3D Visualization of Rock Textures

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Abstract

Computer tomography technique by serial-grinding has been developed for understanding 3D rock textures. Rock samples that were cut into several cm cube were sequentially ground and were taken in color pictures at every 0.5 mm thickness by hand-operation. Based on a set of 2D section images derived from serial section pictures, 3D rock textures were synthesized by a visualization software ìAVSî in two ways; cross-section method and volume-rendering method.
This technique has been applied to two kinds of rock sample; metamorphosed composite intrusive rock showing complicated fluidal texture of mafic and felsic parts from the Hida metamorphic belt, Japan, and garnet porphyroblast-rich eclogite from Franciscan terrane, California. For the former sample, the resultant 3D textures show commingling relation between mafic and felsic parts and strongly suggest the mingling of two magmas before metamorphism. For the latter sample, the 3D images clearly show the size, amount and distribution of garnet porphyroblasts, and such data may contribute to discuss the nucleation of garnet porphyroblast in eclogite.
The serial-grinding CT with the 3D visualization software is available for understanding real rock textures ranging from several mm to cm scale by use of sample block of several cm size cube.

Keywords: 3D visualization, Rock texture, magma mixing, eclogite

Introduction

Recent progress in software and hardware for 3D image processing has greatly improved the methods to understand many kinds of phenomena and objects in several special fields. Computer Tomography (CT) is one of the best successful method and has been a lready applied to medical sciences as X-ray CT.

In petrology, rock textures have usually been recognized as two-dimensional section images by the naked eye and under the microscope, and then petrologists have to imagine or to reconstruct real 3D textures on the basis of 2D information. 3D images of rock textures contain much information on petrogenesis; however, we cannot directly observe inner texture of real rock samples. It has been known that too much reliance on 2D textural information leads to misinterpretation (Shelly, 1993; Hibbard, 1995). To clear such difficulties in rock textures, the 3D visualization technique with graphic computer is much expected; however, its application seems to be hard. The pioneer works of 3D X-ray CT for rock textures have been given by Prof. W.D. Carlsonís group at the University of Texas (e.g., Carlson and Denison, 1992; Denison et al., 1996). They have already made almost fully automatic X-ray CT system for rock textures. Using the 3D visualization software AVS, we also have tried to establish the 3D observation technique by serial-grinding and serial-section pictures (Ando et al., 1994; 1995a,b; 1996). This technique has almost been completed and may be available for several rocks.

The purpose of this paper is to describe ìserial-grinding CTî technique to get 3D image of rock textures as two examples of composite intrusive rock and garnet porphyroblast-rich eclogite, and to show the resultant synthesized 3D textures of those rocks.

Sample description

Metamorphosed composite intrusive rock

Metamorphosed composite intrusive rocks that were utilized for 3D observation were collected at the Higashi-Urushiyama outcrop, Gifu Prefecture, Hida metamorphic belt, central Japan. This rock consists of two parts; melanocratic part of amphibolite, and leucocratic part of metatonalite. This composite rock, which has been subjected to later stage Hida metamorphism, has intruded into the host rock of biotite-hornblende gneiss that has been subjected to earlier stage metamorphism. As shown in Fig. 1a, this rock shows complex mingling and fluidal textures. Such textures seems to suggest the mingling of mafic and felsic magmas. On the basis of Rb-Sr isochron age dating, however, Arakawa (1984) reported the age difference of ca. 82 Ma between leucocratic and melanocratic parts, and he regarded the leucocratic part as a younger intrusive into the older mafic intrusive rock, although his age data have large uncertainties. If this rock has been formed by magma mingling, the age difference should be regarded as error. To observe the real 3D textures may contribute to clarify the genesis of this composite texture. The specimen for 3D observation was cut into 6~Å10~Å12 cm parallelopipedon (Fig. 1a).

Eclogite

The eclogite was collected at Jenner in Franciscan Terrane, northern California, USA. This rock occurs as tectonic blocks in the melange zone (Coleman and Lanphere, 1971; Cloos, 1986). The principal constituent minerals are garnet, omphacite, phengite, glaucophane, chlorite. A large amount of garnet porphyroblasts occurs in this rock. Garnet crystals that usually have a crystal form of euhedral dodecahedron are 2~9 mm in diameter, and show reddish brown color to the naked eye. Under microscope, garnet crystals are often replaced by chlorite along the rim. The matrix of this eclogite mainly consists of omphacite and glaucophane that is a product of retrograde stage. Omphacite-rich part shows dark green color and glaucophane-rich part shows bluish dark gray. The main purpose of 3D observation of this sample is to understand the size, amount and distribution of garnet porphyroblasts in eclogite. The specimen for 3D observation was cut into 5~Å10~Å15 cm parellelopipedon (Fig. 1b).

Method of 3D image synthesis

Sample preparation and image acquisition

The working flow from photograph acquisition to the preprocessing of serial images is summarized in Fig. 2. Samples for this observation were cut into a rectangular parallelepiped in the size about several cm cube. Photographs of all six surfaces of the parallelopipedon were taken before serial grinding in order to compare those with the synthesized surfaces. After the surface for grinding was specified, it was ground with #100, 400, 800 abrasives to be shaved at a 0.5 mm interval, and was taken as a color picture of negative film. Such procedures were repeated two hundred times. The error of one hundred times shaving was less than 1 mm.

Hardware and software

Two kinds of UNIX workstations, Titan3000 manufactured by Stardent Co. Ltd. and Magnum4000 by MIP Co. Ltd. were used in this study. The 3D visualization software, AVS (Application Visualization System) distributed by Kubota Graphics Technologies Inc., was used for the synthesis of 3D images. AVS is one of the famous 3D visualization software available for many kinds of computers. The characteristic features of AVS are the interactive user interface and the four subsystems; image viewer, graph viewer, geometry viewer and network editor. The network editor gives us a visual programming environment to make some application programs only by connecting executable modules with mouse operation.

By use of the network editor, two kinds of applications were made for 3D observations; one is cross-section method and other is volume-rendering method.

Preprocessing of serial 2D images

Color photographs of serial sections were used for 3D observation of rock textures. Each photograph was read with an image scanner in the resolution of 75 dpi and was stored as a file of X-Window Dump File format (xwd). Each xwd file was converted to 2D field data format in AVS. Then, a set of serial section images was converted to 3D voxel data for AVS by our original program ì2D_to_3Dî that is written in C.

Observation by cross-section method

This method generates an arbitrary cross-section of a synthesized 3D object at any directions and creates a continuous section like an animation. Figure 3a shows the AVS module network to observe 3D textures by cross-section method. The function of each module is as follows: ìread fieldî reads AVS field data, ìcropî changes the size of field data, ìdownsizeî changes the size of 3D voxel data, ìgenerate colormapî produces an AVS colormap data structure which is used by ìcolorizerî transforming input voxel data to color values, ìbrickî creates a picture of volume data, ìanimated floatî antomatically modifies the parameters for animation.

Observation by volume-rendering method

This method generates transparent 3D images. Figure 3b shows the AVS module network to observe 3D textures by volume-rendering method. Until ìdownsizeî module, the process follows the cross-section method. The functions of the other modules are as in the following: ìcompute gradientî and the ìgradient shadeî compute the gradient vector at each point in a 3D field data set, ìvolume boundsî generates lines that indicate bounding box of a 3D field data set.

Results and discussions

Metamorphosed composite intrusive rock

The purpose of this sample was to observe the real 3D texture, particularly to detect the commingling texture between leucocratic part and melanocratic part. The synthesized 3D textures both by cross-section and volume-rendering methods were successfully illustrated in the synthesized images (Fig. 4) which are originally represented as black and white gray scale images. The interval of shaving, 0.5 mm thickness, is sufficient for synthesizing 3D images of several cm size rock specimens. Figures 4a to 4c show the synthesized 3D texture by cross-section method. All six surfaces of the real rock sample (Fig. 1a) are clearly reillustrated in the synthesized 3D image (Fig. 4a). Examples of cross sections at arbitrary directions are shown in Figs. 4b and 4c. By observing continuous cross sections at an appropriate direction on monitor screen like an animation, we confirmed the commingling relation between melanocratic and leucocratic parts: some isolated leucocratic parts are included in melanocratic part, and some melanocratic parts in leucocratic part (Fig. 4c, arrow A).

Figures 4d to 4f illustrate the 3D form of leucocratic part generated by volume-rendering method. Melanocratic part is set as completely transparent. The brightness of gray scale image has been employed to discriminate the leucocratic part from melanocratic part. For discriminating objects from other portions in a 3D image, this rock is simple case because this consists of two parts and it is sufficient to divide into two parts by setting an appropriate threshold of the brightness.

The shapes of leucocratic part show ìpipe-likeî and ìbranch-likeî forms in melanocratic part. No leucocratic part shows ìplateî form. The tiny leucocratic part is branching from the relatively large branches, and some show ìdroplet-likeî form as isolated parts in melanocratic part (Fig. 4f, arrow B). In order to explain such texture, we have to introduce the magma-mingling between felsic and mafic magmas. If the origin of leucocratic part is later stage intrusion into melanocratic part that was already consolidated, its form should be a ìplateî. The forms of leucocratic part suggest that the melanocratic part had been a liquid when felsic intruded into it. These 3D shapes of the leucocratic part obtained in our 3D method may strongly suggest that the meta-composite rock at Higashi-Urushiyama outcrop is formed by mingling of mafic and felsic magmas as already reported in Colorado, USA (e.g., Noblett and Stab, 1990).

Franciscan eclogite

The purpose of this sample was to understand the size, amount and distribution of garnet porphyroblasts in eclogite. Synthesized 3D images both by cross-section method and volume-rendering method are shown in Fig. 5. An arbitrary section of the cube is illustrated in Fig. 5b. Being compared with the photograph of the eclogite sample (Fig. 1b), all six surfaces of the synthesized cube are well reproduced (Fig. 5a).

In this paper, the printing of 3D texture of eclogite is represented in black and white although the original synthesized 3D images have been drawn in full-color. Light parts in each photograph in Fig. 5 indicate garnet porphyroblasts. Darker parts are the eclogite matrix mainly consisting of omphacite and glaucophane. The garnet porphyroblasts which are relatively coarse-grained crystals (>6 mm) were well discriminated from the eclogite matrix by the difference of color tones, but small-grained crystals (<2mm) were slightly difficult to be discriminated (Fig. 5b, arrow). Also, it is very difficult to discriminate other minerals in the matrix. Major constituents in matrix are omphacite and glaucophane. Those colors are dark green and dark blue, respectively; so, it is very difficult to discriminate each other by color picture of polished surface. Some special preprocessing to specimen surface or to serial-section images should be required to discriminate those minerals.

The grain size variation is easily recognized in 3D images, but the crystal shape of garnet porphyroblasts is not illustrated in those photographs due to the low resolution derived from 0.5 mm shaving interval. The distribution of garnet porphyroblasts has been well observed in the synthesized 3D images, particularly in those by volume-rendering which were obtained by setting the matrix of eclogite as completely transparent under AVS operation (Figs. 5c, d). Relatively small-grained garnets are concentrated in the lower layer of the specimen (Fig. 5d, arrow); but large-grained garnets are mainly found in upper part and those distribution is a little sparse. Together with the bulk chemical composition data of each layer, 3D distribution data on garnet will contribute to consider the nucleation of garnet porphyroblasts in eclogite though this paper will not mention about this any more.

For another application of 3D texture, we tried to measure a modal composition of garnet in eclogite. The 3D modal value is 24.5 vol. %. This value was calculated from a set of 2D serial-section images. Ordinary point-counting method under the microscope gave 22.5 vol. % as garnet modal composition. This was obtained from three thin sections of other piece of the same sample that looks similar. The value of 3D method may be more reliable than that by point-counting method. Cutting specified portion of a 3D image, we can calculate the garnet modal composition of corresponding part of the sample.

Conclusions

The technique of 3D observation of rock textures by serial-grinding method with 3D visualization software AVS has been proposed. This method is available for understanding real rock textures ranging from several mm to cm scale by use of sample block of several cm cube.

For the sample of metamorphosed composite intrusive rock, mafic and felsic parts were successfully discriminated each other. The observation of animated 3D images by cross-section method confirmed the commingling relation between mafic and felsic parts. The 3D images of felsic part obtained by volume-rendering method indicate the fluidal texture such as pipe-, branch- and droplet-like forms that suggest the felsic magma flow into unconsolidated mafic magma.

For garnet porphyroblast-rich eclogite, garnet crystals are well distinguished from the matrix by the difference of color tone, and the size and distribution of garnet porphyroblasts are easy to recognize in 3D images, particularly in those by volume-rendering. The 3D images are also available for the modal analysis of garnet in eclogite.
Our ìserial-grinding CTî method for rock textures using 3D visualization software AVS is effective to the rock sample having several mm to cm scale texture in the size of several cm cube though this has some faults as follows: 1) this method requires high-level technique for rock-grinding, 2) after the acquisition of a set of serial-section images real rock samples have gone. The precise grinding technique in sub-mm scale developed in this study will be applicable for the synthesis of 3D chemical compositional images of garnet porphyroblast with electron microprobe in order to detect the real 3D compositional zoning.

Acknowledgments

We express our sincere thanks to Mr. Tatuya Nikkuni at KGT. Co. Ltd. for his kind advice on the usage of AVS.

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