CHONDRULE POROSITY IN THE L4 CHONDRITE SARATOV: MESOSTASIS DISSOLUTION AND CHEMICAL TRANSPORT.

J. A. Lewis[1], R. H. Jones[1,2], and S. C. Garcea[3], [1]Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131. jlewis11@unm.edu. [2]School of Earth and Environmental Sciences, University of Manchester, Manchester, M13 9PL, UK. [3]Henry Moseley X-ray Imaging Facility, University of Manchester, Manchester, M13 9PL, UK.

Introduction: Porosity is an important characteristic of meteorites and asteroids because it has significant effects on physical properties such as material strength and thermal conductivity. Porosity in chondrites can facilitate the transport of fluids, during aqueous alteration, and during metasomatism that accompanies thermal metamorphism. In ordinary chondrites (OCs), porosity is seen in association with the development and alteration of secondary minerals, phosphates and feldspar, during thermal metamorphism [1,2].

Bulk porosity is measured in meteorites using glass bead volumetry with ideal-gas pycnometry [3] and micro-computed tomography (μCT) [4]. [3] measured OC falls and found average bulk porosities of ~10% but with a considerable range up to 25% porosity for some samples. Petrologic type 4 OCs have higher average porosity than the other petrologic types for all OC groups. [3] noted an increase in porosity with increase in matrix abundance with all the chondrite groups implying that the majority of the porosity is contained within the matrix. [4] made a similar observation but noted that the OCs with the highest porosity tended to have pores within chondrules in addition to the matrix.

Porosity within chondrules is likely not a primary feature because chondrules are igneous objects. Development of chondrule porosity is thus related to secondary processes such as transport of material in and out of chondrules during metasomatism. In order to better understand the nature of metasomatic chemical exchange, we measured the porosity of individual chondrules from the L4 chondrite Saratov using μCT.

Methods: We separated chondrules from a Saratov hand sample through gentle crushing in a mortar and pestle. We selected two large chondrules (Ch 1, 3.7 mm and Ch 7, 2.0 mm) and 30 small chondrules (0.5-1.2 mm). The large chondrules were scanned individually on a Zeiss Xradia Versa 520 XCT at the Henry Moseley X-ray Imaging Facility, University of Manchester, with voxel sizes of 3.7 μm and 1.3 μm for Ch 1 and Ch 7 respectively. The small chondrules were scanned together with a voxel size of 1.8 μm. We performed thresholding and segmentation using the Avizo software package and calculated the porosity as the percentage void space within the solid material.

Results: Ch 1 (Fig. 1a) and 7 (Fig. 1b) are FeO-rich porphyritic pyroxene chondrules (Type IIB). The small chondrules (Fig. 1c) include a variety of chemical and textural types. Ch 1 and 7 have measured bulk porosities of 0.8% and 1.0% respectively. We measured the volumes and void spaces of the 30 small chondrules as a whole and determined an average porosity of 0.8% for the set.

Ch 1 has several large, nearly spherical pores (~250 μm, Fig. 1d) in the outer few hundred μm in addition to areas of dissolved intercrystalline mesostasis. The large pores may also be formed by the removal of mesostasis, although we cannot rule out the possibility that they were originally spheroidal metal/sulfide grains. Large pores also contain what appear to be vapor deposited minerals along the pore boundaries. Porosity in Ch 1 is not connected at the relatively coarse resolution of the scan but may be interconnected with small veins that are not resolved.

In contrast, most pores in Ch 7 (Fig. 1e) are planar, following the mesostasis morphology. They cluster in one region of the chondrule that is adjacent to remnant matrix (Fig. 1b). The chondrule-matrix interface may be a fracture plane that allowed fluids moving from the matrix to infiltrate the chondrule mesostasis directly. Pores in this chondrule are largely interconnected.

Discussion: *Analysis of porosity measurements.* We have shown previously that Saratov chondrules contain a wide range of pore sizes from sub-μm to 100s of μm [5]. The minimum pore size included in the μCT porosity measurements is on the order of a few times the voxel size of the scan. For chondrule 1 this includes pores greater than ~20 μm, and for all other chondrules pores greater than ~5 μm. Using a backscattered electron image of a Saratov chondrule with a resolution of 0.2 μm/px we estimate that 10-20% of the porosity (by area) was accounted for by pores between 1 μm and 5-20 μm in size. Thus we estimate that μCT chondrule porosity measurements are minimum estimates that account for 80-90% of the total porosity. We use an average chondrule porosity of ~1% for the remainder of the discussion.

Change in bulk chondrule chemistry. Porosity appears to be produced by the dissolution and removal of chondrule mesostasis, and possibly metal/sulfides, through the action of a fluid. Because of the chemical differences between phenocrysts and mesostasis, removal of mesostasis has a profound effect on the bulk composition of the chondrule.

To estimate the scale of this effect, we calculated the phenocryst and mesostasis contributions to the bulk composition using average bulk and mesostasis compo-

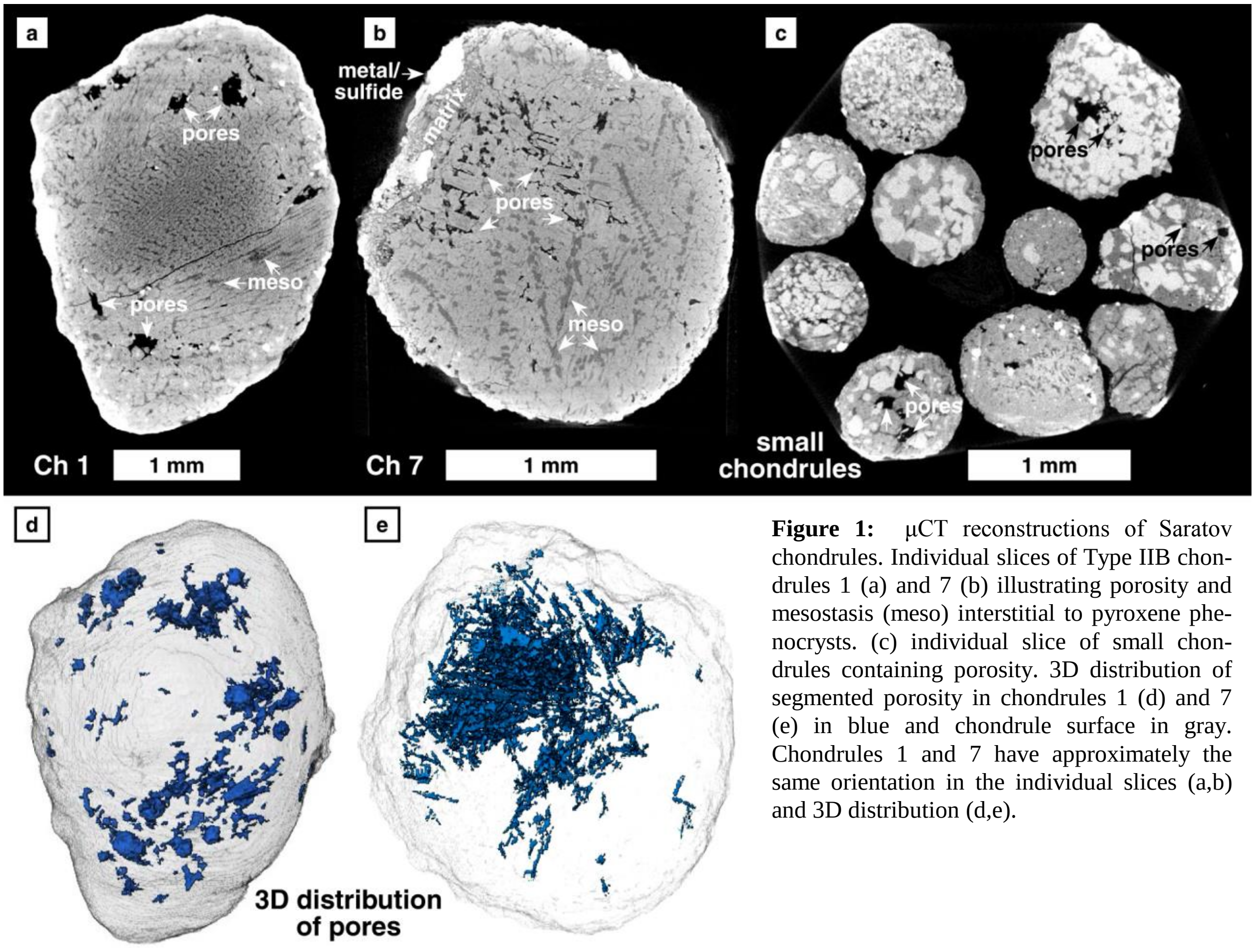

Figure 1: μCT reconstructions of Saratov chondrules. Individual slices of Type IIB chondrules 1 (a) and 7 (b) illustrating porosity and mesostasis (meso) interstitial to pyroxene phenocrysts. (c) individual slice of small chondrules containing porosity. 3D distribution of segmented porosity in chondrules 1 (d) and 7 (e) in blue and chondrule surface in gray. Chondrules 1 and 7 have approximately the same orientation in the individual slices (a,b) and 3D distribution (d,e).

sitions for Type IIB chondrules from Type 3 OCs [6] under the assumption that these are similar to the original chondrule compositions. Chondrule 7 has 2-3% mesostasis by volume (estimated from individual μCT slices) so a 1% bulk porosity concentrated in mesostasis implies ~40% loss in mesostasis. As a rough estimate, this corresponds to removal of ~25% of the original Al_2O_3, ~15% TiO_2, and ~10% Na_2O and K_2O from the bulk chondrule composition, in addition to minor losses of SiO_2 and CaO. Dissolution and transport of these species indicates an aqueous fluid with a high temperature and/or pH.

Development of chondrule porosity implies transport of material (mesostasis) out of the chondrules. However, at the same time, alkali metasomatism of anorthitic feldspar in type 3 and 4 OCs implies the transport of Na and K into chondrules [2,5,7-9]. In this regard, chondrules can be considered open systems during metamorphism/metasomatism. Pores created during mesostasis leaching serve as conduits for further metasomatic processing.

The scale to which the system can be considered open beyond the chondrule scale is ambiguous. Concentrations of the elements lost during mesostasis leaching (Al, Na, and K) do not show appreciable differences in bulk OCs between individual samples or petrologic types [10] suggesting closed system behavior on cm length scales. In contrast, the aqueous fluid must have acted in an open system manner on km length scales because there is no evidence for hydrated minerals in metamorphosed OCs.

Conclusions: Porosity is an important chondrite property and is developed in chondrules by metasomatism during metamorphism. Leaching of chondrule mesostasis, and possibly other phases, by an aqueous fluid redistributes chemical constituents through the chondrite and creates pathways for additional fluids. These processes should not be ignored in chondrite evolution models.

References: [1] Jones R. H., et al.. (2014) *GCA, 132*, 120–140. [2] Lewis J. A. and Jones R. H. (2016) *MAPS, 51*, 1886–1913. [3] Macke R. J. (2010) Ph.D. thesis, University of Central Florida. [4] Almeida N. V., et al. (2014) *77th Annu. Meet. Meteorit. Soc.*, Abstract #5032. [5] Lewis J. A. and Jones R. H. (2016) *79th Annu. Meet. Meteorit. Soc.*, #6121. [6] Jones R. H. (1996) *GCA, 60*, 3115–3138. [7] Lewis J. A. and Jones R. H. (2014) *77th Annu. Meet. Meteorit. Soc.*, Abstract #5176. [8] Lewis J. A. and Jones R. H. (2014) *LPS XLV*, Abstract #1661. [9] Lewis J. A. et al. (2016) *LPS XLVII*, Abstact #2559. [10] Kallemeyn G. W. et al. (1989) *GCA, 53*, 2747–2767.