The formation environment of the Nakhlite Y000593 inferred from deformation microstructures

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Introduction: The Yamato 000593 Antarctic meteorite is classified as one of the Nakhlite meteorite. Previous studies about the Nakhlite formation process suggested that the Nakhlites have formed either in thick lava flows (>125m) or in shallow intrusion (probably less than a kilometer depth) [1]. However, the details of the formation and its environmental conditions (e.g., stress field when the minerals cumulated) are still unknown. In this study, we investigate the formation process and environment of the Nakhlite meteorite (Y000593) on the basis of comprehensive observations of crystallographic orientations in augite grains.

Experimental: We studied two polished thin sections of the Y000593 (Y000593,63-1 and 67-3) supplied from the National Institute of Polar Research by mineralogical, textural and crystallographic observations using an optical microscope, electron probe micro analyzer (EPMA, JEOL JXA 8200) at Hiroshima University, and FE-SEM equipped with an electron backscatter diffraction (EBSD) detector (HITACHI S-3400N with Oxford Nordlys) at Shizuoka University. We measured the lattice-preferred orientations for each grain (~100 data points) in the sections by EBSD patterns. This allows to visualize a trend of crystallographic orientations of augite grains in entire thin section.

Results and Discussion: The primary minerals of Y000593 were augite, olivine and mesostasis that are similar to the previous studies for Nakhlite. All Nakhlites show similar crystallization ages (1.3Ga) (e.g., [2]). We found that Y000593 shows crystal preferred orientation patterns in augite grains (Fig.1). Different colors in Fig.1 displays the degree of the crystal-preferred orientation; red color represents strong crystal-preferred orientation than blue. Both thin sections show {100} and <001> maximum. This preferred orientation in augites suggested that augites arranged by a shear stress in one direction without a friction. Similar texture has been observed in other Martian meteorite and the texture depends on the stress field when the minerals cumulated [3]. Thus, we inferred the Nakhlite Y000593 formed under a shear stress by flows such as a volcano lava. This is the one of evidence to show that large-scale volcanic activity (such as it made thick lava flows (>125m)) had been continued till the last 1.3Ga.

Another possibility to introduce a preferred orientation in augite might be a shock effect when the Y000593 was ejected from Mars. Pyroxenes are good indicator of shock deformation process, which induces mechanical twins as one of the examples of crystal defects (e.g., [4]). To estimate the effect of impact process, we measured the mechanical twin planes in many augites in the Y000593. We found that most of augites with mechanical twin have been formed on (100) planes. This mechanical twin is known to induce deformation in clinopyroxenes at high strain rates and moderate temperatures (700-900 ºC) [5]. In comparison with the microstructural observations in experimentally shocked clinopyroxene to the results of Y000593, the Y000593 pyroxenes are not strongly shocked. Our result is consistent with a previous study that has demonstrated impact effect using degree of extinction in olivine and pyroxene in Martian meteorite [6].

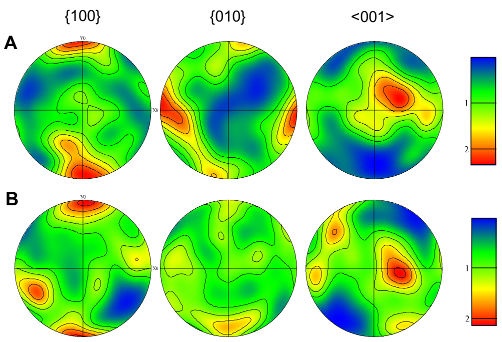

Figure 1. Pole figures of lattice-preferred orientation of augites from Yamato 000593, 63-1 (A) and Yamato 000593, 67-3 (B). Equal-area lower-hemisphere projection was used with half scatter width of 30°. The crystal orientation of ~100 data points were measured. Color coding refers to density of data points (numbers in legend correspond to multiples of uniform distribution). Both sections of Yamato 000593 show {100} and <001> maximum.

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