Microtomography of Dinosaur Shells and Bones

S. T. Pratt, C. A. Raptis, F. DeCarlo, D. C. Mancini
Argonne National Laboratory, Argonne, IL, U.S.A.

Introduction

We are developing a program to apply x-ray microtomography to samples relevant to paleontology, with a particular emphasis on the nondestructive imaging of the structure of dinosaur eggshell fragments. To date, a wide variety of techniques have been used to study these eggshells.[1] These techniques include normal and polarized light microscopy, scanning electron microscopy, tomography, cathodeluminescence, and isotope, mineral, and amino acid analysis. While each of these techniques has been useful, paleontologists have continued to look for nondestructive tools for their analysis. To this end, the high resolution microtomography possible at the Advanced Photon Source looks to be an ideal technique. In particular, tomographic images with micron spatial resolution should be readily achievable. Furthermore, the tomography system at sector 2-BM requires little or no sample preparation, allowing the eggshell to be viewed without sectioning and in an unaltered state. Once the techniques necessary to perform microtomography on these samples are characterized, the goals of this work are to gain insight into the pore structure of the eggshells, and to compare the structure of the fossilized shells with modern shells from evolutionarily related species. The characterization of the eggshells is also important because there is the relationship between their structure (size, shape, porosity) and the nesting behavior of the dinosaur and the environment in which the eggs were laid. For example, the gas conductance through dinosaur eggs has been estimated to be eight to sixteen times greater than that of birds eggs, indicating very different environmental conditions,[1] such as high humidity and CO_2.[1] To date, the methods for the analysis of dinosaur shells require thin sectioning and high-resolution optical or electron microscopy, both of which are time consuming and have the potential for introducing artifacts. The use of synchrotron-based microtomography will ultimately allow the direct, nondestructive visualization of the pore structure and connectivity of the pore structure in the egg shells, providing information that is either exceedingly difficult or impossible to obtain by traditional methods based on sectioning.

Methods and Materials

All samples were provided by Darla Zelenitsky, a paleontologist at the University of Calgary. Her choice of samples reflects the desire to compare modern and fossil shells of a number of different taxa to investigate the connections between them. In the past year, we have imaged shell fragments from a number of different species, including sauropod and theropod dinosaurs from several different regions, fossil and modern turtles, extinct moa, modern gecko, modern alligator, and modern brush turkey. All of the samples were approximately 3 mm x 3 mm, and 1 to 3 mm thick.

The experiments were performed on the bending magnet beamline 2-BM at the Advanced Photon Source. The details of the tomography set up have been described previously,2 and will not be discussed here. However, much of the beam time was used to investigating different options for the tomography measurements. For example, several different imaging and CCD detector systems were used over the course of the year, both YAG and $CdWO_3$ scintillators were tested, and both the multilayer monochromator and crystal monochromator were used. Ultimately, the samples required the use of 25 to 30 keV x-rays, which ruled out the use of the multilayer monochromator. This energy is at the high end of the energy range of the beamline, resulting in relatively low fluxes. In addition, these energies are not optimum for the YAG scintillators. Taken together, these restrictions required acquisition times of ~10 hours to collect a full data set, and in the end, we have only recorded high-quality data sets for a fraction of the desired samples.

Results

Tomographic data sets have been recorded for each of the samples described above. We experimented with a number of data acquisition setups, which resulted in collection times for a full data set that ranged from approximately 40 minutes to over 12 hours. Unfortunately, subsequent reconstructions of the data sets indicate that only those data sets obtained with the longest acquisition times had sufficient signal-to-noise ratios and dynamic ranges to show the details of the pore structure of the eggshell fragments. The best quality reconstructions to date have been for sauropod and theropod dinosaur shell fragments, while adequate, although somewhat lower quality, reconstructions have been obtained from modern turtle and alligator shell fragments.

Discussion

The reconstructed images of the theropod eggshell fragment shows relatively few features, but several indentations that may be the start of pores are visible. Theropod shells are known to have relatively straight pores surrounded by relatively uniform shell material. In contrast, the reconstructed images of the sauropod shell show complex, convoluted pore structure throughout the shell. Interestingly, the construction and pore structure of the modern turtle eggshell fragment appears to be similar to the sauropod fragment. In contrast, the modern alligator eggshell fragment appears to be similar to the theropod fragment. However, a detailed comparison of the reconstructed images will require somewhat better data for the turtle and alligator samples. In the coming year, we hope to obtain these data, to improve the data sets for the remaining samples, and to develop more quantitative methods to extract the pore volume from the reconstructions.

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References

[1] See, for example, *Dinosaur Eggs and Babies*, ed. K. Carpenter, K.F. Hirsch, and J.R. Horner (Cambridge University Press, New York, 1994).

[2] Y. Wang, F. DeCarlo, D.C. Mancini, I. McNulty, B. Tieman, J. Bresnahan, I. Foster, J. Insley, P. Lane, G. von Laszewski, C. Kesselman, M.H. Sui, and M. Thiebaux, Rev. Sci. Instrum. **72**, 2062 (2001).