MULTIPLE INDICATORS FOR MULTIPLE MELTING OF CHONDRULES. Alan E. Rubin[1,2], [1]Department of Earth, Planetary, and Space Sciences, [2]Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90095-1567, USA. (aerubin@ucla.edu)

Introduction: Many workers maintain that most chondrules crystallized after a single melting event. However, petrographic and experimental constraints show that most chondrules were melted multiple times.

1. Relict grains: These include "dusty" ferroan olivines in Type-I chondrules [1] and low-FeO olivines in ferroan olivine grains in Type-II chondrules [2,3]; many low-FeO grains are ^{16}O rich [4-6], resembling grains in Type-I chondrules [4,5]. Relicts occur in ≥15% of OC & >90% of CO Type-II chondrules [3,7].

2. Olivine shards: Many Type-II CO3 chondrules have small olivine shards with acute internal angles; these appear to be fragments of prior chondrules [3].

3. Small FeO-rich olivines: Some Type-II CO3 chondrules have ~10-µm olivines with central Fa values much higher than those in the centers of large olivine grains (e.g., Fa_{47} vs. Fa_{26}) [3]. Both sets of grains are normally zoned with similarly ferroan edges; they could not have crystallized at the same time.

4. Dynamic crystallization experiments: Normal porphyritic textures were produced only in those experiments with precursor nuclei ≥40 µm [8], suggesting that relatively coarse relicts (and more than one heating event) are required for forming porphyritic textures.

5. Overgrowths on relict olivines: A Type-II chondrule in Semarkona contains relict olivines with many small blebs of low-Ni metal formed by reduction of FeO; these grains are flanked by 3-5-µm-thick low-FeO overgrowths formed after remelting [9]. Numerous Type-II CO3 chondrules have small relict low-FeO olivines with 2-12-µm-thick high-FeO overgrowths [3].

6. Pyroxene overgrowths: In some Type-II LL3 chondrules, low-Ca pyx grains show multiple overgrowth layers apparently produced by secondary melting [10]. After initial melting produced the original spheroidal chondrule, minor reheating events melted only mesostasis. The first low-Ca pyx overgrowth that forms after reheating has low Ca and Fe; these cations gradually increase in concentration until cooling halts diffusion. The next melting event remelts and mixes local mesostasis; a normal igneously zoned layer subsequently forms. This process is repeated several times.

7. Trapped chromite within olivine: A coarse ferroan olivine grain in a Type-II CO3 chondrule contains small chromites (similar to those in the mesostasis) located ~5 µm from the olivine grain edge. This suggests that, after the final reheating event, a 5-µm-thick olivine overgrowth layer trapped the chromites [3].

8. Overgrowths in FeO-rich olivines: P X-ray maps reveal that many Type-II LL3 and CO3 chondrules have multiple sets of thin P-poor/P-rich olivine layers that appear to be overgrowths formed during secondary heating [11]. These layers are generally not evident in Fe, Cr, Ca or Al X-ray maps because rapid diffusion of these cations during reheating smoothed out the overgrowths, mimicking normal zoning.

9. Very large phenocrysts: About 20% of PO CO3 chondrules contain large phenocrysts that constitute 40-90 vol.% of their chondrules [12]. These are likely relicts that acquired small amounts of dust and debris that melted during later chondrule heating.

10. Microchondrules in chondrule rims: Numerous microchondrules occurring within fine-grained rims around Type-I chondrules formed by partly melting pyroxene grains at the chondrule edge [13].

11. Igneous rims: These rims surround ~10% of OC and ~50% of CV chondrules. They have igneous textures and formed by melting finer-grained rims around pre-existing primary chondrules.

12. Enveloping compound chondrules: These commonly consist of a primary chondrule surrounded by a secondary chondrule spherical shell. The shell formed by a later melting event.

13. Nested BO chondrules: A Semarkona chondrule consists of a primary BO chondrule surrounded by three nested BO layers, each containing olivine bars, mesostasis and small metal blebs [14].

14. Non-spherical chondrules: Most Type-I CO3 chondrules are multi-lobate or irregular objects with rounded margins. If they had been totally molten, they would have collapsed into spheres far faster than their ~20-µm-size olivines could have grown. They are likely chondrule fragments rounded during remelting [15].

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