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Availability of morphological analysis using X-ray computed tomography in microfossil study: Example of planktonic foram

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X-ray computed tomography (X-ray CT) reconstructs non-destructive measurement of three-dimensional structure and interior by calculating the X-ray absorption. Also fossil studies, X-ray CT can reconstruct any tomographic image and transmission image in any size fossils. In addition, X-ray CT can also freely enlarge, reduce and rotate images. X-ray CT has become popular as a new technique for observing fossils which are more difficult to observe.

Theoretical morphological models have been developed to describe quantitatively the form of organism (e.g., Thompson, 1915; Raup, 1966; Okamoto, 1988). Models of planktonic foraminifera are developed by many researchers (e.g., Berger, 1969; Tyszka and Topa, 2005). Those models are based on three-dimensional shell form, but measurement methods are based on the two-dimensional images such as optical or electron micrograph and X-ray transmission. So, the error due to distortion of the measurement angle and the projection operation is ignored, which means reproducing the structure of the sample is impossible in principle. In this study, we solved this problem by using X-ray CT. Firstly, we developed measurement method for planktonic foraminifera. Secondly, we discussed on an array pattern and growth pattern of planktonic foraminifera. Finally, we show the availability of X-ray CT analysis in microfossils.

High resolution X-ray CT imaging system used in our study ScanXmate-A150S145/2 (producted by Comscantecno) has 5 micron resolution and pixel size of tomographic image is 2.5 micron. The basic principle of X-ray CT is as follows. Firstly, when X-rays transmitted through the sample is irradiated, detectors measured the X-ray absorption value of the path integral as projection image. Secondly, projection images are taken in many different directions. Thirdly, the X-ray absorption value is reconstructed from many projection images by the discrete Fourier transform. This is mathematically equivalent to solving the inverse Radon transform problem (Radon, 1917). Finally, the X-ray absorption value is output as a brightness value on a tomographic image.

This study intended planktonic foraminifera to measure as a test of microfossils. Planktonic foraminifera is one of the important key fossils, the indicator of paleoceanography and the subject for evolutionary. Planktonic foraminifera are going to add a new spherical or egg-shaped shell (chamber) in their growth process. In this study, we selected *Globoconella inflata*, modern planktonic foraminifera. We observed results of reconstruction which each tomographic image and rendering image by software Molcer Plus (producted by WhiteRabbit). We adopted the center of gravity and volume of the each chamber as a site of measurement.

Tomographic images ware processed by the free software ImageJ 1.43 and aggregated calculation by the software Microsoft Excel. Firstly, to detect the contour of the inner wall of each chamber, we binarized tomographic images of the average brightness value as the threshold. Secondly, those images are segmented into each chamber. Finally, volume and growth trajectory of chambers were measured. We determined curvature and torsion of growth trajectory by using Frenet-Serret formula (Frenet, 1847; Serret, 1851), in the reference growing tube model (moving frame models) by Okamoto (1988). Briefly, curvature is the reciprocal of the radius for curve, and torsion is the variable representing the rate of twisting from the plane of curve.

Measurement results were obtained with 11chambers. Volume of chambers tends to increase exponentially, and growth rate of chambers constituting the last whorl more increases. However growth rate of last chamber decreases rapidly. To calculate the curvature and torsion of the growth trajectory, we found that the curvature was positive and increased at a constant rate, and torsion was positive and almost close to zero. We will present these data in detail.

Keywords: X-ray computed tomography (X-ray CT), morphological analysis, planktonic foraminifera