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3D-imaging of foraminifera by X-ray microtomography

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The low abundance of *Heterostegina depressa* in the Caribbean coastal reefs of Costa Rica have led us to use a new, non-destructive method to study the internal structure of foraminifera. X-ray microtomography, in contrast to traditional transmission X-ray imaging, allows us to obtain non-destructive digital 3D-image data (volume up to 1000 * 1000 * 1000 voxels) from geological objects in which variations in mineralogy, chemical composition and/or porosity create sufficient X-ray density contrasts.

We present here preliminary results of an application to the external and internal morphology of Permian to Recent "larger" Foraminifera. We used a SkyScan-1072 high-resolution desk-top micro-CT system. The system has a conical X-ray source with a spot size of about 5 µm that runs at 20-100 kV, 0-250 µA, resulting in a maximal resolution of 5 µm. X-ray transmission images are captured by a scintillator coupled via fiber optics to a 1024 x 1024 pixel 12-bit CCD. The object is placed between the X-ray source and the scintillator on a stub that rotates 360° around its vertical axis in steps as small as 0.24 degrees. Sample size is limited to 2 cm due to the absorption of X-rays by geologic materials. The transmission images are back-projected using a Feldkamp algorithm into a vertical stack of up to 1000 1 Kpixel*1 Kpixel images that represent horizontal cuts of the object. This calculation takes 2 to several hours on a Double-Processor 4 GHz PC. The stack of images (.bmp) can be visualized with any 3D-imaging software, such as Tview (Skyscan, Ltd), used to produce axial and equatorial cuts of Foraminifera. Among other applications, the 3D-imaging software furnished by SkyScan can produce 3D-models by defining a threshold density value to distinguish "solid" from "void". Several models with variable threshold values and colors can be combined, rotated and cut together.

The best results were obtained with microfossils devoid of chamber-filling cements (Permian, Eocene, Recent). However, even slight differences in cement mineralogy/composition can result in surprisingly good X-ray density contrasts. We compared split specimens of *Operculinoides ocalanus*, and *O. soldadensis* from the Upper Eocene of the Southern Nicoya Peninsula (Costa Rica) with X-ray microtomographs of entire specimens. The split specimens were cracked along the equatorial plane by heating and chilling in the classical way (with a high risk of failure and destruction). They show irregular, chamber-filling glauconite aggregates separated by curved, narrow voids and calcite cement. This structure could by perfectly imaged by X-ray tomography of an entire specimens from the same locality. No risk was taken to destroy the specimen. The X-ray transmission images used for the calculation of the image stack, already show a good contrast between chamber lumen and septa. Composite equatorial sections built from several cuts calculated in Tview, clearly show the foraminiferal structure and the chamber-filling mineral(s). To calculate 3D-models of inner structures we defined a threshold value between the foraminiferal test and the cements.

X-ray microtomography may develop into a powerful tool for larger microfossils with a complex internal structure, because it is non-destructive, requires no preparation of the specimens, and produces a true 3D-image data set. We will use these data sets in the future to produce cuts in any direction to compare them with arbitrary cuts of complex microfossils in thin sections. Many groups of benthic and planktic Foraminifera may become more easily determinable in thin section by this way.