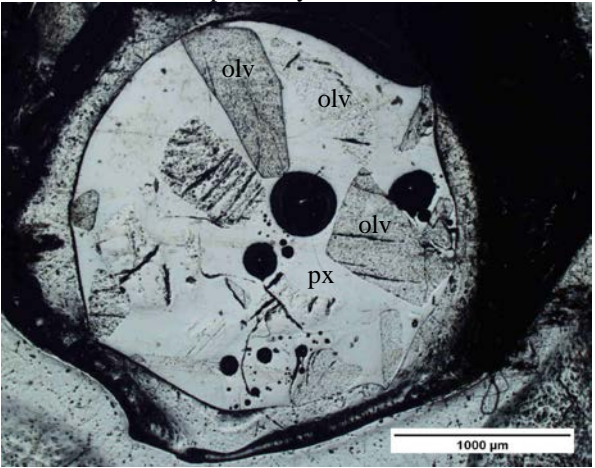


Figure 2. First experimental run. The peak temperature was 1400°C and the sample had a heating duration of one minute. The cooling rate was 1000 K/hr. This sample displays large anhedral fragmented olivine phenocrysts set in a fine grain pyroxene matrix. EDS analysis shows the starting olivine grains did not fully melt and recrystallize.

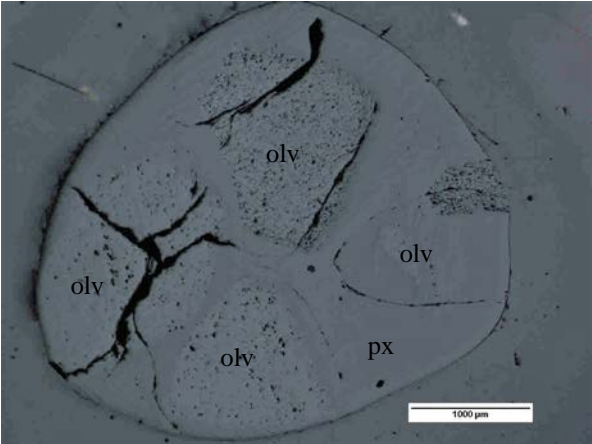


Figure 3. Experimental run using a peak temperature of 1550°C, heating duration 10 minutes, and cooling rate 1000 K/hr. Sample consists of large subhedral olivine phenocrysts set in a fine grain pyroxene matrix.

Ongoing Work: Several models for chondrule formation have been proposed, but not one model has been settled as an ideal chondrule formation mechanism. Our experiments test the viability of bow shocks around planetary embryos as a chondrule formation mechanism.

At the meeting we will present results from cooling chondrule analogs at cooling rates ≥ 3000 K/hr, varying peak temperatures, grain size, and heating duration. If we successfully reproduce porphyritic textures at the higher end cooling rates (≥ 3000 K/hr), the planetary embryo shock model would be found to be consistent with all the known chondrule properties to make a chondrule formation model successful. This would validate planetary bow shocks as a chondrule formation mechanism and increase our understanding of the energetic event(s) present during the initial stage of the Solar System.

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