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Using spatial point patterns to interpret polygonal terrain network assemblages on Earth and Mars: An analogue approach

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Abstract

This research outlines the application of Spatial Point Pattern Analysis (SPPA) to examine variations in polygonal terrain network assemblages on Earth and Mars. Our results show that SPPA successfully differentiates between the geometric patterns observed at various sites on both planets by analyzing the spatial distribution of polygon-bounding trough intersections. Extensive fieldwork in the Canadian High Arctic illustrates that an observed point pattern is related to a given site's: (i) particle size fractions composing the substrate, and; (ii) relative stage of development. Using the field results as an analogical source, we demonstrate that similar geomorphic relationships may be present at a variety of polygonal terrain sites on Mars.

1. Introduction

Polygonal terrain is one of the most common landforms found throughout continuous permafrost environments on both Earth and Mars [1, 2]. These networks of interconnected trough-like depressions in the ground form through an interaction of climatological and rheological processes, resulting in surface patterns comprised of enclosed geometrical shapes of varying dimension and pattern [3, 4]. On both planets, although the morphological similarities amongst sites are often noted, relatively little effort has been devoted towards the development of numerical methods by which to quantify the observed patterns [5]. Here, we present an overview of one such method, Spatial Point Pattern Analysis (SPPA), that can be used to better describe the myriad assemblages presented by polygonal terrain fields and interpret the processes responsible for their formation.

2. Spatial Point Patterns

A complete explanation of SPPA is provided by [6] and a description of its application to polygonal terrain is presented by [7], summarized briefly below. Using SPPA to describe the geometry of an overall network arrangement is based upon examining the spatial distribution of polygon-bounding trough intersections. A *"Regularity Index"* (RI) is determined by calculating how evenly the intersections are dispersed within a site, with values ranging from 0 (completely irregular) to 1 (completely regular). By combining the observed RI with a cumulative distribution of trough segment lengths, a statistical 'fingerprint' can be ascribed that facilitates more objective comparisons with other sites on Earth and Mars.

3. Relating Observed Point Patterns to Site-Scale Substrates

Field studies were conducted on Axel Heiberg Island and Devon Island in the Canadian High Arctic, where seven polygonal terrain sites displaying vastly disparate network arrangements were selected for investigation. A negative relationship between substrate material size and overall network regularity was observed, whereby sites composed of homogeneous fine-grained sediment deposits (e.g. silts and sands) displayed smaller, more regularly distributed polygons than those composed of heterogeneous coarse-grained deposits (e.g. gravels and boulders). Data returned from the Phoenix mission illustrates that a similar relationship may also be evident on Mars, as extremely small and regular polygons in the vicinity of the landing site [8] are shown to be associated with a substrate matrix dominated by fine-grained clay-sized materials [9].

4. Relating Observed Point Patterns to Stage of Development (Age)

At each field site, changes in observed point patterns over time were examined by comparing present-day SPPA results to those derived from historical interpretations. In all cases – regardless of initial geometry or substrate composition – progressive polygon subdivision is accompanied by an increase in RI, indicating that the networks become statistically more regular as they age. By using polygonal RI as a proxy indicator of landscape maturity, we developed a geomorphic reconstruction of ice-rich terrains in Utopia Planitia containing scalloped depressions [10], demonstrating that: (i) the polygonal networks evolve over a continuum of geometrical patterns, and; (ii) the degree to which polygonal networks have evolved is closely related to terrain subsidence.

5. Summary and Conclusions

This work has sought to address the utility of SPPA for describing the diversity of network assemblages displayed by polygonal terrain on Earth and Mars and interpreting the observed point patterns based on terrestrial geomorphic theory. Through field studies in the Canadian High Arctic, we have shown that an increase in the spatial regularity of a given polygonal terrain network is associated with: (i) more homogenous, finer-grained materials within the substrate, and; (ii) advanced stages of development. Extrapolation of the field results (analogical source) to comparable Martian landscape features (analogical target) can provide insight into the geomorphic processes contributing to the formation of a suite of periglacial features found throughout the northern latitudes of Mars.

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