

Automatic identification and statistical characteristics of annual layers in stalagmites

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Records of chemical and isotopic compositions of stalagmites, such as Mg/Ca, and carbon isotope ratios, provide various kinds of paleoenvironmental details, for instance, information related to changes in vegetation and solar cycles. Annual layers recognized in stalagmites are also used as an age proxy for paleoenvironmental information. These layers are mainly formed by annual changes in the impure materials incorporated within the layers, and in some layers, it is possible to use ultraviolet rays to observe fluorescent impurity materials such as fulvic acids. It has been concluded that the process of formation of annual layers in stalagmites is deeply related to the following: the sedimentation rate affected by the rate of dripping water, the calcium ion concentration in that water, the form of the stalagmite, the carbon dioxide concentration in caves, and the surface environmental changes affecting fulvic acid production. However, a number of unsolved problems remain related to the ways in which these factors affect the thickness of an individual annual layer and the fluorescence intensity.

When using annual layers in stalagmites as an age proxy, the sedimentation rate during specific intervals is estimated from the average thicknesses of these layers. If the sample includes indistinct layers, their adjacent upper or lower section data are used. However, the frequent use of microscopes in performing annual layer counts and thickness measurements in stalagmites is associated with problems of reproducibility. Therefore, establishment of a method for objectively and quantitatively measuring annual layers in stalagmites that includes statistical analysis, as is strongly suggested in paleoenvironmental studies, would improve data reliability. In this study, an automatic measuring method developed for lacustrine varved diatomites was applied to annual layers in stalagmites, and statistical analyses were performed on the measurement results.

Annual layers in stalagmites were photographed using a fluorescence microscope. Identification and measurement of annual layers in digital images were performed using the method proposed by Sasaki et al. (in press). The procedure used for identifying and measuring annual layers using this method was as follows: (1) the gray values in the images were smoothed, and the change rates of these values were calculated, (2) the median values of the smoothed gray values in a moving window were calculated, (3) the annual layers were identified based on combinations of the maximum change rate in (1) and the median value in (2). After identification of the annual layers, their thicknesses were measured at boundaries of the identified layers.

The results suggest that the automatic identification method developed for lacustrine deposits can be applied to the annual layers of stalagmites. An asymmetrical stratigraphic variation of the fluorescence intensity, which can be related to the formation process of the layer, was observed within a layer of stalagmites. The thicknesses of the layers and their average fluorescence intensities have a wide range of values, even in the short term, so their time series fluctuate considerably. In an example of annual layers in a stalagmite obtained in Ryuo-do Cave in Saikai City, Nagasaki Prefecture on Kyushu Island, the following was found: a wide range of the normal thickness frequency distribution or an approximately lognormal thickness frequency distribution with a range of approximately 50-200 micrometer; an increasing fluorescence intensity in each layer from the lower to upper part; and a fluctuation of the fluorescence intensity in layers unrelated to the fluctuation of the layer thicknesses. The results suggest that the formation process of the annual layers is highly affected by the cave environment, and thus further study involving direct observations of the formation process of annual layers on stalagmites is indicated.

Keywords: annual layer, image analysis, stalagmite, time series analysis