THERMAL RECYCLING OF CHONDRULES: I. EXPERIMENTAL STUDY OF REMELTING ON TEXTURE; Lofgren, G.E., SN-4, NASA-JSC, Houston, TX 77058 and L. Le, Lockheed, Houston, TX 77058

INTRODUCTION: Recycling of chondrule material is clearly a significant part of the chondrule forming process. Recycled material includes whole chondrules, but more often fragments of chondrules comminuted down to individual crystals. These recurring relicts attest to the vigor of the forming process and its duration. Experimental study of the remelting kinetics of recycled material can provide further constraints on the nature and duration of the chondrule forming process. We have begun an experimental study of the thermal recycling history of chondrules, chondrule fragments, and minerals primarily by conducting experiments that duplicate aspects of their kinetically controlled heating and cooling (crystallization) histories. This study builds on a decade of experimentation directed towards developing a general model for chondrule crystallization [1]. The current study is an enlargement of the dynamic crystallization chondrule model to include recycling of chondrule material during chondrule formation.

PETROGRAPHY OF RECYCLED MATERIAL: Relict crystals in chondrules were first documented over a decade ago [2] and recent investigators have found increasing evidence for the importance of recycled chondrule material in chondrules [3-6]. The recycled material suggests a multiplicity of chondrule forming events of significant duration. The dominant and most readily identifiable recycled material appears to be individual crystals of mostly olivine and some pyroxene that are so distinctive that they could not have formed in the chondrule in which they now reside. Jones [7] describes relict dusty olivine and pyroxene grains present in low-FeO (type I) chondrules and Fo-rich olivine in FeO-rich chondrules. Jones and Danielson [8] document that dusty, relict olivine grains occur in 10% of chondrules in ordinary chondrites. The presence of these relicts indicates that the nebula was dense enough for the necessary mixing of materials and collisions necessary to allow the individual grains to be first separated from their source chondrule and then to be incorporated in newly formed chondrules. Alexander [9] suggests that interstitial glass in chondrules is an important recycled component that contributes to the chemical variation in chondrules and Alexander et al. [10] have observed fragments of chondrules in the rims of other chondrules. Wasson et al. [6] describe chondrule in chondrule textures and suggest that whole chondrules or fragments were part of the aggregate of materials that were subsequently melted to form new chondrules. These studies suggest that chondrule formation is a recurring event of sufficient length and vigor that early formed chondrules are broken and individual fragments, crystals, and in some cases whole chondrules become part of the material that later melted to form new chondrules.

Chondrules, either whole or as fragments, and mineral fragments can be incorporated into other chondrules by 2 basic processes: (1) relict material can be incorporated into a molten droplet usually by collision or (2) relict material can be a part of the aggregate that is partly melted to form a chondrule. In most cases, the material would have to remain relatively unaltered while the newly formed melt crystallizes around it. The first process would require that the relict be incorporated in a melt droplet by impacting the droplet, becoming enclosed by the droplet, and in most cases not affecting the crystallization texture of the melt into which it has been incorporated. Connolly et al. [11] have completed experiments that show such a process is possible for compound chondrule textures. In the second process, there must be a large grain size or compositional difference between the relict and the rest of the material in the aggregate. Fine grained material melts faster than larger precursor material and, if the melting event is short enough, the relict material could be preserved in the newly formed melt and be part of the final product as the newly formed melt crystallizes. Wasson et al. [6] suggest that the aggregate is extremely porous, perhaps similar to aggregates in Allende [12]. Wasson et al. [6] further suggest that the porous aggregates will collect heat more readily increasing the rapidity of melting. For whole or parts of chondrules to be preserved within newly formed chondrules or individual grains to be preserved, some amount of chondrule melt has to form...
and crystallize without affecting the recycled material significantly. Greenwood and Hess [13] have already shown that the kinetics of melting are rapid and that melting must be brief to preserve unmelted crystals. It is clear that to fully understand the significance of the inclusion of early-formed chondrule material in later-formed chondrules, it is essential to study, by experiment, the melting kinetics of chondrule material. Greenwood and Hess [13] have examined the melting kinetics of individual crystals, but it remains to study the effect of reheating on whole chondrules or fragments, especially to subliquidus or near liquidus temperatures, and to study melting of aggregates with fine grained materials enclosing much larger whole chondrules or chondrule fragments.

EXPERIMENTAL STUDIES: The simplest recycling case is reheating of a preexisting chondrule. For surely if complex recycling occurs, then simple reheating of whole or fragmental chondrules and their subsequent cooling must occur. Can we recognize these straightforward remelting textures? The simplest experiment is the reheating and cooling of chondrules produced earlier by experiment to determine the rate at which melting affects the existing texture and the nature of subsequent crystallization texture. It should be possible to establish criteria to identify such recycled chondrules. It will be easiest to determine the recrystallization potential for significantly non-equilibrium textures, e.g. barred or radial. The remelting effects on porphyritic chondrules will most likely be less dramatic because there will be less driving force for the phenocrysts to change shape and the changes will be less dramatic, with a simple increase in the interstitial melt and rounding of the existing phenocrysts. A more complex experiment would attempt to determine whether barred or radial chondrule fragments within an aggregate of fine grained material can be heated to form a partly molten droplet without significantly affecting the texture of the included fragment. When such chondrules are cooled a second time, what will the final textures be and how will the newly formed melt crystallize—especially with respect to the included chondrule material?

First we examine the effects of simple reheating. We have crystallized chondrules with dendritic (barred) and radial textures from previously studied olivine- and pyroxene-rich chondrule compositions [14]. These experimentally produced chondrules are then heated for varying times and at different temperatures both above and below the liquidus to determine the rate of melting. At first the experiments are rapidly quenched in order to study the melting kinetics alone. Initial results on the rapidity of melting agree with [13]. Subsequent experiments will be cooled at rates in the range 10-250°C/hr to examine the nature of overgrowths on not only preexisting nuclei, but on preexisting relict chondrule material. During this cooling, the initially nonporphyritic materials will most likely develop quite different textures and mineral compositions depending on the cooling rates imposed. The appearance of the porphyritic textures, however, will probably not be significantly affected. The evidence in this case should be most readily observed in the composition of the phenocrysts, especially the outer 10's of microns of the crystals that grew upon recrcoiling.