DEVELOPMENT OF NONDESTRUCTIVE IMAGING TECHNIQUES TO IDENTIFY AND LOCATE PRESOLAR GRAINS IN METEORITE SAMPLE JBILET WITH APPLICATION TO SAMPLE-RETURN MISSIONS. D. Z. Shulaker[1], M. Ferrucci[2], B. M. Rogers[2], M. R. Savina[1], and B. H. Isselhardt[1]. [1]Nuclear and Chemical Sciences Division, Lawrence Livermore National Laboratory, CA (shulaker1@llnl.gov), [2]Materials Engineering Division, Lawrence Livermore National Laboratory, CA.

Introduction: Non-destructive analysis methods preserve grains and contextural information as compared to the traditional dissolution of meteorite fragments to obtain presolar grains. Previous studies target presolar graphite and silicon carbide (SiC) grains using nanoscale secondary ion mass spectrometry (NanoSIMS), scanning electron microscopy (SEM), and/or focused ion beam (FIB) to image regions of meteorite fragments or thin sections [1–5]. When compared to traditional dissolution of meteorite fragments, these methods preserve grains and contextural information. However, these methods are exceptionally time consuming, cover very little sample surface area, and often result in locating few presolar grains. X-ray computed tomography (CT) is a non-destructive imaging technique that generates a three-dimensional representation of a sample in terms of an X-ray attenuation image. X-ray CT is used extensively in many fields of research and in industry, though its application to locating and identifying graphite and SiC grains in meteorites and other precious samples from sample-return missions is limited. X-ray CT is promising for this task because of its potential to locate and identify 10s to 100s of presolar grains while preserving the sample. The X-ray CT images can also be used to efficiently target specific regions in the sample for more precise characterization by NanoSIMS or for subsequent analyses, such as by resonance ionization mass spectrometry (RIMS). In this work, we present ongoing work in the development of an X-ray CT based paradigm for imaging fragments of meteorite sample Jbilet Winselwan (hereafter referred to as Jbilet) to locate and identify presolar grain types.

Applications: This will be the first use of X-ray CT to locate and image presolar SiC and graphite in situ. The X-ray CT image of the full meteorite sample will be used to intelligently target smaller regions of interest for subsequent analyses by NanoSIMS and RIMS. Integrating presolar grain isotopic composition with in situ context in three-dimensions will allow for reconstructing how the meteorite parent incorporated presolar grains and agglomerated in the early solar system. Perhaps most importantly, the developed nondestructive analyses of meteorites can be applied to future sample return missions, whose material will be extremely precious.

Methods: A fragment ~150 μm diameter of Jbilet was mounted with carbon tape onto an SEM stub and

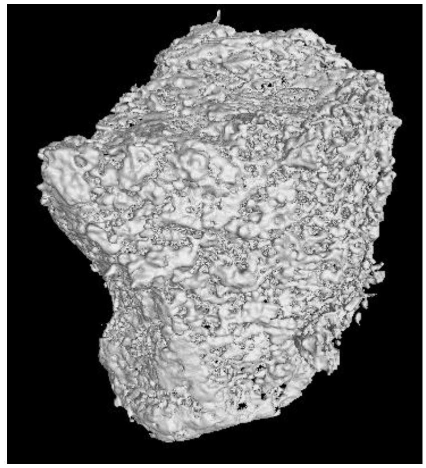

Fig. 1. X-ray CT image of a ~150 μm diameter Jbilet fragment.

imaged on a Zeiss Xradia 510 Versa using a conventional acquisition and subsequent tomographic reconstruction by cone-beam filtered back projection.

The reconstructed image consists of a three-dimensional array of volumetric picture elements (voxels), each assigned a gray value corresponding to the attenuation of X-rays by the material(s) contained within the voxel. The ability to distinguish features in the sample is dependent on the ability to detect changes in the reconstructed gray values. X-ray attenuation is a function of material composition (namely, atomic number, and physical density) and photon energy. Conventional cabinet X-ray systems typically use vacuum tube X-ray sources, which generate polychromatic 'bremsstrahlung' X-rays, i.e., characterized by a broad range of photon energies. However, since conventional reconstruction algorithms assume monochromatic X-rays, changes in the reconstructed gray values are not linearly related to changes in atomic number and/or physical density. The absence of sensitivity to photon energy in conventional X-ray CT imaging means that it is difficult to distinguish features with similar material properties, such as presolar grains.

One of our long-term objectives is to perform multi-spectrum acquisitions for direct material characterization by leveraging so-called 'dual-energy' acquisitions: two datasets acquired under distinct X-ray spectra, and a home-grown algorithm for decomposing the acquired data into voxel-wise effective atomic number and electron density [6]. As a precursor to our long-term objective, in this study we performed a conventional 'single-spectrum' acquisition at 40 kV

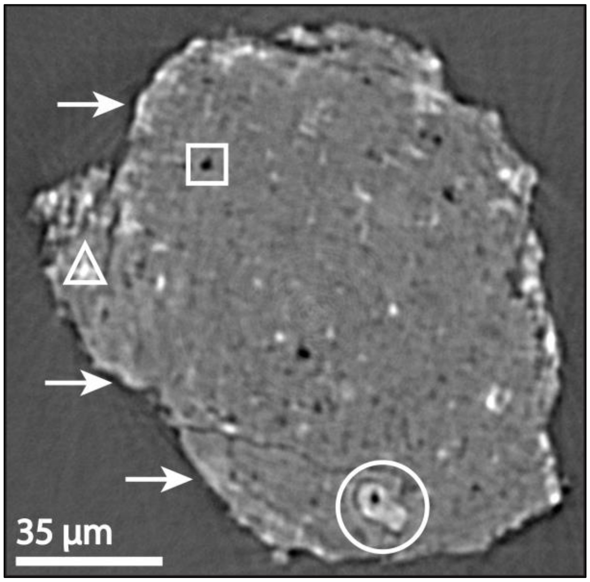

Fig. 2. Cross section slice through a reconstructed X-ray CT image of Jbilet fragment. Examples of observed characteristics: square is a pore, triangle is metal bleb, and the circle is a chondrule. Arrows point to the “beam hardening” artifact that appears around the meteorite edge.

tube acceleration voltage with a voxel size of 240 nm (Fig. 1). The reconstructed image was subsequently analyzed with VGStudio (Volume Graphics GmbH) and its foam/powder analysis functionality to identify individual particles and to extract their morphological and gray value statistics.

Results: Despite the previous caveat on relating gray value changes to material differences, features with substantially different attenuation properties could be distinguished using the mean gray value of the voxels contained within the particle regions. Furthermore, we can compare the extracted particle morphology, such as sphericity, diameter, and volume, to expected morphology for each grain as an additional criterion for particle classification. Based on these criteria, we make the following observations: (1) pores are typically less than 15 μm in diameter; (2) larger spherical voids approximately 20 μm in diameter are surrounded by purportedly concentric shells of high attenuation particles with a finer particle size compared to the matrix, and (3) particles with the highest mean attenuation values are highly spherical and generally less than 5 μm in diameter.

Using the data collected in this study in concert with previous studies of Jbilet [7,8], we hypothesize the identification of various discrete particles. For instance, that the larger, spherical features could be chondrules or chondrules with alteration phases and smaller high mean grey value spherical particles could be metal blebs.

Future work: We have identified several ways to overcome identified limitations with X-ray CT, such as reducing imaging artifacts, improving image quality, and spatial and attenuation resolution. For instance, without energy sensitivity in the acquisition and subsequent reconstruction, it is difficult to separate grains with similar morphology but distinct material properties, like SiC and graphite. Beam-hardening artifacts (such as false high gray value regions due in large part to the absence of energy sensitivity observed at the exterior edge of the meteorite as shown in Fig. 2) can interfere with the correct identification of features. By imaging a thinner fragment, we can use lower energy photons, which will result in reduced beam hardening artifacts and increased sensitivity to small changes in material properties within the sample.

We will also investigate the inclusion of external material references, such as synthetic SiC and graphite, into the measurement volume to serve as gray value benchmarks for identifying the same materials inside the sample.

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