PROTON TOMOGRAPHY OF METEORITES MILTON AND ABBOTT.
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Introduction: We present tomographic images of samples from meteorites Abbott and Milton obtained at the Proton Radiography facility at Los Alamos National Laboratory. This demonstration of capability exploited a spontaneous opportunity for beam-time, so samples had to be quickly identified that could fit within the field of view (~4 cm x 4 cm) of the installed electromagnetic lens, limiting sample size to < 2cm. In consultation with UNM's Institute of Meteoritics two samples were identified for use:

Milton—An ungrouped pallasite with ~73% olivine (mean grain size 1.6 mm) in an iron metal matrix[1], was selected to determine whether tomographic images could be obtained in meteorites with a bimodal (Fe/Ni metal, Olivine) distribution. We anticipated that this would be a relatively straight forward, bounding condition on the tomographic capability for meteorite studies. A ~4 mm thick slice of Milton was selected.

Abbott—A gas-rich H chondrite regolith breccia, metamorphosed to type-4 to 6 and with foreign CM carbonaceous-chondrite clasts[2] was selected for this study to determine whether sufficient contrast could be achieved to non-destructively identify clasts and inclusions in meteorites that do not have the clean bimodal distribution of the more simple pallasite structure. An irregular sample that varied from ~10 – 20 mm in each dimension was selected.

Proton Radiography: These two meteorite samples were examined using the 800 MeV proton radiography system at the Los Alamos Neutron Science Center of the Los Alamos National Laboratory. The samples were radiographed using the permanent magnet 2.7 times magnifier.[3] The samples were rotated and tomographic reconstructions were performed. As configured this system was providing about 100 μm root mean square position resolution. Protons have high penetrability when compared to most conventional x-ray sources. Because of this, the tomograpic data can be obtained quickly and with low background.

Data were taken at 721 angles in 0.5° steps covering the range of 0 to 360°. Protons transmitted through a 7.5 mr collimator were imaged on a columnar CsI phosphor screen and were recorded using fast gated CMOS cameras. At each angle images were recorded for three proton pulses on 6 three-frame cameras providing 18 simultaneous frames per angle. The data analysis reported here uses a subset of this data (15

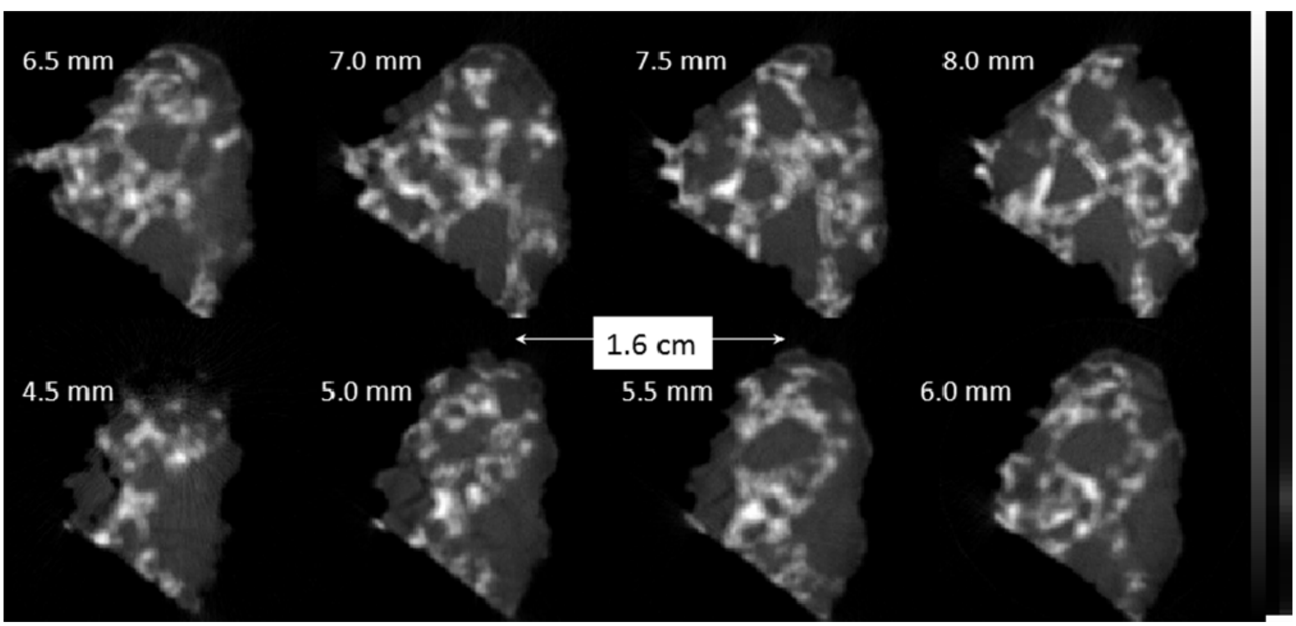

Figure 1) Tomographic slices through the Milton sample. Sequential slices are separated by 0.5 mm and are 100 μm thick. The density scale is linear from 0 (black) to 12 (white) in units that are weighted by the radiation length of the material.

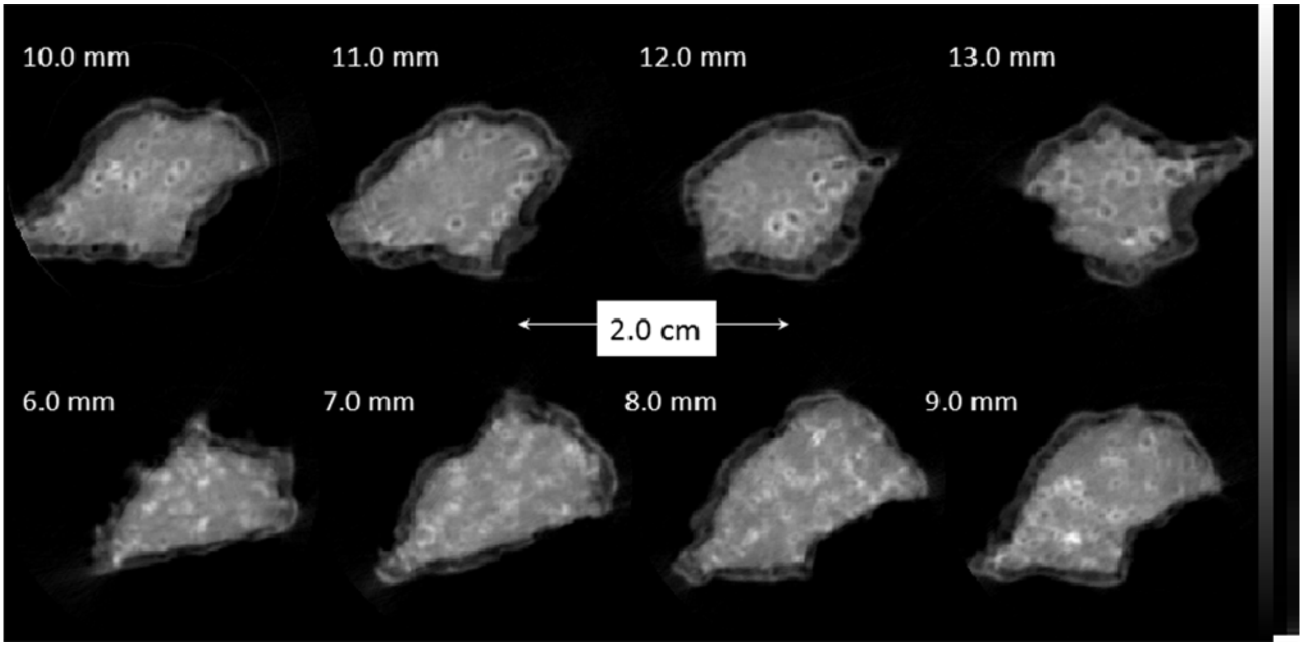

Figure 2) Tomographic slices through the Abbott sample. The density scale runs from 0 to 8.

images per angle for Milton and 9 images per angle for Abbott), because not all of the data were available at the time of the analysis. Radiographic images were inverted into relative areal densities as reported in other work.[4]

An image showing a set of slices 100 μm thick spaced by 0.5 mm moving up through the Milton sample are shown in Figure 1. Slices in 5.0 mm steps through the Abbott sample are shown in Figure 2.

Discussion: Differences in morphology between these two meteorite classes are readily apparent in the radiographs. The bimodal distribution of Fe/Ni metal and olivine is clear in Milton. Individual chondrules, inclusions down to a few hundred microns and the fusion/weathering crust clearly show up in the radiographs of Abbott. For both samples proton radiography is demonstrated to non-destructively provide internal characterization of internal structure. Associated movies of these tomographic reconstructions that reveal more continuous 3-dimensional views, similar to familiar medical MRI and CT scans, will be presented.

This ability to obtain detailed tomography of meteorites and materials from sample return missions will provide new tools to preserve knowledge of correlated internal structure and to optimize sampling of clasts and inclusions for complementary destructive analyses while minimizing sample disruption. Using another electromagnetic lens system, sample size for future studies could be increased up to approximately 12 cm x 12 cm, although special resolution does degrade as sample size is increased.

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