THE VAGURIES OF PYROXENE NUCLEATION AND THE RESULTING CHONDRULE TEXTURES.
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Introduction: Pyroxene is a major phase in chondrules, but often follows olivine in the crystallization sequence and depending on the melting temperature and time may not nucleate readily upon cooling. Dynamic crystallization experiments based on total or near total melting were used to study PO (porphyritic olivine) and PP (Porphyritic pyroxene) compositions as defined by [1]. The experiments showed that pyroxene nucleated only at subliquidus temperatures in the PP melts [2] and rarely in the PO melts [3]. Porphyritic chondrules with phenocrysts of both olivine and pyroxene (POP chondrules) were not easily produced in the experiments. POP chondrules are common and it is important for deciphering their formation that we understand pyroxene nucleation properties of chondrule melts.

Nucleation of pyroxene in chondrule melts is directly related to its presence as heterogeneous nuclei in these melts as they begin to cool. In the PO melts, the pyroxene appearance (or disappearance) temperature is significantly below the liquidus and if the chondrule precursor is melted near the liquidus, all pyroxene nuclei will be eliminated. Pyroxene will then have great difficulty nucleating during the crystallization episode. In PP melts, pyroxene is usually the liquidus phase and if melting is subliquidus temperatures in the PP melts [2] and rarely in the PO melts [3]. Porphyritic chondrules with phenocrysts of both olivine and pyroxene (POP chondrules) were not easily produced in the experiments. POP chondrules are common and it is important for deciphering their formation that we understand pyroxene nucleation properties of chondrule melts.

Experiments: The same experimental techniques were used in this study as in the earlier studies [2, 3]. The main differences in the experiments were the amount of time the experimental charge was at the melting temperature and the range of melting temperatures employed. Melting times were 3 to 17 hours in the original experiments and that was reduced to 30 seconds to 5 minutes. The range melting temperatures in the original study was 1450-1525°C and that was broadened to 1250-1575°C. A cooling rate of 1000°C/hr was added to the range of cooling rates used in the earlier study.

Results: The shorter melting times used in the current set of experiments combined with lower melting temperatures provided conditions that allowed increased levels of pyroxene nucleation. In these experiments, pyroxene nucleated and grew in all PP experiments even at the highest melting temperature of 1550°C. The pyroxene in all experiments is euhedral to subhedral and elongate to equant (Fig. 1) except at the 1550°C melt temperature where the crystals are dendritic (Fig. 2). In the experiments melted at temperatures significantly below the liquidus, the pyroxene cores are Fe rich (En85 Fs14) relics of the starting material. They are overgrown with more Mg rich pyroxene (En92 Fs7) and are normally zoned to more Fe rich compositions. With increasing melt temperature, the pyroxenes are totally melted and the pyroxene is more magnesian with a normal zoning trend. Olivine is not a stable phase in the PP composition and while it is present in rapidly melted and cooled experiments, it does not remain in longer experiments.

The textures in the PO experiments are typical of PO chondrules, i.e., microporphyritic (Fig. 3). In spite of the shorter melt time and lower melt temperatures, pyroxene nucleation was rare. It nucleated profusely in only one of over 30 experiments. This experiment was melted at 1350°C for 5 minutes and cooled at 1000°C/hr. The pyroxene occurred as extensive overgrowths on olivine and as individual crystals.

Discussion: The results of these experiments show that pyroxene nucleation is strongly dependent on the presence of pyroxene nuclei. Pyroxene is more likely to be present the closer the pyroxene appearance temperature is to the liquidus of the chondrule. In the PP
composition, pyroxene nucleated under all experimental conditions. In the original experiments [2], which had much longer melt times, the pyroxene did not nucleate readily near the liquidus. If the pyroxene nuclei were eliminated, olivine, which generally nucleates more readily than pyroxene, would be the phenocryst phase. If the melting temperature was significantly higher, there would be no phenocryst phase and a radial pyroxene texture would form [2].

Figure 2. PP starting composition melted at 1550°C for 30 seconds and cooled at 1000°C/hr show well developed dendritic texture. Width of image is 1900µm.

One of the most significant results of the short melt times is that porphyritic textures formed at much higher cooling rates than in the earlier experiments. In the earlier experiments, porphyritic textures formed at cooling rates of 100°C/hr or less and with the shorter melt times, equivalent texture formed at cooling rates of 1000 to 2000°C/hr.

The presence of abundant pyroxene in porphyritic chondrules strongly suggests that most chondrules with porphyritic textures were not melted near or above their liquidus temperatures. PP chondrules with dendritic pyroxene on the other hand were melted above the liquidus by as much as a few 10s of degrees. The formation of a pyroxene dendrite requires that all nuclei be eliminated, that nucleation during cooling occur, and that a significant degree of supercooling is present.

Pyroxene does not nucleate readily in PO chondrules, and this depends on the normative olivine content. The larger the temperature gap between the olivine liquidus of the chondrule and the pyroxene appearance temperature, the greater the likelihood that pyroxene will not nucleate.

The formation of POP chondrules requires the preservation of pyroxene nuclei during melting to foster pyroxene nucleation and growth. This requires that the host chondrule melts be near cotectic with respect to olivine and pyroxene and that melting is enough below the liquidus so as not to totally melt the pyroxene. The limited potential for pyroxene nucleation as determined by the phase appearance temperatures of the phases in chondrule melts sets compositional limits on the textures that can form from chondrule melts.


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