ALL CHONDRULES ARE COMPOUND.

E. Jacquet[1],
[1]IMPMC, UMR7590, CNRS & MNHN, CP52, 57 rue Cuvier, 75005 Paris, France.

Introduction: The origin of chondrules is a long-standing enigma, where consensus is lacking even on whether such origin should be sought in a "planetary" (e.g. planetesimal collision) or a "nebular" (e.g. shock wave) setting [1]. It would be certainly profitable to know about chondrule populations produced by *single* events e.g. in terms of compositional variability or number density, as predictions from either class of scenarios would be quite different. Yet the mere coexistence of two chondrules in a chondrite thin section does not guarantee co-formation, for any chondrite accreted several generations of components, starting with refractory inclusions and ending with chondrules from reservoirs of various oxygen fugacities. However, *compound* chondrules, i.e. pairs or multiplets of chondrules fused together [2-6], do offer such a genetic link between their components, assuming the consensus opinion that they collided while (partially) molten [2,4,6].

Compound chondrules appear uncommon, with literature frequency estimates typically on the order of a few percent [2-4]. However, most of the recognized compound chondrules display nonporphyritic textures [2,3], which are a minority in the chondrule population at large. This may partly betray a recognition bias, for collisions with an undercooled droplet (bound to solidify as a nonporphyritic chondrule) may be the very cause of its nucleation, freezing in the boundary between the primary and secondary chondrule and making the composite nature conspicuous [6]. The collisions of *partially* molten droplets (bound to solidify as porphyritic chondrules) may produce only "blurred" compound chondrules [5], more or less relaxed toward sphericity. Such may be the case of lobate chondrules abundant e.g. in CO chondrites [7]. I have thus set to study them [8].

Methods and samples: I studied two thick sections of CO3 chondrites Miller Range (MIL) 07342 and 07193 in BSE and EMPA and selected 18 lobate type I chondrules for LA-ICP-MS analyses of their individual lobes. Some bulk- and mineral-scale analyses of typical and mesostasis-rich chondrules were also performed.

Results and discussion: The X-ray maps show that individual lobes display the mineralogical zoning (from olivine-dominated cores to pyroxene-rich rims) typical of most type I chondrules in carbonaceous chondrites [9-10]. This is a first suggestion that these lobes were independent objects interacting with the ambient gas (promoting pyroxene formation by recondensation of SiO, e.g. [9]). Further evidence may be found in the moderately volatile elements analyzed by LA-ICP-MS, which are correlated between lobes of the same chondrules, although refractory elements are not. The chondrules indeed must have behaved as open systems for the moderately volatile elements, which recondensed more or less depending on the cooling history of the reservoir. In contrast, refractory element patterns were mostly inherited from their precursors (and liable to a nugget effect associated with admixed refractory inclusions, as suggested by some volatility-fractionated patterns in mesostasis-rich chondrules [11]).

In addition, the viscosity should prevent relaxation of irregular droplets to sphericity (because of surface tension) only below ~1300 K, so lobate chondrules simply cannot have started as such upon initial melting. In fact, the departure from sphericity of most chondrules in different chondrite groups (e.g. [12, 13]) suggests that most chondrules are compound, variously relaxed toward sphericity. The frequency may have been very nearly 100 %, 1-2 orders of magnitude above literature estimates, if one considers that microdroplets, such as may have formed microchondrules [14] and igneous rims [15], greatly outnumbered "normal" droplets, unless one defines some threshold in size ratio or relaxation degree.

The LA-ICP-MS evidence for significant refractory element variation in single chondrule-forming events contrasts with the uniformity that would be expected in planetary scenarios (where the targets should be homogenized before or by the impact). However, the high collision rate suggested by this work (or even previous estimates) would be challenging for nebular models, unless a well-settled dust subdisk and increased relative velocities can be invoked.

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