Overview of the Special Issue “Martian Surface Processes”

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I. Progresses of Martian exploration and geomorphic research

Earlier Martian explorations by the Mariner and Viking orbiters during the 1960s and 1970s found large-scale landscapes including volcanoes, fault scarps, impact craters, flooded channels, and giant eolian dunes; in addition, their landers acquired onsite images of surface rocks, sediments, and micro-eolian forms (e.g., Baker, 1981; Summerfield, 1991). Most of these forms are considered to be relics that have escaped long-term erosion under hyper-arid conditions. During the 1990s the Mars Global Surveyor provided satellite images at 1-m resolution and 3D topographic data, which enabled identification of small-scale landforms (e.g., Malin et al., 1998; Carr, 2006). These landforms are likely to include products from the recent past resulting from climate change, or even active forms possibly associated with ice or liquid water (e.g., Baker, 2001).

Martian exploration further evolved in the 21st century. In 2004, a long-term mission with two rovers, Opportunity and Spirit, started field surveys of surface geology and acquisition of surface images over wide areas (Squyres et al., 2004a, b). Furthermore, dramatic advances in recognition of detailed landforms at 0.3 m resolution have been achieved with the HiRISE camera mounted on the Mars Reconnaissance Orbiter since 2006 (McEwen et al., 2010). HiRISE images display a variety of landforms commonly found on the Earth. High-function landers have also promoted Martian exploration: the Phoenix lander (landed in 2008) discovered near-surface ice at high latitudes through excavations with a robotic arm (Smith et al., 2009); and the Curiosity rover (landed in 2012) sampled surficial rocks and sediments for mineralogical/petrophysical analyses (Vasavada et al., 2014). In addition, a novel remote sensing technology mounted on new orbiters has also provided data on meteorology, ground temperature and moisture, near-surface structure, and ground material compositions (e.g., Holt et al., 2008; Murchie et al., 2009; McCleese et al., 2010). Lack of vegetation also gives us an advantage in analyzing detailed topography on the Martian surface.

An enormous volume of high-resolution data on the Martian surface acquired during these advanced explorations demonstrate a number of fresh erosional and/or depositional landforms, which may indicate the presence of liquid water or ice, and may be active under current cold-arid environments. In addition, the data also provide information on internal compositions beneath these landscapes and on environmental conditions. Nevertheless, modern geomorphic findings have not yet been systematically described in the Japanese literature.

II. Background of this special issue

This special issue was planned mainly by participants of research meetings during 2011–2013 (representative: Miwa Yokogawa), which were supported by the Institute of Low Temperature Sciences (ILTS), Hokkaido University, and other researchers on the geomorphological processes of the Martian surface. This chapter overviews these research meetings that form the background of this special issue. Detailed programs are shown in reports on the joint research programs of the Institute of Low Temperature Science, Hokkaido
2011 FY (fiscal year): The research meeting was held on November 2–3, 2011 at the Institute of Low Temperature Sciences (ILTS), Hokkaido University. The title of the meeting was “Cyclic steps: analogy between the deep-sea on the Earth and Mars’ North Polar Ice Cap.” The number of participants was 18. Invited speakers, Drs. Isaac B. Smith and John W. Holt, proposed the new hypothesis that spiral troughs on Mars’ North Polar Ice Cap are formed by the katabatic wind blowing down the ice sheet. The following issues were discussed: detailed observation and modeling of Mars’ North Polar Layered Deposits and Spiral Troughs; introduction to experimental and theoretical studies on “cyclic steps” in various environments and substrates; preliminary report on experiments to study cyclic steps on ice; numerical simulation of mega-dunes in the Antarctica; sediment waves in the deep sea; experimental study on the formation of cyclic steps by density flows; reconstruction of Martian atmospheric circulation system based on the eolian dune deposits; comparison between dunes on Mars and those of flume experiments.

2012 FY: July 7–8, 2012, at ILTS, Hokkaido University. The meeting was titled “Formation of landforms and strata on planetary surfaces” and was attended by 19 researchers. This meeting addressed a much wider range of issues and discussed various kinds of topography on Mars and their formative processes in comparison with analogues on the Earth. The following topics were included: analogue experiments and theoretical analyses on ice step formation; numerical simulations of atmospheric characteristics of Mars; modeling of glaciations of Mars; frozen soils and periglacial landforms on Mars and the Earth; rheological properties of Martian debris-flows; numerical simulations of tsunami propagation using boulders on Mars; unique characteristics of cones on Mars; experimental studies on eolian dunes and deltas; and, theoretical analyses on the formation of wavy morphology at the water-ice interface in a brackish lake.

2013 FY: August 24, October 25–26 (joint session with the Impact Research Group), 2013, at ILTS, Hokkaido University. In 2013, we had two research meetings titled “Formation of landforms and strata on planetary surfaces” and attended by 38 researchers. The latter one was held jointed with the Impact Research Group, whose meeting title was “Evolution of Mars.” The issues addressed in the two meetings included: comparison of landforms formed by flooding or crater-like landforms between the Earth and Mars; fluctuations of Greenland Ice Sheet; analogue experiments and theoretical analyses of steps on ice; numerical simulations of ice “bedforms;” observation of ice jam at a frozen river in Hokkaido; analogue experiments and theoretical analyses on the formation of cyclic steps on bedrocks; linear stability analyses of various wavy topographies; analogue experiments on the formation of submarine fans by turbidity currents; and numerical simulations of movements of eolian dunes and sand particles.

The four research meetings gave us opportunities to connect specialists from a variety of fields, and to realize various approaches to the formative process of landforms and strata on planetary surfaces including Mars. The second author of this introduction would like to take this opportunity to acknowledge Profs. Ralf Greve of ILTS and Norihiro Izumi of Faculty of Engineering, and staff of Hokkaido University for their generous cooperation in organizing these research meetings.

III. Contents of this special issue

This special issue collects 11 papers (review and/or original articles) and two pictorials presenting recent research on a variety of Martian geomorphic processes that may be active or may have operated in the recent past (equivalent to the terrestrial Quaternary), with particular focus on water- or ice-related processes. Eolian processes also prevail on the Martian surface, and an example of the experimental approach to simulate a special dune is introduced in a pictorial (Taniguchi, 2016).

1) Part I: Exogenic and endogenic processes

Part I includes two papers on landforms originating from external (meteorite impact) and internal
(volcanic eruption) sources. Suzuki and Kurita (2016) overview the morphology, distribution, and physics of ejecta from impact craters and propose various degradation processes of craters. Noguchi and Kurita (2016) compare and classify Martian cones having pyroclastic, periglacial, erosional, and other origins, highlighting the abundance of rootless cones that may indicate recent volcanism and the presence of groundwater.

2) Part II: Ice-related processes

Part II describes various surface features related to surface or near-surface ice. Recent Martian explorations demonstrate the widespread occurrence of ice-rich ground (permafrost or ice cores) and associated periglacial-like landforms in the middle to high latitudes. Saruya (2016) reviews field evidence of near-surface ice, and laboratory and numerical models of ice-lens formation, concluding that unfrozen water can produce frost heaving in salt-rich regolith at temperatures far below 273 K. Matsuoka (2016) reviews possible periglacial landforms identified on Mars, including polygons, sorted circles, frost mounds, thermokarst depressions, rock glaciers, and linear slope features, and comments on the environments and ages of their formations. In addition to relict forms produced in the past warm period, some polygons and slope features (lineae and lobes) may be active under present surface condition.

Striking features of the Martian polar landscape are ice caps consisting mainly of H$_2$O (partially of CO$_2$) ice. Martian ice caps differ significantly with terrestrial ice sheets, with respect to seasonal changes in the extent and the presence of spiral troughs (Yokokawa et al., 2016). Recent ground-penetrating radars have revealed the internal structure and evolution of spiral troughs. Two papers address the spiral troughs. Yokokawa (2016) reviews recent findings on the morphology, internal structure, and genesis of spiral troughs on the northern polar ice cap, and supports their cyclic-step origin based on an analogue experiment. Izumi (2016) shows the results of a linear stability analysis of the formation of boundary waves on the water-ice interface, assuming that spiral troughs originate from katabatic winds flowing down the ice cap.

3) Part III: Water-related processes

Part III features geomorphic processes associated with liquid water, which attract attention also as a possible indicator of life on Mars. The introductory paper by Dohn and Miyamoto (2016) overviews a collection of water-sculpted Martian landscapes and sediments. Abundant water in the past is indicated by deltas produced by mega-floods and minerals deposited in paleo-oceans or lakes. Evidence for recent aqueous activity on slopes is given by sedimentary sequences, gullies, debris flows, fluvial valleys, alluvial fans, deltas, and glacial and periglacial landscapes; in particular, a combination of multiple indicators enhances the possibility of modern water. Rock breakdown and weathering processes on the Martian surface have been inferred by on-site images and mineral analysis with landers, as well as laboratory simulations. In a review of active rock weathering processes and their products Sato et al. (2016) address both chemical processes that induce oxidation or minor solution of basalt and the resulting formation of weathering rinds, and physical processes such as crystallization of perchlorate salts (and resulting honeycomb structures) and thermal stress triggered by diurnal temperature change; some of these processes require the presence of minimal water.

Distinct gullies carving crater walls and lobes extending downward from the gullies have received most attention since their recognition by Malin and Edgett (2000). Based on this milestone paper and following a large number of papers, Parkner (2016) reviews the major results of gully studies, discussing liquid-induced origins (e.g., overland flow, headward sapping, and debris flow) or liquid-free origins (e.g., dry granular flows and dry-ice outbreak). Naruse (2016) presents the results of a numerical analysis examining the hypothesis of lobe formation by debris flows and proposes a method for estimating debris-flow properties.

Finally, Miyamoto et al. (2016) discuss potential landing sites for exploring life on Mars in view of geomorphology and hydrology. The candidates for future missions include volcanic areas with a
higher probability of releases of volatiles or areas close to recurrence slope lineae with relatively high water activity.

Notes

1) http://www.lowtem.hokudai.ac.jp/kyoudou/report/H23/itiran.html [Cited 2016/01/12].
2) http://www.lowtem.hokudai.ac.jp/kyoudou/report/H24/itiran.html [Cited 2016/01/12].
3) http://www.lowtem.hokudai.ac.jp/kyoudou/report/H24/itiran.html [Cited 2016/01/12].

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