DUAL ENERGY CT SCANNING AND PROCESSING OF CORE FROM THE PEAK RING OF THE CHICXULUB IMPACT STRUCTURE: RESULTS FROM IODP-ICDP EXPEDITION 364.

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Introduction: Computer assisted tomography (CT) has emerged as one of the most effective non-destructive methods for understanding the composition and internal structure of core samples. Whole core CT scans provide a high resolution 3D model of the bulk density and chemical composition of the entire core.. The CT volume provides a rich dataset of compositional and textural information that can be incorporated into scientific drill core analysis workflows [1].

IODP/ICDP Expedition 364 recovered 829 meters of core from the peak ring of the Chicxulub impact structure (Hole M0077A) [2]. CT scanning was performed on the entire core while intact, prior to being split for study and archiving. Processing of the data was performed to correct scanning artifacts and produce 2D images and 3D data volumes. The resulting data provide a full 3D model of the entire core that allows visualization of the interior structure (not just exterior surfaces and cut planes) and quantitative data that can be used for analysis.

CT Scanning: All of the recovered cores from Exp. 364 core were shipped to Weatherford Labs in Houston TX for CT scanning. The scanning was performed using a Toshiba Aquilion Prime Dual Energy Helical CT scanner. The device performed two scans of each core section. One scan was performed at a high X-ray energy level (135 kV) and one was performed at a low energy level (80 kV). This produces a series of axial cross section 'slices' or images of X-ray attenuation coefficients (or CT number, measured in Hounsfield units or HU), as shown in Figure 1. The images have a spatial (X, Y) resolution of 250 μm/pixel. Each slice represents a thickness of 0.3 mm. This results in approximately 3300 slices per meter, approximately 5 million for the entire core. The slices are stored as DICOM files organized by section. Each core section had a black marker line on the liner that provided a reference position that could later be rotated relative to magnetic north. When placed on the scanning fixture, the cores were rotated so the marker line was facing upward. The black line is located at the top of all slice images (indicted by the white 'X' in Figure 1).

The curated depth scale of the core sections (mbsf) results in apparent overlap between some sections because of expansion. The CT data are indexed by depth, and requires a unique depth for every slice. A CT depth scale (mCCSF-A) was created by adding the actual lengths of each section to the start depth.

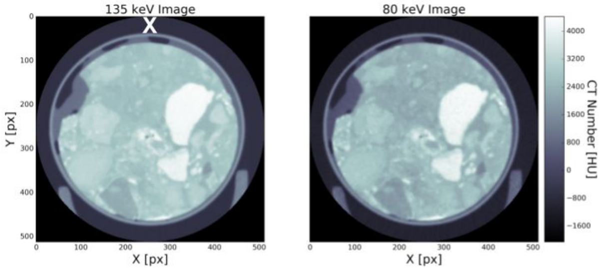

Figure 1: Unprocessed dual energy CT slice from 697.12 [mCCSF-A]. The high energy (135 keV) scan is on the left, and the low energy (80 keV) scan is on the right. The lighter regions correspond to higher CT numbers and higher x-ray attenuation. The location of black marker line (magnetic north) is shown by the white 'X' at the top of the left image.

CT Processing: The CT data were processed using the procedure outlined in [3]. The raw CT data were combined into a 3D volume and stored using a high performance scientific data format (HDF5). The data were cleaned by identifying and removing non-rock elements, such as the liner and fixture visible in Figure 1. Scanning artifacts such as beam hardening were corrected. A number of feature detection algorithms are run to extract data that can be used for advanced core description. These include 2 & 3D images, measures of texture (eg. local binary pattern) and prevalence of high density features. Figure 2 displays a sub-set of data generated during this step:

XZ slice. This is a vertical slice through the center of the core volume. The X (and Y) axis orientations are shown in Figure 1. The Z axis points downward along the length of the core. The core was split along the XZ plane.

CT histogram. A histogram of the CT numbers is created for every 10 slices of core. This gives a visual representation of the distribution and heterogeneity of core material.

Cylinder unwrap. This image is formed by extracting the CT numbers around a given circumference within the core. This image can be used for rotational alignment of the core by comparison with borehole images (see McCall et al., this volume).

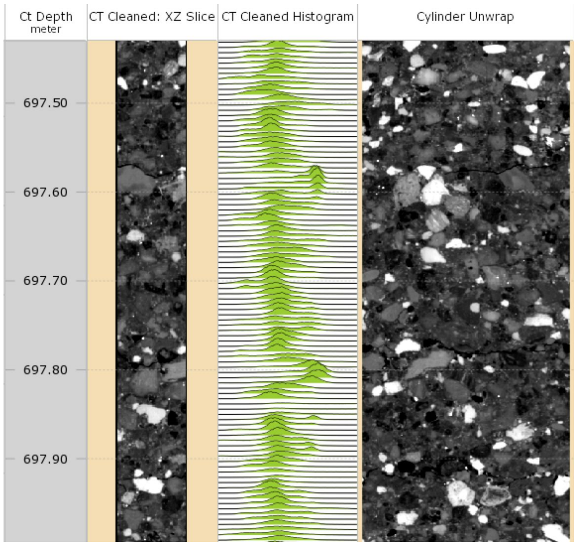

Figure 2: 2D images generated during processing of CT data. The CT histogram provides a visualization of the distribution of CT numbers every 10 slices.

Dual Energy Analysis: The attenuation coefficients measured by the CT scan depend on the material properties of the sample. Quantitative approaches have been developed to calculate bulk density (ρ_b) using the data from both high and low energy scans [4]:

$$a \times CTN_{low} + b \times CTN_{high} + c = \rho_b \qquad (1)$$

Thus ρ_b is a linear combination of each point in the low energy (CTN_{low}) and high energy (CTN_{high}) data. Bulk density measurements (see Rae et al., this volume) from core samples were used to determine coefficients (a-c) in (1) by calibrating with CT values at sample locations. This allows the calculation of ρ_b through the entire core volume. Figure 3 shows the result of (1) applied to an XZ slice of the dual energy CT volume from 697.09-698.09 [mCCSF-A]. The line scan image from the same section is shown for comparison. This section is suevite from the upper portion of the peak ring, and the density variation between individual clasts and melt can clearly be seen. The dual energy CT scan provides a ρ_b dataset at higher resolution than other measurements, and can be used to quantify the distribution of material.

Acknowledgements: The Chicxulub drilling expedition was funded by the International Ocean Discovery Program as Expedition 364 with co-funding from the International Continental scientific Drilling Program. The European Consortium for Ocean Research Drilling implemented Expedition 364, with contributions and logistical support from the Yucatán state government and Universidad Nacional Autónoma de México. Dual energy CT scanning was provided by Weatherford Laboratories with CT processing and software provided by Enthought, Inc.

References: [1] Duliu O. G. (1999) *Earth Science Reviews,* 44, 265–281. [2] Morgan J. V. et al. (2016) Science, 354, 878–882. [3] Hall, B. and Govert, A. (2016) *URTeC San Antonio TX, USA,* URTeC: 2434059. [4] Siddiqui, S. and Khamees, A. (2004) *SPE ATC Houston TX USA,* SPE 90520.

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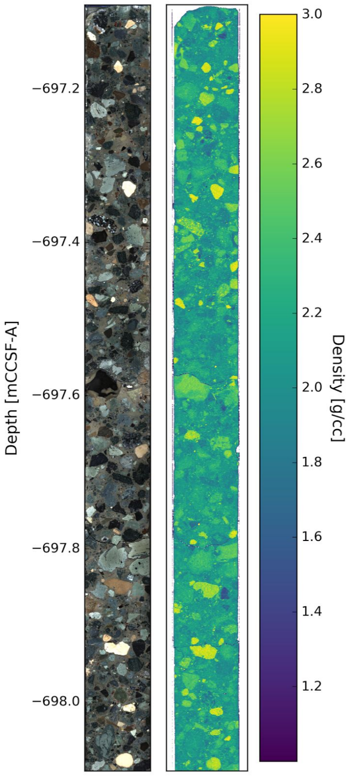

Figure 3: Line scan image (left) and XZ slice image (right) of bulk density (ρ_b) for CT depth range 697.09 to 698.09 [mCCSF-A].