COMPUTED MICROTOMOGRAPHY (CMT) OF THE INTERNAL STRUCTURES OF RARE EXTRATERRESTRIAL OBJECTS

S. R. Sutton[1,2], P. Spanne[2], M. L. Rivers[1,2], and K. W. Jones[2]; [1]Department of the Geophysical Sciences and Consortium for Advanced Radiation Sources, The University of Chicago, Chicago, IL 60637; [2]Department of Applied Science, Brookhaven National Laboratory, Upton, NY 11973.

Introduction: Large numbers of meteorites are routinely collected from Antarctica. Although the majority of these specimens fall into the conventional meteorite groups (irons, chondrites, etc.) a small fraction are very unusual objects including rocks from the Moon and possibly Mars. An unfortunate characteristic of these interesting objects is that they tend to be small, i.e., typical dimensions of centimeters. One of the most basic pieces of information needed prior to developing analytical strategies for these samples (dissection, allocation, application of destructive techniques, curation) is the "petrography", i.e., the spatial distribution of clasts, mineral phases and voids. Ideally, cuts/breaks could be made along planes that intersect large clasts which often hold important clues to the origin and history of rock. Presently, exposure of clasts is a hit-or-miss proposition.

Computed Microtomography at NSLS: X-ray computed microtomography (CMT) can be used to obtain "petrographic" information in a relatively non-destructive manner. Reconstruction from line integrals are applied to two types of imaging data - absorption and fluorescence. In absorption CMT, a pencil x-ray beam is used in conjunction with intensity monitors (e.g., ion chambers or scintillation counters) before and after the specimen. By rotating the sample around the vertical axis and translating it in the horizontal plane during the measurements, absorption data are acquired that can be used to reconstruct the internal structure in a horizontal plane through the sample. By vertically translating the sample and repeating this process, a 3D image can be produced. Fluorescence CMT is an analogous procedure except that an energy dispersive x-ray detector is used to detect characteristic x-rays excited by the pencil beam. In this way, element-specific images can be produced.

Spatial resolutions below 5 microns have been achieved using bending magnet synchrotron radiation at the National Synchrotron Light Source (NSLS; Brookhaven National Laboratory, NY) [1]. A bending magnet delivers high flux up to about 30 keV and is sufficiently energetic for millimeter-sized samples. However, more energetic x-ray sources are required to penetrate a typical cm-sized, silicate-bearing object. The superconducting wiggler (SCW) at NSLS (beamline X17) has a gain at 60 keV of about 1000 over the intensity of the bending magnet and is well-suited to this purpose.

Allende Microtomogram using Superconducting Wiggler Radiation: A demonstration, absorption CMT image was made with the X17 SCW radiation using a 1 x 1.5 x 0.5 cm fragment of the Allende carbonaceous chondrite (kindly supplied by I. Steele, U. of Chicago). This meteorite was selected as a test sample because it contains abundant, spherical to pseudo-spherical chondrules in the size range 0.1 to several millimeters. The incident wiggler radiation was filtered with 0.25 mm Ta and collimated to 25 micrometers. A NaI(Tl) scintillation detector was used "downstream" from the specimen. 419 points on each of 667 angles were measured for 30 milliseconds for a total imaging time of 150 minutes. The resulting reconstructed tomogram (figures 1 and 2) clearly shows the chondrule positions with a spatial resolution of about 30 micrometers. This 2-dimensional scan can be repeated at various sample heights to produce a 3-dimensional image.

These results demonstrate the ability of CMT for imaging the internal structures of stony objects. In principle, it would be possible to obtain CMT images of rare Antarctic meteorites as part of the curatorial procedure.

Obviously, the CMT technique is also useful in cases where sectioning might compromise the original petrography of a specimen. One such example is a comet nucleus return specimen which is likely to consist of a mixture of ices and mineral grains [2]. For a solid water ice core which is 1 cm in diameter, the x-ray attenuation at 20 keV is about 50% , which is ideal for CMT measurements using the bending magnet radiation. Larger samples can be imaged using higher energy sources, such as the NSLS SCW or sources on the Advanced Photon Source currently under construction at Argonne National Laboratory.

Acknowledgments: NASA NAG9-106, DOE DE-AC02-76CH00016, NSF EAR86-18346, NSLS staff, U. of C. CARS Startup Grant, State of Ill. Tech. Challenge Grant.

References: [1] P. Spanne and M. L. Rivers (1987) Computerized microtomgraphy using synchrotron radiation from the NSLS. Nucl. Instr. Methods B24/25, 1063-1067; [2] G. J. Flynn, S. R. Sutton, and M. L. Rivers (1989) Non-destructive analyses of cometary nucleus samples using synchrotron radiation. In Proc. of Workshop on Analysis of Returned Comet Nucleus Samples, Milipitas, CA, Jan. 1989, in press.

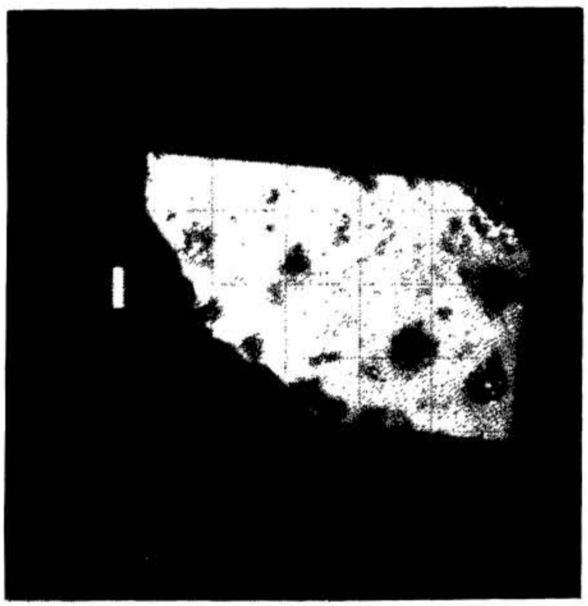

Figure 1 (left): Computed microtomography (CMT) image of the internal structure in a 1 cm fragment of the Allende carbonaceous meteorite. This 2D slice through the object is about 1 x 0.5 cm. Regions of high linear attenuation coefficient appear white while those of low attenuation appear dark. The dark, circular features show the positions of silicate-bearing chondrules intersected by the tomography plane. The scale bar is 1 mm. **Figure 2 (right):** A portion of the same image magnified by 4 times showing details of the chondrules, matrix and physical defects such as fractures. The 25 μm pixels are discernible.