ORIGIN OF NA-, AL-, GLASS-RICH CHONDRULES IN H, L AND LL CHONDRITES. C. E. Nehru[1], M. K. Weisberg[2,3], D.S. Ebel[3], J. S. Boesenberg[3] and H. C. Connolly[2,3] [1]Brooklyn College Dept. Geology, Brooklyn., NY 11235. [2]Kingsborough Community College, Dept. Physical Sciences, Brooklyn NY 11235. [3]American Museum of Natural History, Dept. Earth Planet. Sci., NY, NY 10024. (Nehru@Brooklyn.cuny.edu)

Introduction: Glass-rich chondrules, defined as containing more than 50 vol % glass, are minor components of ordinary chondrites (OC). A subtype of these containing more than 90% glass, referred to as glass chondrules, are extremely rare. For example, Krot and Rubin [1] studied 11 thin sections of ordinary chondrites and identified 15 glass-rich chondrules, only four of which are glass. Nehru et al. [2] studied 197 CC, RP and glassy chondrules in thin sections from 21 ordinary chondrites and found only 2 with more than 90% glass. The glass-rich chondrules are remarkable in containing abundant glass compared to most chondrules, which generally contain less than 20% and, they generally have Na-, Al-rich (nepheline or albite normative) bulk compositions with up to 15.6 wt. % Na_2O. The goal of our work is to understand the (primary vs. secondary) origin of these unusual, rare chondrule compositions and what they may reveal about chondrule precursors. Additionally, we are interested in the nucleation behavior of these feldspathic compositions and the fact that they remain uncrystallized even in equilibrated (type 4) chondrites, which may help constrain temperatures and timescales of metamorphism in OC parent bodies.

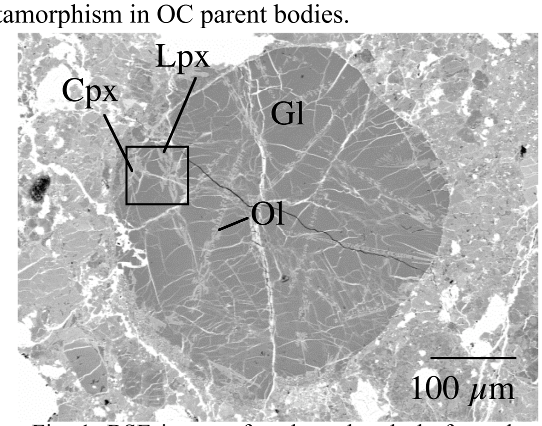

Fig. 1. BSE image of a glass chondrule from the Dimmitt H4 chondrite. Gl-albitic glass, Ol-olivine, Lpx-low-Ca pyxroxene, Cpx-Ca-pyroxene.

Results: We studied thin sections of 21 ordinary chondrites and found 2 chondrules having >90% glass. These chondrules are from Dimmitt (H4, regolith breccia) and RKPA 80205 (H3.8). Glass-rich chondrules have previously been reported in H, L and LL chondrites of petrologic types 3.4-4 [1]. Textures and Modes. Glass-rich chondrules include porphyritic, barred and glassy (>90% glass, Fig. 1) textures. They contain anhedral to subhedral olivine and/or pyroxene crystals surrounded by a glassy to microcrystalline mesostasis. Many, especially the most glass-rich chondrules, contain skeletal crystals of olivine, low-Ca pyroxene and Ca-pyroxene surrounded by glass (Fig.1, 2). Even in Dimmitt (H4) they contain uncrystallized (or poorly crystallized) brownish, isotropic glass. We recognize that thin sections reveal an apparent modal abundance that may be due to heterogeneous distribution of phenocrysts out of the plane of the section. However, because average OC chondrules contain only 10-20 vol% glass, it is highly likely that the identified glass-rich chondrules (>50 vol% glassy mesostasis) are anomalous. Indeed, some glass-rich chondrules, especially those containing >90% glass, with their skeletal crystals (e.g., Fig.1, 2) are clearly distinct in texture from other chondrule types. Their textures suggest that they are melt-droplet (completely molten) chondrules but are texturally distinct from CC and RP chondrules.

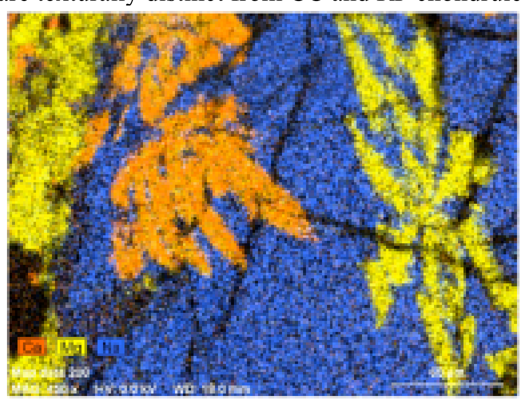

Fig. 2. Ca,Mg,Na map of the area boxed in Fig. 1, showing the skeletal crystals of Cpx (orange) and Low-Ca pyx (yellow), in a Na-Al-rich glass (blue).

Bulk Compositions. Using the electron probe we determined bulk compositions of the glass chondrules from Dimmitt and RKPA 80205. Recognizing the problems associated with analyzing chondrule glasses [e.g., 3], we use a combination of defocused beam, low sample current (10nA) and correction curves for alkali elements. Based on our results and data from [1], a total of 10 glass-rich chondrules including 4 glass chondrules, glass-rich chondrules have (in wt.%) 54-62 SiO_2, 0.8-1.6 TiO_2, 13-30 Al_2O_3, 0.7-9 FeO, <0.03-20 MgO, 0.4-5 CaO, 2-15 Na_2O and 0.4-1.5 K_2O. Bulk composition are enriched in Al and Na, with Al/Mg $\leq 4 \times 10^3$ and Na/Mg $\leq 8 \times 10^3$ CI, respectively, whereas other major and minor elements (Mg-normalized) are at ~CI (solar) abundances or slightly depleted (Fig. 3).

Na and Al are strongly correlated in these chondrules, whereas Ca and Al show no correlation. We also note that the glass compositions are fairly uniform throughout the chondrules with no evidence of chemical zoning. The average bulk composition of the glass-rich chondrules is ~20 x CI. Other melt-droplet chondrules, such as CC and RP, have average compositions with CI (or near-CI) abundances of major and minor elements (Fig. 4).

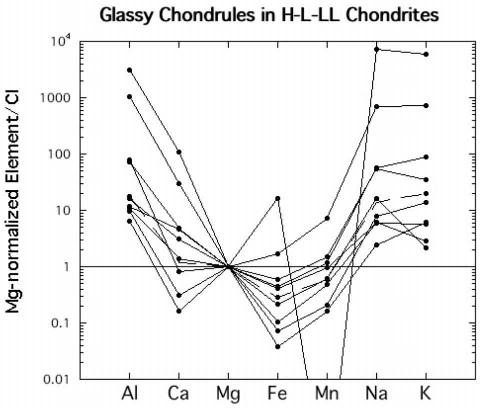

Fig. 3 Bulk compositions of 10 glass-rich chondrules from H, L and LL chondrites, 4 are glass chondrules. (Includes new data and data from [1].)

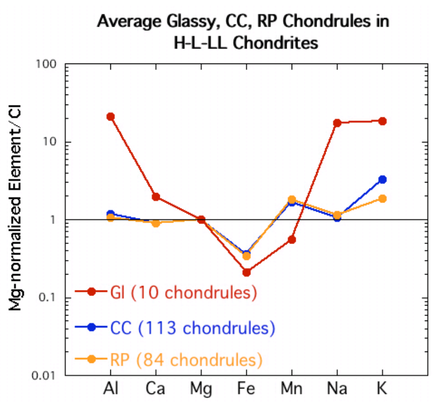

Fig. 4 Average bulk compositions of glass-rich (Gl), crypotcrystalline (CC) and radial pyroxene (RP) chondrules from H, L and LL chondrites.

Discussion: A detailed review of chondrules from our previous study [2], using SEM, revealed that many of the chondrules initially classified as glassy were not completely glass and contained feathery- and dendritic- micro crystals throughout the chondrule. Thus most of them were re-classified as cryptocrystalline, although this crystallinity may be due to devitrification well after chondrule formation. There are, therefore, few truly glass-rich and even fewer glass chondrules.

The origin of these rare glass-rich chondrules with Na-, Al-rich compositions is perplexing. Origins previously proposed for glass-rich chondrules include (1) separation of chondrule glass through collisions of an earlier generation of ferromagnesian chondrules [4, 5] and (2) mixing of refractory and moderately volatile-rich precursors [1]. Other possible scenarios are (3) melting of CAI-like precursors followed by open system behavior (mobilization of Na) after accretion [i.e., 6, 7] or (4) nebular alteration of CAI-like precursors.

The collision model (1) has a number of flaws. It has not been demonstrated that collision would be an efficient mechanism for partially melting and fractionating chondrule compositions. Additionally, in the least equilibrated chondrites, mesostases in the common type I chondrules is alkali-poor [8]. Therefore, unusual alkali-rich precursor chondrules would be required. The mixing hypothesis (2) is inconsistent with the nonexistent correlation between Al and Ca and the strong positive correlation between Al and Na. Evidence of zoning in mesostasis and bleached zones on chondrules has been used to support mobilization of Na during parent-body alteration [6,7]. However, the Na-, Al-rich chondrules show no evidence for (3) *in situ* alkali enrichment. We propose that melting of a mixture of albitic or nepheline-bearing and ferromagnesian precursor components is the most justifiable scenario for formation of glass-rich chondrules. Nepheline in some CAIs occurs as needles in textural settings that support condensation from a nebular vapor [e.g., 9, 10], and Na-metasomatism followed by remelting has been proposed to explain CAI melilite compositions [11]. Such materials could be among the precursors that melted to form glass-rich chondrules.

Further work is needed to understand the origin of glass-rich chondrules. Measurements of oxygen isotopes may provide information on their relationship to other chondrules and their evolution. Parent body hypotheses for Na diffusion by aqueous fluids, such as (3), can be tested by measuring the water content in chondrule glasses and, if present, determination of D/H ratios may help track the evolution of the water.

References: [1] Krot A. E. and Rubin A. E. (1994) *Meteoritics & Planet. Sci., 29,* 697-707. [2] Nehru C. E. et al. (1988) *Meteoritics & Planet. Sci., 23,* 293. [3] Greenwood G. H. (1996) (1995) *Meteoritics & Planet. Sci., 30,* 512. [4] Bischoff A. and Palme H. (1988) *LPS XIX,* 86-87. [5] Bischoff A. et al. (1988) *EPSL 93,* 170-180. [6] Grossman J. N. et al. (2002) *Meteoritics & Planet. Sci., 37,* 49-73. [7] Grossman J. N. et al. (2000) *Meteoritics & Planet. Sci., 35,* 467-486. [8] Grossman J.N. and Brearley A.J. (2005) *Meteoritics & Planet. Sci.,40,* 87-122. [9] Russell and MacPherson (1997) Workshop on Parent-Body and Nebular Modification of Chondritic Materials, LPI., 4045. [10] Murray J., Boesenberg J.S. and Ebel D.S. (2003) LPSC XXXIV, #1999. [11] Beckett et al. (2000) *Geochim. Cosmochim. Acta* 64, 2519-2534.