

GLASSES IN CHONDRULES: UNDERSTANDING THE ROLE OF LIQUIDS DURING CHONDRULE FORMATION PROCESSES. Varela, María Eugenia, ICATE-CONICET Av. España 1512 Sur, San Juan, Argentina (evarela@icate-conicet.gob.ar).

Introduction: Since the first summaries, in which the theories of chondrule origin were exposed [1-2], chondrules and chondrule formation have been studied intensively. However, there is no real consensus regarding the nature of the liquid droplet from which chondrules are supposed to be formed and other issues concerning their formation still remain unresolved [e.g., 3]. Two principal models can be outlined concerning the origin of chondrules in the solar nebula (e.g., 4 and references therein): a) Chondrules are formed by melting of pre-existing solids (e.g., MSP: Melting of Solid Precursors) during transient and locale heating. As a result, their properties can be established by their precursors if these systems remained as close-system [e.g., 5-6], due to evaporation and recondensation processes, if they went through open-system melting [e.g., 7]. b) Chondrules are formed through direct condensation of solar nebula gas into liquids and crystals [e.g., 8]. As chondrules are individuals and have extreme compositional diversity, the question that arises is whether objects that are characterized by having different textures (e.g., PO, POP, glass-rich), could have been formed through a single process.

Here I compare the chemical composition (major and trace elements) of porphyritic chondrules with the glass-rich chondrules [9-10] from the UOC Tieschitz L/H3.6 (PTS, Tieschitz L 3441-3443, NHMV), to understand further the role of liquids (the glass precursor) during crystal growth.

Results: Chondrule 3(2) is a glass rich PO chondrule with a metal belt surrounded by a sulphide belt at the surface (Fig. 1a). The clear glassy mesostasis (~13 vol% of the object), is Mg-Al-Si-rich with low contents of CaO (~4 wt%) and high contents of Na₂O (~12 wt%). The bulk chemical composition of chondrule 3(2) is Si-Mg-Al-rich with an olivine-nepheline-plagioclase normative composition.

Chondrule L(A) is a POP chondrule (Fig. 1b), composed of Mg-rich olivine (Fo_{97.9}) and low-Ca pyroxene (En_{97.6} Fs_{1.45} Wo_{0.99}) occupying similar volumes of the chondrule (~51 % and ~45 %, respectively). The glassy mesostasis (~4% of the object), is clean without signs of devitrification, silica-rich (53.6 wt%), and show no reaction with the olivine grains. The bulk chemical composition of chondrule L(A) is Si-Mg-rich with an olivine-hypersthene-plagioclase normative composition.

Chondrule L(B) is a PO chondrule (400 µm in apparent diameter) composed of Mg-rich olivine (Fo_{93.3}) coated in a fine-grained matrix. The scarce glassy

mesostasis (~5% of the object) is clean, silica-rich (55.4 wt%) without signs of devitrification (Fig. 1c). The bulk chemical composition of chondrule XII is Si-Mg-Fe-rich with an olivine-plagioclase-nepheline normative composition.

Olivine grains from the above described chondrules have primary glass inclusions.

Chondrule IIIM is a round chondrule with an euhedral olivine [CaO-rich (0.51 wt% core, 0.28 wt% rim) and FeO-poor (0.22 wt% core to 1.03 wt% rim)] at the center (Fig. 1d) of the chondrule [10]. Euhedral olivines, which are decorating the surface of the chondrule, have high CaO (varying from 0.31 to 0.52 wt%) and low FeO (varying from 0.2 to 4.7 wt%) contents. The cryptocrystalline mesostasis (~70 vol% of the object), is Ca-Mg-Al-Si-rich with low contents of Na, Ti and Fe. The bulk chemical composition of chondrule IIIM is Ca-Mg-Al-Si-rich with a plagioclase-olivine-diopside normative composition.

Chondrule XII consists mainly of a bluish-red glass that contains olivine plates (compositionally zoned, with FeO ranging from 1.7 to 12.7 wt%), a Ca-rich pyroxene (FeO-poor (0.16 wt%) and Al₂O₃-rich), sulphide dendrites, and a large spinel (with variable FeO contents (2.4 – 10.9 wt%) and Cr-poor (0.46 wt%)), which is surrounded by a cryptocrystalline matrix (Fig. 1e) [9]. CIPW-norms show the matrix to be rich in anorthite and the glass in nepheline and both containing substantial amounts of diopside. The bulk chemical composition of chondrule XII is Si-Al-Mg-Na-Ca-rich with a plagioclase-nepheline-olivine-diopside normative composition.

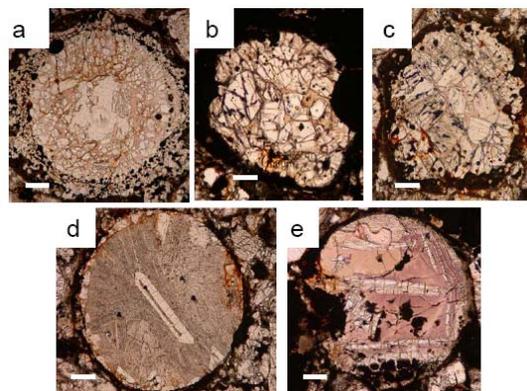


Figure 1: a) Chondrule 3(2), scale bar. 200 µm; b) Chondrule L(A), scale bar: 100 µm; c) Chondrule L(B), scale bar: 50 µm; d) Chondrule IIIM, scale bar: 50 µm; e) Chondrule XII, scale bar: 50 µm.

The glasses of the primary glass inclusions as well as the glassy mesostasis in *Chondrule 3(2)* and [*chondrule L(B)*] are rich in TEs with abundances of refractory elements at 4-14 x CI and [4-10 x CI] (Fig. 2 a-b). Those in *chondrule L(A)* as well as the recrystallized mesostasis of *chondrule IIIM* and the glass and matrix in *chondrule XII* are also rich in TEs with abundances of refractory elements at 10-20 x CI. All glasses (primary glass inclusions and mesostasis) are depleted in moderately volatile and volatile elements (~ 1 and 0.1 x CI), except for Sr and Ba which are abundant in mesostasis of chondrules: 3(2), IIIM and Matrix XII, and Rb, which is abundant in the glass inclusions L(B) (Fig. 2 a-b).

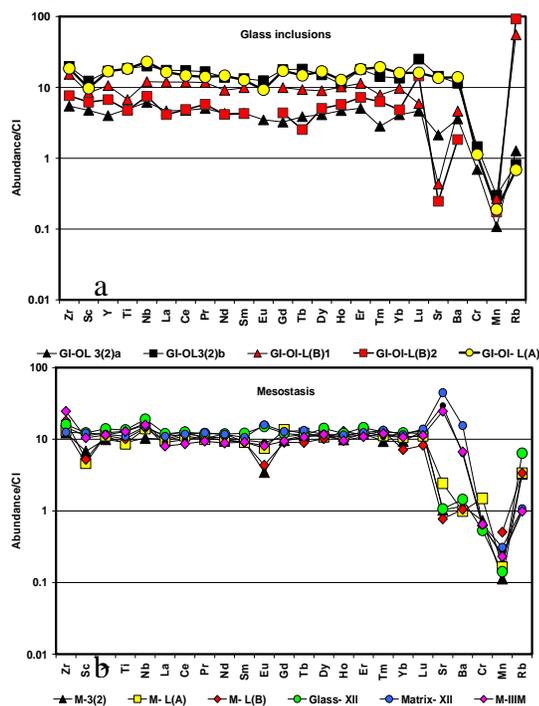


Figure 2: Trace element abundances and patterns of glasses and recrystallized mesostasis are governed by volatility only and documents vapor fractionation.

Discussion: Chondrules with the bulk chemical composition of IIIM represent the most refractory members of the all-liquid chondrule class. The recalculated (volatile-free) CMAS liquid composition of IIIM (weight % MgO: 23.5, Al₂O₃: 16, SiO₂: 46, CaO: 11) is similar to the one calculated by [11] for liquid condensates from a $\sim 100x$ dust-enriched solar nebular gas at 10^{-3} bar and ~ 1700 K.

Chondrules IIIM and XII are example of refractory chondrules, which – in contrast to common PO or POP chondrules – originated from an all-liquid droplet possibly formed by direct condensation from the solar nebula gas. In chondrule XII the Na, Al-rich glass and the Ca, Al-rich matrix show similar abundances of the

refractory lithophile elements (~ 10 x CI), which in turn are similar to the glasses from the PO, POP and the IIIM chondrules. Glasses have almost identical trace element abundance patterns, with cosmochemically refractory elements being enriched over all more volatile elements (Fig. 2), that do not correlate with the textures and /or the mineralogy of the objects. Furthermore, they show no fractionation among the abundances of geochemically very different elements (e.g., La vs Yb), that instead are well-correlated around the primordial ratio (Fig. 3). A clear sign of a cosmochemical (condensation) process.

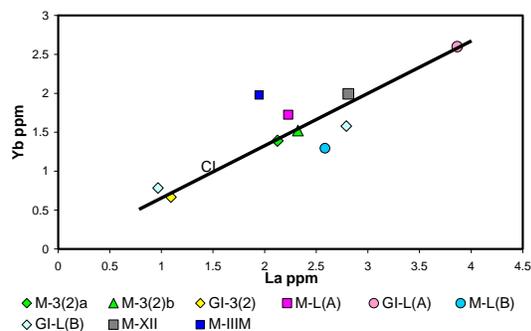


Figure 3: Yb vs La contents in glass inclusions (G.I) and mesostasis glass (M).

As the liquid (the glass precursor) is in chemical equilibrium with a large gaseous reservoir, it does not change its composition according to chemical partitioning of elements between growing crystals and liquid. but rather according to any compositional changes of the vapor. Thus, glasses show no signal of geochemical fractionation, as it is observed. These chilled liquids (=glasses) -possibly formed by condensation- could by a phase that was independent from the crystalline ones and that carry their own characteristic features.

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