博士論文の要約

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論文題目：Study on the transition of anisotropy in polygonal crack patterns of paste and its application to Martian terrain

The gully focused on in this thesis is a groove-like feature found on the Martian slope that was most likely formed by flowing water. However, there were various theories of formation, and the debate has not been settled. Therefore, I focused on the shape of thermal contraction polygons seen in gullies and hypothesized that the gully formation process could be restricted. One of the effects that can control the contraction fracture phenomenon, a process similar to thermal contraction fracture, is the memory effect of the paste. This effect is a phenomenon in which the paste remembers the direction in which it is vibrates or flows during horizontal shaking due to plasticity, and cracks tend to propagate in the corresponding direction. When the solid volume fraction is high and the paste vibrates during shaking, cracks perpendicular to the shaking direction propagate (memory of vibration). On the other hand, when the solid volume fraction is low and the paste flows during shaking, cracks parallel to the flow direction propagate (memory of flow). Since this effect can be used to control the shape of crack fragments, I hypothesized that it could be applied to shape interpretation of Martian polygons. However, it was not clear by which parameter the memory effect transition occurs.

First, in order to quantitatively discuss the anisotropy of crack patterns, I devised an image analysis method using Shannon's information entropy. I quantified the randomness of cracks at each angle in a square image and used the fact that the entropy value is smaller when the cracks propagate along a particular direction to determine the anisotropic structure of crack pattern.

Next, experiments were conducted to confirm the relationship between the frequency and amplitude of oscillatory shear strain applied directly to the paste and the desiccation crack pattern in order to clarify the conditions under which the transition between memories of vibration and flow occurs. The jig of a rheometer, which measures the flow behavior of samples, was modified to apply oscillatory shear strain to the paste, which was then dried, and the desiccation crack patterns were observed. Previously, the experimental method has been to place the paste in a container, shaking the entire container horizontally, and then observe the crack pattern after drying. In this thesis, I established, for the first time, a method for conducting experiments by directly controlling the oscillatory shear applied to the paste. The crack patterns imaged were used to quantitatively determine the direction of the crack propagation using Shannon's information entropy. The results revealed that the memory of vibration appears when the amplitude of oscillatory shear strain is small at about 100%, and the memory of flow appears when the amplitude is large, exceeding 300~700%. I also found that frequency and the solid volume fraction of the paste have little effect on this transition. It was also clarified that multiple vibrations are required for the memory of vibration to appear, whereas in the case of memory of flow, no vibrations are required and only a large shear deformation in one direction is needed. Consistent with the already proposed theory of memory of vibration, these results clearly demonstrated the conditions for transition, and it is considered that theoretical studies on the memory of flow and transition will be advanced. The clarification of the conditions for the occurrence of memories of vibration and flow has expanded the possibility of applying the memory effect to other fields, including interpretation of surface terrain of solid planets.

Next, I examined the effect of changing temperature on the memory effect and investigated the relationship with rheology by measurement. This was done because the temperature dependence of the rheology of pastes that are subject to attraction has not been systematically investigated on Mars, despite the fact that temperatures on Mars vary widely. Since it has been reported that clay minerals with an attractive force in water exist on Mars and that an attractive force between particles is necessary for the memory of flow, I target pastes with an attractive force system. Yield stress was derived from measurements by stress control, and viscosity was discussed as a ratio to elasticity by the Small Amplitude Oscillatory Shear (SAOS) measurements. The measurements revealed that the yield stress increased with temperature rise, and the rate of increase was higher than that of repulsive pastes. This is considered to be due to the fact that the attraction between particles becomes stronger as the temperature rise. The memory of the flow is expressed if a large deformation is given, which means that the stress required to give that deformation increases with temperature rise. This may affect the angle of repose for sediment flow on a Martian slope. The suggestion is that temperature could be one of the parameters to consider when discussing Martian terrain through memory effects.

Finally, based on the above results, a comparison was made between the ground-based desiccation fracture experiments and the analysis of Martian images. On planetary surfaces, sediment is not subjected to regular vibrations, and it is unlikely that anisotropy in fracture direction due to memory of vibration would occur. However, memory of flow only needs to be given shear in one direction and is likely to occur on planetary surfaces as well. Therefore, I conducted an experiment to see if the same trend is observed in the desiccation crack pattern formed after the paste flows on the slope. The results of the experiment showed that the memory of flow is also manifested when deformation is applied on the slope. The analysis of Martian images also revealed that it is consistent with the idea that the memory of flow was manifested by sediment flowing down the slope. Assuming that the gully was formed by water flow, the results of the experiments in this study suggest that the sediment was subjected to more than 600%~1400% strain during gully formation.

As a result of this thesis, the conditions for the transition between memories of vibration and flow and the conditions for the occurrence of each have been clarified. This has made it easier to consider the effects of the memory effect in interpretation of surface terrain of solid planets. It is suggested that there is no situation where the memory of vibration appears on Mars, but the memory of flow generated by one-directional shear, such as sediment flow, may appear. It is consistent to assume that the polygons with anisotropic crack direction seen on the gully were formed by flowing sediment and that the anisotropy of the cracks appeared due to the memory effect of the paste after shrinkage fracture.