THREE-DIMENSIONAL STRUCTURE OF MARTIAN METEORITE ALH84001 BY X-RAY CT METHOD.

A. Tsuchiyama[1], T. Kawabata[1], G. A. McKay[2], and G. E. Lofgren[2], [1]Department of Earth and Space Science, Graduate School of Science, Osaka University, 1-1 Machikaneyama-cho, Toyonaka, 560-0043, JAPAN (akira@ess.sci.osaka-u.ac.jp), [2]SN2/NASA Johnson Space Center, Houston, TX 77058, U.S.A.

Introduction: Since possible relic biogenic activity was reported in Martian meteorite ALH84001 [1] intensive researches have been made on this meteorite. However, we do not know much about its three-dimensional structure. X-ray computed tomography (CT) provides three-dimensional information about X-ray absorption difference by stacking successive images [2-4]. Especially, high-resolution X-ray CT method with spatial resolution of •10μm [5] can give three-dimensional information on fine structures that cannot be obtained by successive conventional thin sectioning [2]. In the present study, the high-resolution X-ray CT method was applied to ALH84001 to determine three-dimensional distributions of shock features and possibly carbonates for understanding secondary processes of the meteorites, such as shock events and/or possible hydrothermal event.

Experiments: X-ray CT images of ALH84001-253 (irregular shape, about 8x8x12 mm) were taken. Two different high-resolution X-ray CT scanners of third generation were used; scanner-1: BIR/ACTIS+2 with a microfocus X-ray source of W-target (5 μm in diameter) and an image intensifier of effective 922 channels with 12 bit gray scale (80 mm in size), and scanner-2: Nittetsu-Elex/ELE SCAN NX-NCP-C80-I(4) with a microfocus X-ray source of W-target (6x8 μm in size) and an image intensifier of 768x510 channels with 10 bit gray scale (72x54 mm in size). Three slices (512x512 pixels and slice width of 50 μm for each image) were taken at a time by the scanner-1 with the accelerating voltage of 110 keV and the X-ray tube current of 0.06 mA. Totally 180 successive slices were taken to obtain a three-dimensional image (the voxel size is about 16x16x50 μm). A hundred slices (1024x1024 pixels and slice width of 15 μm for each image) were taken at a time by the scanner-2 with 41 keV and 0.1 mA. Totally 816 successive images were taken to obtain a three-dimensional image (the voxel size is about 9x9x15 μm). The former was used to obtain rough information, which corresponds to observation under low magnification, while the latter to obtain detailed information, which corresponds to observation under high magnification. A filtered back-projection (FBP) method was used for reconstructing each image from the raw data in the both scanners. The gray scales of the images were reduced to 8 bits, and these reduced images were used for image analysis and three-dimensional imaging.

CT images: Contrast in an X-ray CT image corresponds to X-ray absorption, which is mainly correlated with density. Previous study on ALH84001 analog [6] showed that orthopyroxene (opx), plagioclase glass (pl), chromite (cm), and cracks should be easily recognized by their contrast difference, ($m_{cm}>>m_{opx} >m_{pl}>m_{crack}$, where m is the linear attenuation coefficients of X-rays). The contrast of carbonate (cb) is between those of opx and pl depending on its composition ($m_{cb}(Fe\text{-}rich)$•m_{opx} and $m_{cb}(Mg\text{-}rich)$ •m_{pl}). So, carbonate might be recognized if its zoning is observed. Simulation of a CT image from an SEM image suggests that about <20 μm resolution is required for the recognition [6].

An example of the CT image by scanner-2 is shown in Fig.1. Opx, pl, cm, cracks and air are recognized with a spatial resolution about a few tens of μm. Cracks and pl are sometimes indistinguishable due to noise and artifacts in the images (ring artifact, beam hardening, artifact by scattering of X-ray, etc.). Carbonates cannot be recognized at present although some candidates are present. Comparison with an optical microscope or SEM image after sectioning is required. We cannot identify crushed zones clearly too. However, very small contrast difference is present in opx. This may correspond to crush zones.

Image analysis: It is hard to attribute each voxel to opx, pl, cm, cracks and air clearly in all the successive images by simple thresholding of their contrasts. So, we developed a special algorithm for thresholding considering three-dimensional connection (T3DC). In this T3DC algorithm, voxels, which is connected three-dimensionally (6 directions) and have a range of contrast thresholds corresponding to each phase, are searched. By this algorithm most of the voxels are properly attributed to the phases (opx were divided into bright and dark ones, pl and crack were not distinguished, cm and air were also distinguished) although some errors are still remain. Two voxels were eroded from the sample surface to remove the region with intermediate contrasts between the air and sample. Three-dimensional images taken by the scanner-1 before and after T3DC are shown in Fig.2.

Three-dimensional structure: Most of pl+crack (blue) is distributed along many planes together with cm (red) three-dimensionally, and they form a foam-like structure (Fig.2). The three-dimensional distribution of cm is shown in Fig.3. From this stereo graph, the foam-like distribution of cm can be also recognized. In the stereo graph showing pl+crack and cm (Fig.4), the materials are so crowded that their three-dimensional distribution is not clearly seen. The foam-like structure may be seen in the lower part of the sample.

The size of each frothy bubble is about a few mm. Because the sample size is not so large compared with the bubble size, the whole structure of the foam cannot be understood clearly. At least in this sample, the bubbles seem to distribute randomly in the lower part of the sample, while a plane structure seems to be present in the upper part (Fig.3). At least some of the foam-like structure should be related to shock features although details are not known from the CT-images alone. Comparison with observation by an optical microscope and SEM is highly required.

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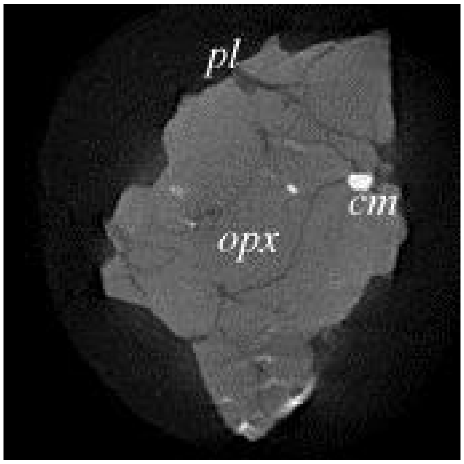

Fig.1. An X-ray CT image (slice) of ALH84001-253 taken by scanner-2. Brighter contrast corresponds to higher X-ray absorption. Cracks can be recognized as well as plagioclase glass (pl, dark gray), orthopyroxene (opx, gray), chromite (cm, white) and air (black). The contrast of opx near the upper left edge is slightly brighter than that near the center and upper right edge. Ring artifact is seen. The photo width is 7.7 mm.

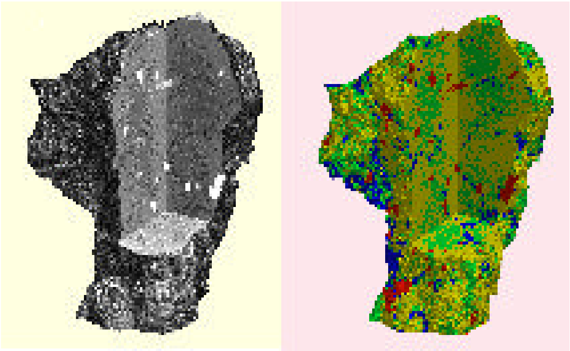

Fig.2. Three-dimensional structure of ALH84001-253 taken by the scanner-1. Images before and after thresholding by T3DC algorithm are shown on the left and right, respectively (red=cm, yellow=bright opx, green=dark opx, blue=pl+crack). The sample is 9 mm long vertically.

Fig.3. A stereo graph showing chromite distribution. The voxels of cm in Fig.2(right) are presented.

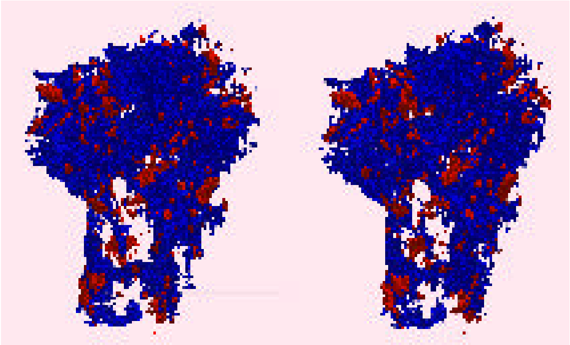

Fig.4. A stereo graph showing the distributions of plagioclase glass+crack (blue) and chromite (red). The voxels of these phases in Fig.2(right) are presented.