MELTING HISTORIES OF CHONDRULE PRECURSOR AGGREGATES IN UOC'S.

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Introduction: Chondrules are presumed to have formed in the solar nebula and understanding their formation is key to determining the processes at work in the nebula. A model for the crystallization of chondrules proposed by Lofgren [1] predicts a complete range of melting of crystalline aggregate materials from barely perceptible to total. If true, then one would expect to find aggregates in the early stages of melting as well as those recognized as chondrules. We found such particles in thin sections of several unequilibrated ordinary chondrites (UOC's). They characteristically display irregular shapes, a wide range of grain size and/or compositional variation, and varied thermal histories. They are usually composed of fine grained debris and/or crystal fragments. Large isolated crystals or relic crystals are not uncommon, some particles even contain whole chondrules or fragments. Many of these aggregates are enclosed in a nebular derived rim.

We will report on a series of aggregates that show progressive degrees of partial melting. There are several clues one can use to determine the amount of heating/melting a particular particle has experienced. An unmelted aggregate will have angular metal and silicate crystals, and no visible mesostasis glass. The initial sign of melting is rounded Fe-metal, the product of melting eutectic mixtures of troilite and kamacite at approximately 990°C. With increased degree of melting, the metal begins to move outward, however, if there is rapid quench, it may not move far. If the metal does migrate, it often remains attached to the particle, forming an iron and/or sulfide-rich rim. Evidence of silicate melting is highly dependent on the subsequent cooling rate. Slower cooling rates will result in crystallization of the mesostasis and crystals with euhedral overgrowths. Faster rates will produce rounded grains and a glassy mesostasis. Also, the more melting a particle has experienced, the more round its overall shape will become.

Techniques: We examined polished thin sections of five UOC's; Semarkona (USNM 1805-8) (LL3.0), Bishunpur (USNM 2359-2) (LL3.1), Krymka (USNM 1729-8)(LL3.0), Chainpur (USNM 1251-9) (LL3.4), and LEW86134 (L3.0). Nearly 100 particles were identified and studied under both optical microscope and electron microprobe. They resemble closely those aggregate particles found in Antarctic UOC's [2,3]. Backscatter electron images, chemical x-ray maps and mineral analyses were completed using the Cameca SX-100 electron microprobe at JSC.

Petrography: The aggregate particles are described below in accordance with the degree of melting observed.

Less than 10% melting:

Krymka P-10 is an irregularly shaped, fine-grained, clastic aggregate, 800x300µm. The grain size variation is 1-100µm, with the majority of grains in the 10-30µm range It is predominately composed of angular and broken grains of olivine, Fo_{72-85}. There is no evidence of silicate melting and metal is largely angular. The particle is enclosed in a sulfide-rich, nebular rim.

LEW86134,8 P-7 is a clastic olivine, Fo_{78-92} aggregate, 1000x800µm, with a large (400µm) skeletal olivine (Fig. 1). Aside from the skeletal olivine, grain size ranges from 1-250µm. On average, the larger grains, particularly the skeletal olivine, are more Mg-rich than the finer grains. There is a very small amount of mesostasis and it contains a few acicular crystals that grew upon cooling. The particle has a metal/sulfide rich nebular rim.

Some Melting (10-25%):

Chainpur P-39 is an elongate particle 800x400µm. Olivine, Fo_{78-97}, is the dominant mineral. The mesostasis (near 10%) is irregularly distributed and has crystallized to a finely dendritic texture. Some of the olivine has been affected locally by metamorphism or reaction with the melt during the latest melting event, especially around the edges of the particle.

Chainpur P-13 is a rounded, 500µm aggregate composed mainly of olivine, Fo_{72-82}. The grain size is highly variable ranging from a few µm to nearly 200µm. The crystals shapes vary from subangular to euhedral with some of the smaller crystals tending to be euhedral. The amount of mesostasis is between 10-15% and is incipiently crystallized. There is no rim.

LEW86134,8 P-4 is a generally ovoid particle with an irregular outline 1.5 mm in diameter. The grain size variation is large, a few µm to nearly 500µm for the largest grains. The mesostasis is about 15-20% and has crystallized to a fine dendritic texture. There appears to be some growth on some of the crystals. Many crystals show the effects of Fe enrichment at the edges either by metamorphism or reaction with the melt during heating. There is no rim.

Chainpur P-16 is over 600mm in diameter and is composed of olivine, Fo_{75-86}, and pyroxene, En_{84} Fs_{15} (Fig. 2). There is significant variation in the Fe/Mg content of the mineral phases. The crystals are subangular to euhedral with evidence of overgrowths. A few of the crystals show igneous zoning. The melting was probably 20-25% with some crystallization occurring upon cooling. The partition coefficients are not in equilibrium. Grain size is a few µm to nearly 200 µm. There is no rim.

Significant Melting (25-40%)

Krymka P-11 is a round particle, 500mm in diameter. Olivine, Fo_{75-86}, is the dominant mineral. There is one very large, subrounded olivine 300mm in largest dimension. The grain size ranges down to a few µm. The smaller grains are more Fe rich and more of them are euhedral. Many of them may have grown during cooling and the Fe/Mg Kd's approach equilibrium even though the partition coefficients for the minor elements (Ca, Mn, Cr) do not. Melting in this particle is difficult to determine, but could have approached 35%. There is a partial rim.

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Chainpur P-28 is an ovoid particle 800x600µm. It has a complex olivine, Fo_{83-90}, texture with many large angular to subangular relic crystals set in a dendritic mesostasis with some larger radial dendrites and dendritic projections from some of the crystals. The smaller dendritic crystals approach equilibrium while the large relic crystals do not. Mn partitioning does not approach equilibrium in any of the crystals. There is a partial rim.

Greater Than 40% Melting:

Semarkona P-5 is an elongate particle, 1.5x.75µm (Fig. 3). The largest relic pyroxene crystal is 500mm. The mesostasis is coarsely dendritic and probably exceeded 40 % prior to cooling. There appears to be some overgrowths on the crystals with a thin rim of Fe rich zoning on some cry stals. There is a partial rim.

Discussion: The juxtaposition of partially melted and unmelted particles, many with unaltered nebular type rims, strongly ties this melting to nebular events and most probably the chondrule forming events. It is an arbitrary line where this type of particle ceases to be a partially melted aggregate and becomes a chondrule. With a little more melting many of these particles will begin to erase the evidence of their aggregate history and they would be considered melt droplet chondrules. Even a small amount of melting, under the proper conditions, can significantly affect a particle, making its history difficult to discern. In another part of this study in this volume [4] we define a similar series of partially melted particles with Type 1 chondrule composition. The particles show even higher degree of partial melting and merge obviously with particles that are unequivocally chondrules. It is now clear that chondrites contain not only the well defined chondrules that have long been recognized, but also the not so obvious particles that represent the low temperature part of the chondrule forming process. The presence of such particles clearly shows that the melting events must be large enough to provide for a broad range of temperatures. One obvious feature of forming chondrules at the minimum possible temperature is that the preservation of volatiles will be maximized.

Conclusion: We have demonstrated that there is a continuum from unmelted to near 50% melting in these aggregate particles. With greater degrees of melting it would become difficult to recognize the aggregate nature of the particles. These particles make up a significant fraction of chondrites and with further study will allow us to learn more about the fragmentation of chondrules, the kinds of particles present, and aggregation processes in the ne bula.

References: [1] Lofgren G.E. (1996) *Chondrules and the Protoplanetary Disk*, R.H. Hewins, R.H. Jones, E.R.D. Scott, eds. Pp. 187-196. [2] Russell P. and Lofgren G.E. (1997), *LPSC XXVIII*, 1207-1208. [3] Lofgren G.E. (1997), *LPSC XXVIII*., 827-828. [4] Lofgren G.E. and L. Lee, this volume

Acknowledgments: We thank the Smithsonian Institution for use of thin sections. Work performed on NASA RTOP 344-31-20-20.

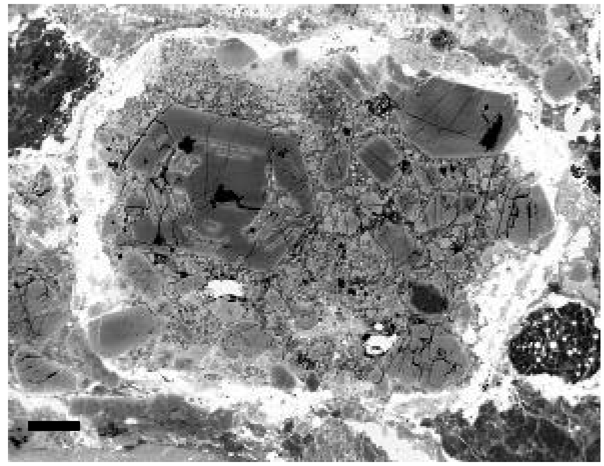

Fig. 1. BSE image of LEW86135, P-7. Melting is less than 10 %. Scale bar is 100 µm

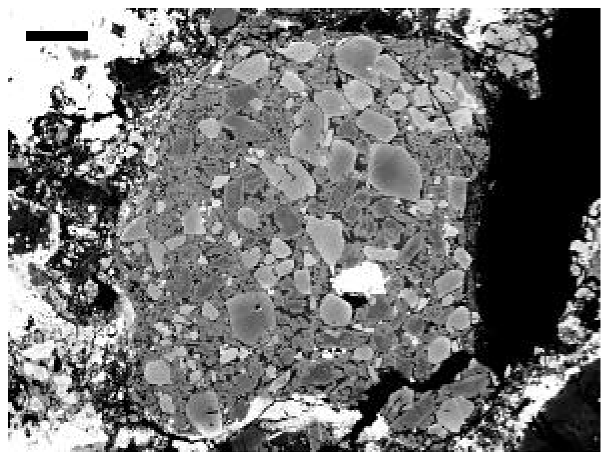

Fig. 2. BSE image of Chainpur, P-16. Melting is between 10 and 25 %. Scale bar is 200 µm

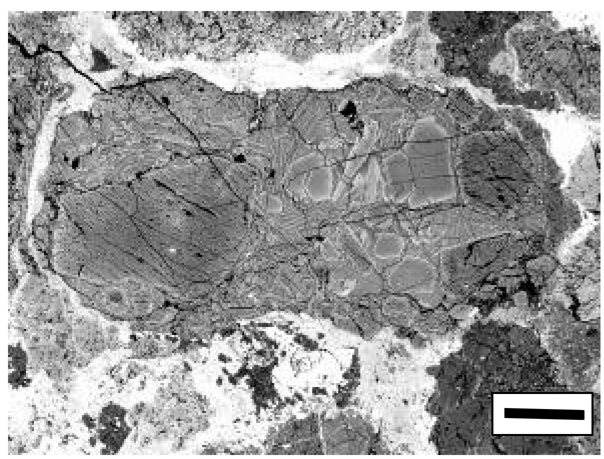

Fig. 3. BSE image of Semarkona P-5. Melting may exceed 40 %. Scale bar is 200 µm