Analogue experiments for understanding of factors controlling morphological transition in columnar joints

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Columnar joints in lava flows and welded tuffs have two different types of column structures adjacently within a single flow unit in terms of columns widths, column configurations and the directions of developed columns, which are called as Colonnade and Entablature. Colonnade consists of relatively large width, straight and ordered columns, while Entablature consists of relatively small width, curved and disordered columns. Columnar joint are formed due to volume contraction during cooling. The isotherms at a time are assumed to be perpendicular to the direction of columns if the directions of maximum tensile stresses are parallel to the isotherms. The assumption, which is based on thermal diffusion process during cooling, has been applied to the formation of simple cases in the curved structures. However, it still has not clearly solved how the complex structure in Entablature is related to the complex isotherms. In order to understand the formation process of Colonnade structure in columnar joints, analogue experiments using starch and water mixture as analogue materials have been conducted in terms of morphology, theory and crack formation. However, attempts to reproduce morphological transition from Colonnade to Entablature have not been conducted yet. This thesis aims at understanding the factors to control the transition between Colonnade and Entablature by means of drying experiments as well as reproducing curved structures which are seen in Entablature. I investigated the process of crack propagations and the relations between the water distribution and crack developments in mixture by observing X-ray CT images with changing time. Three sets of experiments conducted focus on: (1) Transfer processes in drying and cracking samples, (2) Water concentration and the direction of cracks with time and (3) Effects of sudden increase in desiccation rate on drying and cracking processes. The samples after all experiments are observed by using X-ray CT and compared with the models based a diffusion equation in Experiment 1 and 2. Further morphological analysis is developed for images taken in Experiment 3 for suggesting the possibility of column nucleation in nature. Results suggest: 1. Water transportation within the mixture can be explained by the diffusion process, 2. Crack development occurs perpendicular to the iso-water concentration surface in the mixture and 3. Instantaneous increase in desiccation rate causes columns nucleation.
I propose a scenario of morphological transition from Colonnade to Entablature at Shakushiiwa, which shows a threefold structure (Upper Colonnade –Entablature –Lower Colonnade) within Aso-4 welded tuffs in Oita prefecture, Japan, on the basis of above suggestions by introducing two heat transports: vertical heat transport within rocks by thermal diffusion to the uppermost of the rock, Q_1 and heat transport through the cracks, Q_2. Central Entablature has radial structures by originated from the tips of cracks in Upper Colonnade. These radial structures are horizontally aligned repeatedly. As the cooling process proceeds in Upper Colonnade by thermal diffusion Q_1 from hotter interior of the rock to the cooling surface at the top of the rock, cracks develop perpendicular to the isotherm of T_c, which is the temperature when cracks restart to propagate to form Upper Colonnade. When cracks developed from Upper Colonnade part to the boundary to Entablature, cracks themselves become the cooling surface and the heat transport Q_2 proceeds. This cooling process makes the configuration of the isotherm T_c to be convex downward around the tips of cracks. The heat transport transition from Q_1 to Q_1+Q_2 causes the abrupt increase in cooling rate and form smaller widths of columns than those in Upper Colonnade by column nucleation. Such

morphological change of columns is consistent with the field observation.

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