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PERIGLACIAL AND GLACIAL ANALOGS FOR MARTIAN LANDFORMS

NASA GRANT NAGW-0715
PLANETARY GEOLOGY AND GEOPHYSICS PROGRAM

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Principal Investigator: Dr. Lisa A. Rossbacher*
Geological Sciences Department
California State Polytechnic University, Pomona
3801 West Temple Avenue
Pomona, CA 91768
(909) 869-2961

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(renamed to the Cal Poly Pomona Foundation, Inc.)
3801 West Temple Avenue
Pomona, CA 91768-4038

*Current address: Vice President for Academic Affairs/Dean of Faculty and Professor of Geology, Whittier College, Whittier, CA 90608.

FINAL TECHNICAL REPORT
PERIGLACIAL AND GLACIAL ANALOGS FOR MARTIAN LANDFORMS
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LISA A. ROSSBACHER

Research goals

The goals of this project have been to study terrestrial periglacial and glacial features as possible analogs for similar landforms on the surface of Mars. The underlying questions have been: What can landforms tell us about the history, volume, and role of water ice on Mars? What can the study of terrestrial analogs tell us about Martian geomorphology, and how can studies of Martian landforms and geomorphic processes increase our understanding of Earth's geology? The question of the quantity and role of water in Martian history continues to interest planetary scientists (e.g., Squyres and Kastning, 1994) and motivate missions to help answer it (as with Mars Observer and efforts now being planned).

Project history

This work was originally funded under NASA Grant NAGW-517, to Dr. Lisa A. Rossbacher (then at Whittier College), and began October 1, 1983. A Final Technical Report was submitted in 1984 for NAGW-517, covering this first year of funding; support for the project was continued, beginning January 1, 1985, under NASA Grant NAGW-0715. The grantee institution for the continuation of this research was the California State Polytechnic University, Pomona, and the grantee agency was the Cal Poly Pomona Foundation, Inc. The project continued with a series of no-cost extensions through December 1992.

Major topics and results

Catastrophic outflow channels on Earth and Mars

Streamlined erosional remnants on Mars are some of the strongest evidence for quantities of flowing water in Martian history (Mars Channel Working Group, 1983). A frequently cited terrestrial analog for these features is the Channeled Scabland in eastern Washington state, where islands were carved into bedrock or fine-grained material by huge floods associated with the catastrophic outbreak of a glacial lake. The Båldakatj area of Swedish Lapland, located about 45 km south of the Arctic Circle, also has large, streamlined hills that are morphologically similar to the ones on Mars, but these were eroded into a boulder till with large (cobble-to-boulder) grain sizes. This coarse-grained surface material may have a much stronger similarity to the Martian surface materials than the Channeled Scabland (Masursky et al., 1977), and therefore provide a stronger terrestrial analog (Elfström and Rossbacher, 1985; Rossbacher and Rhodes, 1985, 1987). The Båldakatj site provides a range of additional terrestrial features that may have Martian counterparts, including boulder deltas, large boulders (up to 8 m in length) that may have been transported by "ball-bearing" action of rounded cobbles, and meltwater channels between erosional remnants.

Underwater sorted ground in the Moskosel area, Swedish Lapland

One of the benefits of doing field work in a remote area of Swedish Lapland was the opportunity to see unusual and little-known periglacial and glacial features. One of these was a spectacular example of well-sorted patterned ground on the floor of a lake in a remote region of Lapland. Studies by Ray et al. (1983) predicted, but did not test, the sorting depth for patterned ground that formed underwater; preliminary results from field work seemed to support these predictions. This research focused on an effort to apply the understanding of terrestrial sorting to Martian conditions, with an emphasis on establishing the general principles of sorting processes operating at density boundaries and associated with temperature fluctuations across the freeze-thaw boundary. One question to be resolved is whether the formation of sorted ground could occur beneath the Martian regolith - and whether this could help explain the areas with apparently exhumed patterned ground near the Martian north polar cap.

The preliminary results of this work were published in Rossbacher (1985c). Some important questions remain to be investigated in this part of the research; the appropriation of the field notes from this study by a Swedish researcher preclude further progress without revisiting and resurveying the site.

Quantitative analysis of polygonally patterned ground

Most quantitative methods to describe patterned ground concentrate on the number of sides, polygon diameters, and the intersection angles of outlining fractures. The nearest-neighbor technique, commonly used in physical geography, gives a statistical description of the patterns that is independent of polygon size (Clark and Evans, 1954; Vitek, 1973).

The work undertaken in this study correlated the R-statistic (a measure of the degree to which an observation departs from an expected random pattern) with the mechanism of terrestrial pattern formation. Possible values of R range from 0.00 (maximum clustering) through 1.00 (a random pattern) to 2.1492 (a hexagonal lattice). The R-statistic is particularly valuable in comparing patterns and highlighting differences that are not subjectively obvious. The nearest-neighbor technique eliminates the effect of scale, emphasizing the pattern itself.

The R-statistic may be used in discriminating between different mechanisms of pattern formation. Terrestrial patterns that formed by ice-wedging have R-statistics less than 1.35; polygons that formed by ice-wedging have R-statistics between 1.35 and 1.72 (Rossbacher, 1985a). The Martian data show that the polygonal ground generally has a statistically more-regular-than-random pattern (Rossbacher, 1985a, 1986a, 1986b), and the large-scale polygons have a lower R-statistic than small-scale groups. If size reflects the mode of origin, then this approach may help identify different polygon origins. Similar relationships between patterns on Earth and Mars, despite the different absolute sizes of the polygons, suggest an underlying similarity in the factors that control the size, randomness, and origin of the patterns (Rossbacher, 1986a).

Desiccation as a geomorphic process

Although one goal of this project was to understand the role of water and water ice in the history of Mars, the absence or loss of water was also important. Desiccation seems to have played a significant role on Mars, both globally and locally. Desiccation processes have also been important on Earth; desiccation creates small-scale fracture patterns in clayey materials, and climatic drying has produced large-scale fracture patterns (Neal and Motts, 1967; Fife, 1988). Desiccation must be included as a significant process operating in both cold and hot regions that are characterized by current or past aridity (Rossbacher, 1988), and desiccation features have been added to the list of Martian landforms with terrestrial analogs.

The scale of geomorphic features

A theme throughout this research has been to search for explanations of why most Martian landforms are an order of magnitude or more larger than their terrestrial analogs. The study of large-scale landforms on planetary surfaces is developing into its own specialty: megageomorphology.

Initial interpretations of large-scale Martian features suggested that their size might be a function of the photographic scale and quality of the Viking photographs, but this explanation was quickly rejected as higher resolution images became available and the scale differences persisted. The search for a single cause, looking at physical parameters such as gravitational attraction, crustal thickness, atmospheric density, and tectonics, was inconclusive (Rossbacher, 1985b). The more likely explanation is unique to each geomorphic process. So far no unifying cause has been identified to explain the sizes of geomorphic features on Mars relative to Earth.

A technique for establishing relative areas of planetary surfaces is the G-scale (Haggett et al., 1965), which uses a logarithmic relationship to compare the area being studied to the planetary surface area. This provides a way to standardize the sizes of landforms relative to the planet being studied and may facilitate comparisons between landforms and different planets (Rossbacher, 1986c).

The question of size limits for landforms has some interesting philosophical implications, as well as broad potential application to planetary studies, and this work will continue beyond the end of this NASA grant.

Summary of presentations

This NASA-funded research also contributed to an overview of the geomorphic features and processes on Mars. This perspective was shared through a number of media. The results of this work also contributed to the 13 abstracts and 5 refereed papers listed in the attached cumulative bibliography. Research results were presented at the Lunar and Planetary Science Conferences, the Binghamton Geomorphology Symposium, the NASA-International Union of Geological Sciences Conference - Workshop on Global Megageomorphology, and the International Geological Congress in Moscow. A complete list of these publications is attached to this report.

The research results were presented in a number of guest lectures at California State Polytechnic University, Pomona, Whittier College, Pomona College, Dickinson College (PA), University of Southern Colorado, Rio Hondo College, the National Science Teachers Association (both regional and national meetings), Association for Women in Science (Kansas City Chapter), the Montclair (CA) Unified School District, the National Geographical Society of Sweden, the University of Uppsala, and televised courses broadcast from PolyNet (California State Polytechnic University) and TI-IN (San Antonio, Texas).

In addition, elements of this work were included in an overview of Martian geomorphology published in Ymer (the yearbook of the Swedish Geographical Society) (Rhodes and Rossbacher, 1985) and a book titled Recent revolutions in geology (Rossbacher, 1986c), which was named by the National Science Teachers Association and the Children's Book Council as "outstanding trade book for children in 1986."

Summary

The principal contributions of this project include the following:

The list of useful terrestrial analogs for Martian landforms has been expanded to include:

- features developed by desiccation processes;
- catastrophic flood features associated with boulder-sized materials; and
- sorted ground developed at a density boundary.

Quantitative analytical techniques developed for physical geography have been adapted and applied to planetary studies, including:

- quantification of the patterns of polygonally fractured ground to describe pattern randomness independent of pattern size, with possible correlation to the mechanism of origin, and
- quantification of the relative area of a geomorphic feature or region in comparison to planetary scale.

Information about Martian geomorphology studied in this project was presented at professional meetings in the United States, Sweden, and the former Soviet Union, at seven colleges and universities, in two interactive televised courses, and as part of two books.

Overall, this project has expanded the understanding of the range of terrestrial analogs for Martian landforms, including identifying several new analogs. The processes that created these terrestrial features are characterized by both cold temperatures and low humidity, and therefore both freeze-thaw and desiccation processes are important. All these results support the conclusion that water has played a significant role in the geomorphic history of Mars.

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