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火星北極冠にみられるスパイラルトラフの形成機構解明のためのアナログ実験：氷上に形成されるサイクリックステップ
Analog experiments of formation of the spiral troughs on Mars' North Polar Layered Deposits: cyclic steps on ice

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The spiral troughs observed on the Mars' North Polar Layered Deposits (NPLD) show intriguing features that contain a detailed stratigraphic record of surface processes in Mars' recent polar history. SHARAD radar data showed that the troughs have migrated as much as 65 km towards the north during the accumulation of the uppermost ~ 600 m of NPLD (Smith and Holt, 2010). Though they are suspected to have some relation with katabatic wind blowing on the ice cap, it has not been known how the spiral troughs are formed in detail. Considering that the troughs are formed perpendicular to the direction of katabatic wind, they are assumed to be boundary waves rather than streak-like configurations such as rills and gullies. From features that the step length is much larger than the step height, and that internal structures show traces of upstream migration (Smith and Holt, 2010), the spiral troughs may possibly be cyclic steps formed by a density current created by cooling of the atmosphere due to ice. Cyclic steps are spatially periodic bedforms where each wavelength is delineated by an upstream and downstream hydraulic jump. They migrate upstream keeping the same wavelength. Recently cyclic steps have been reported from various environments on the Eargh, such as fluvial and deep-sea settings, and in various bed materials, such as bedrock, non-cohesive sediments, and cohesive sediments (e.g., Kostic et al., 2010). Smith et al (2011) have demonstrated that numerical simulation with a cyclic step model can show reasonable consistency with an observed migration rate. In this study, we have performed a series of physical experiments analogous to the formation of cyclic steps on ice by density currents.

The experiments were conducted using the cold laboratory of the Institute of Low Temperature Science, Hokkaido University. In the case of Mars, sublimation by katabatic winds results in erosion in some places and in the other places, water included in the atmosphere blowing on ice is sublimated to become ice and deposited on the bed covered with ice. In order to model this process, we used two kinds of liquid that include water but do not freeze even below the ice point. The liquids we used were (a) ethylene glycol-water solution (17 %-83 %) whose freezing point is -6.6 degrees C, (b) mixture of silicon oil (20cS) and water (9:1) whose freezing point is -0.7 degrees C. We used a 1.4 m long, 2 cm wide, and 25 cm deep flume made by plexiglass. The flume has 8 cm high weirs at the downstream end and 1.2 m upstream from the downstream end, so that there is an 8 cm deep reservoir. We put water in the reservoir and froze it so that the flume has an 8 cm ice layer on its bottom. The flume with ice bed is tilted by 5 up to 35 degrees. The liquid is supplied from a head tank to the upstream end of the flume, flows on ice in the flume, and was dropped from the downstream end into a downstream reservoir, then pumped up to the head tank. In point of temperature, everything in the room is chilled by the air of the room. The temperatures of the liquids were (a) -6.1 to -6.6 degrees C, and (b) -1.0 to 1.5 degrees C.

As a result, cyclic steps were formed under erosional conditions in series (a) and both erosional and depositional conditions in series (b). The step length is observed to be different in each case. At this moment, steps develop almost vertically, both downward and upward, and show no prominent lateral, neither up-current nor down-current, movements.

In these experiments, we demonstrated that cyclic steps can be formed on rigid ice by the fluid flowing on the ice surface. Further experiments will be needed to examine the conditions for up-current movement of cyclic steps on ice, which should lead us to understand the migration of the spiral troughs on NPLD.

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