UNAMBIGUOUS VOIDS IN ALLENDE CHONDRULES AND REFRACTORY INCLUSIONS. J. Murray[1], J. S. Boesenberg[1], and D. S. Ebel[1], [1]Department of Earth and Planetary Sciences, American Museum of Natural History, Central Park W. @ 79th St., New York, NY 10024 (janem, bosenbrg, and debel, all @amnh.org).

Introduction: Void spaces in the components of chondritic meteorites have received little attention, perhaps due to ambiguities attendant upon their very existence, and also their origin. Computer-aided microtomography allows the 3-dimensional imaging and analysis of void spaces within solid objects. Several striking examples of void spaces, apparently enclosed by solid material, resulted from our observations of large chondrules and CAIs from the Allende (CV3) meteorite. These voids are "unambiguous" because their existence *cannot* be ascribed to plucking during sample preparation, as would be the case in traditional 2-dimensional thin section petrography. Although we focus on large objects in Allende, preliminary observations indicate that void spaces are prevalent in chondrules and refractory inclusions in many meteorites.

Voids remain ambiguous, however, because their structure and appearance vary between chondrules and CAIs, suggesting there may be different causes of void formation in particular objects. Some voids appear to have formed as a result of dilation during cooling. Others are evidence of hydrothermal leaching on the parent body followed by partial chemical replacement. Alternatively, vapor-mediated leaching and replacement may have occurred in the nebula. Yet another possibility is internal brecciation caused by impact, while the object was still free floating in the nebula, and perhaps still partially molten.

Method: Two very large chondrules constituting a compound pair, and one large type B1 CAI were separated from Allende using dental tools, and analyzed on the GSE-CARS APS beam line at Argonne National Laboratory in Illinois. Images from 30 to 40 KeV x-rays were collected on CCD, at spatial resolutions of 12.92 (BB1), 9.55 (BB2), and 10.24 µm/pixel (AC1), and reprocessed to obtain density structures of the targets. This method allowed us to scan the entire sample, showing relationships between all the components prior to cutting the sample. Images were analyzed quantitatively using routines written in the Interactive Data Language (RSI/Kodak), and using the ImageJ and Imaris software packages. Samples were then cut through void spaces observed from the tomography, and polished thick sections were analyzed on the electron microprobe and field emission scanning electron microscope (SEM) at the AMNH.

Results: The chondrule pair consists of a relatively smooth, near-perfectly spherical 8 mm diameter radiating pyroxene (RP) chondrule (BB1). BB1 has no metal or sulfide, and a single 3 mm diameter, 0.5 mm deep concave depression (Fig. 1a) occupied by the slightly smaller, ovoid BB2. BB2 is a 5mm layered porphyritic pyroxene-olivine (avg. Fa 12, Fs 7) chondrule with abundant sulfide associated with Fe-rich silicates (to max Fa 18, Fs 21). BB1 and BB2 are separated by a septum (~0.6mm) of rim-like material, suggestive of dust trapped between them. The modes of occurrence of void spaces in these two chondrules are very different. In BB1, voids are thin (30 um), elongated (1-3 mm) lenses parallel to the radiating pattern of the pyroxene (Fig. 1a). Voids are measured to be 0.05% of the total volume (V^{tot}=204.1 mm^3). Similar void textures were illustrated by [1] in a RP chondrule, where voids also appear thin and elongate between the pyroxene crystals.

In BB2, voids occur in two ways. One type (#1, Fig. 1b) are small, roughly spherical voids near the boundary between inner, coarse FeO-poor silicates, and the outer FeO-rich zone. The second is a large, very irregular void in the central zone (#2, Fig. 1b). All voids account for 0.61% of BB2's V^{tot}=58.6 mm^3. In a plagioclase-olivine inclusion from Maralinga (CK), [2, their Figs 3-5] reported on similar pore spaces in plagioclase, filled with olivine and feathery carbonates.

The type B1 CAI from Allende (AC1 Fig. 1c) is very irregular in shape, ~4.5 mm diameter by ~9mm long, but missing a portion sawed from one end. Subhedral tabular melilite crystals grow inward from the surface ('Mel', Fig. 1c), abundant anhedral fassaitic pyroxene is interstitial to melilite and rarely touching the CAI surface, 2-15 µm spinels are superabundant, and one large anorthite grain was found. Trails of disseminated sulfide are observed, with some local concentrations. Grains with very high x-ray attenuation (white, Fig 1c) may be PGE-rich fremdlinge. Voids in AC1 extend very irregularly throughout the sample and are measured to be approximately 3.0% of its V^{tot}=83.6 mm^3. Voids contain brecciated material, primarily fassaite, which is evident on cut samples. Voids appear to occur preferentially between the melilite tablets, and in no case appear to crosscut melilite. Voids are not observed to connect to the CAI surface, unless through fractures below our spatial resolution. Suspected impact features on this CAI may be related to void formation.

SEM analysis of AC1 revealed euhedral crystals on void walls (Fig. 1c, inset) similar to those in Allende type A CAI CG-11 [3]: elongate nepheline, some striated, 10μm thick, to 35μm long (1); wollastonite whiskers to 15μm long (2); platy grossular ranging to 10μm to 15μm (3). Wollastonite "whiskers" are abundant, intergrown with euhedral grossular crystals.

Discussion: Three types of voids appear to be present in these three samples. A model which best explains what appear to be dilational voids in BB1, is formation in tension during rapid cooling, after crystallization of pyroxene from the supercooled chondrule droplet [4]. Only a very few of these voids are visibly connected to the chondrule surface. The largest subset of pyroxene seems to radiate from a point on the chondrule surface which is on the rim of the concave depression occupied by BB2.

In BB2, abundant sulfide in type 1 voids (#1 Fig. 1b), associated with Fe-rich olivine, suggest void formation by leaching and secondary alteration on the parent body. Most chondrites have been thermally metamorphosed enabling element migration across chondrule borders [5]. Furthermore, shock metamorphism on the parent body may mobilize metal and sulfides. It is more difficult to propose a model for the interior void, bordered by orthopyroxene euhedra (# 2, Fig. 1b).

In AC1, morphologic features (arrows, Fig. 1c) suggest a low velocity (<5 km/sec) microimpact may have caused internal brecciation and perhaps the voids themselves, while AC1 was free floating in the nebula. Crystals on void walls (Fig 1c, inset) suggest infiltration by a vapor [3], as opposed to parent-body metamorphism [6], as may have occurred in BB2. It appears likely that the voids in AC1 formed prior to incorporation into the parent body.

Conclusions: This tomographic-petrographic approach demonstrates that void features were not formed as a result of plucking during sample preparation. However, determining the exact process which formed these voids is difficult. Four models have been proposed for void formation. It is abundantly clear that more research needs to be focused on determining the circumstances of void formation and crystal deposition in these and similar objects.

References: [1] Krot AN *et al.* (2002) *Meteoritics Planet. Sci.,* ***37,*** 155-182. [2] Kurat G *et al* (2002) *Geochim. Cosmochim. Acta,* ***66,*** 2959-2979. [3] Allen JM *et al.* (1978) *Proc.* ***9****th LPSC,* 1209–1233. [4] Connolly HC Jr. *et al.* (1998) *GCA,* ***62,*** 2725-2735. [5] Grossman JN *et al.* (1997) *LPI Tech. Rept. 97-02,* 19-20. [6] MacPherson GJ & Davis AM (1997) *LPI-Tech. Rept. 97-02,* 42-43.

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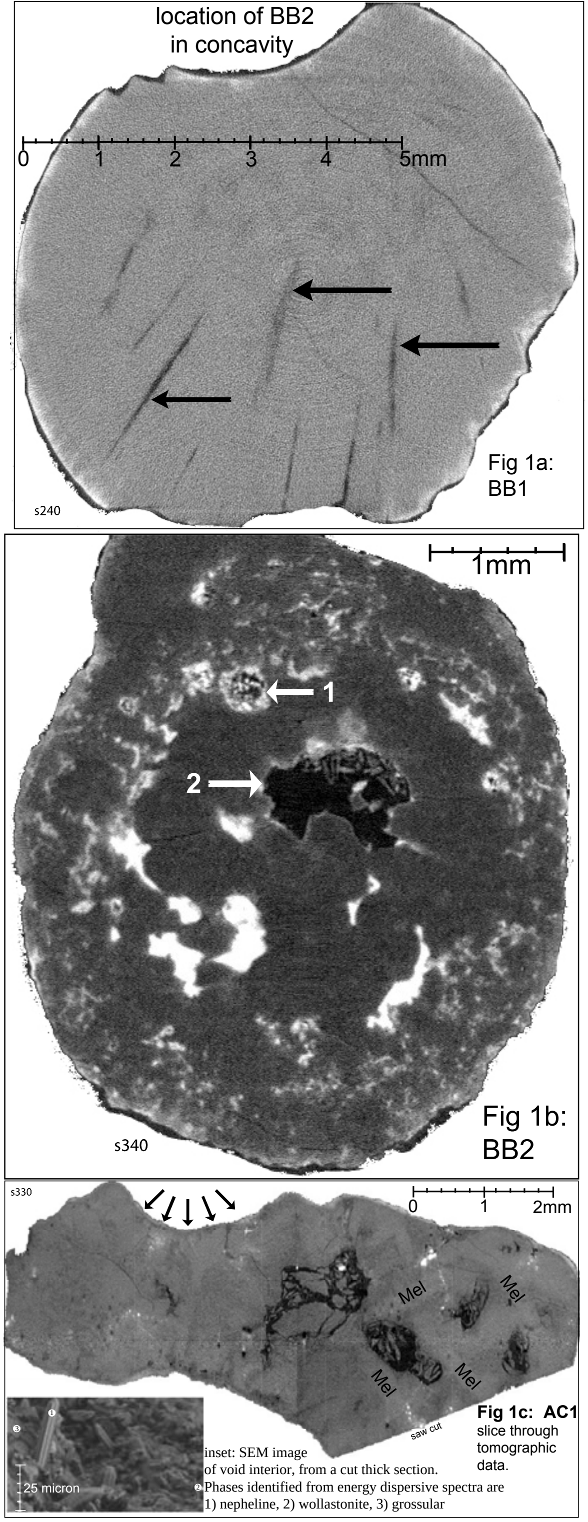

Fig. 1 Images of slices through 3D tomographic datasets. Voids are black interior spaces. White grains are most dense.