USING SPATIAL POINT PATTERNS TO QUANTIFY POLAR DESERT POLYGONAL GEOMETRY.
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Introduction: Polygonal terrain is one of the most common landscape features found in Earth's Arctic and Antarctic regions and is widely distributed throughout Mars' high latitudes [1]. On Earth, polygonal networks form as a result of thermal contraction cracking, often signifying the presence of underlying water ice deposits in the form of ice wedges [2].

It is possible that polygons on Mars are also indicative of subsurface ice reserves. Like their terrestrial analogues, small-scale Martian polygons: (a) appear to be formed as a result of thermal contraction cracking due to seasonal temperature variations [3]; (b) have geomorphic and latitudinal controls suggesting ice wedge growth [4], and; (c) are spatially coincident with zones of regolith hydrogen enrichment as detected by Odyssey's GRS [5].

Although considerable effort has been directed towards understanding Martian polygonal networks, at present there is currently no method available to quantify potential volumes of ground ice stored in these repositories. Through the Canadian Space Agency's CARN program, we have begun a long-term study aimed at developing a relationship between ice wedge volumes and polygonal surface morphology through geophysical and image analysis techniques. This paper reports on the first stage of the research, which concentrates on the collection and analysis of high-resolution aerial imagery of selected polygon fields in the polar deserts of Axel Heiberg Island, Canadian High Arctic.

Ice Wedge Formation and Polygon Morphology: Seasonal decreases in surface and subsurface temperatures result in an increase in tensile stress that, when exceeding the ground's tensile strength, leads to the development of vertical cracks to relieve the stress. As numerous cracks interconnect, a network of polygons is formed with diameters on the order of tens to hundreds of meters [6]. When temperatures subsequently warm, meltwater infiltrates the cracks and freezed within the underlying permafrost, forming a thin vertical vein of ice termed an *ice wedge*.

When temperatures continue to rise in the spring and summer, thermal expansion of the ground produces movements in the near-surface sediment layer that results in both the upturning of ridges marking the boundary of the wedge and also a depression immediately above the wedge [7]. While individual cracks are only millimeters wide, repeating the process over many years results in the gradual thickening of the wedge as ice continues to accrue and also in an enhancement of the surficial polygonal patterns.

Although ice wedges can form in any type of ice-bonded sediment [8], different substrates display varying rheological properties [9]. Namely, a soil's thermal contraction ratio dictates the ground's physical response to thermal stresses, and thus it will also determine the rate and magnitude of sediment redistribution. Because ice growth is a function of crack size and polygon geometry is a function of sediment movement [7], it is likely that both wedge volume and overlying polygon morphology are dependent on the material in which the wedge is growing.

Comparing Terrestrial and Martian Polygonal Terrain: Although reference to the visual similarities between terrestrial and Martian polygons is often noted [e.g. 1,10], there remain few examples of detailed statistical comparisons of the two.

This may be a result of how polygonal ground is categorized on Earth and Mars. Previous researchers have grouped Martian polygons based on combinations of polygon diameter, geographical location, and proximal landforms [e.g. 1,5; 12]. Terrestrial polygons, meanwhile, are generally classified according to ice growth direction and sequence rather than to surficial geometry [7].

Although some attempts have been made to develop statistical tools by which to describe polygonal geometry [e.g. 12; 13], there remain few mecahnisms by which to quantitatively compare terrestrial and Martian polygons because no common classification scheme exists. Given the uncertainties regarding sediment's relation to polygon morphology and perceived similarities between terrestrial and Martian polygonal terrain, the goals of this work wereto identify characteristics of sediment distribution and relate them to varyiations in polygon morphology.

Field Sites: Three study sites near Expedition Fjord on Axel Heiberg Island, NU, Canada (79 26 N, 90 46 W) were chosen for investigation. Ranging in surface sediment size, source, and distribution, these sites provide extremely diverse polygon morphologies, with mean diameters ranging from 15m to 60m. Sites within extremely close proximity of each other were selected to minimize the effect of surface age [9] and climate [7] on polygonal geometry.

Aerial Photo Acquisition and Processing: Aerial photos were collected to examine the polygonal geometries displayed at each site. Before the photos could be acquired, a series of transects spaced 40m apart were lined with brightly colored ground markers that served as control points (GCPs). Subsequently, a Trimble dGPS was used to survey each marker - along with selected polygon trough intersections - so that the photos could be attributed with spatial data.

Photos were collected from a helicopter using a Nikon D200 digital SLR camera equipped with a 50mm Zoom Nikkor lens. Images taken from an altitude of approximately 300m translate to a footprint size of just over 100m; therefore, transects flown 40m apart allowed for photo overlap of 60% - the common requirement for stereophotogrammetric analysis - at sub-decimeter resolution.

Photo mosaics were produced for the arctic field sites, consisting of 50-75 high-resolution images each (Fig. 1). The geometrical distribution of polygon intersections was examined using spatial point pattern analysis [14]. Spatial coordinates of trough intersections were analyzed to determine if their distribution were random, clustered, or regular, and the degree to which they are so classified.

Summary of Findings: A positive relationship is displayed between surface sediment size and polygon diameter. Site 1, which displays polygon diameters of approximately 30-60m, has individual clasts up to 0.5m in diameter interspersed within a general matrix of coarse gravel and sands. Sites 2 and 3, respectively, have decreasing mean polygon diamteters and grade from mostly gravels (Site 2) to finer sands and silts (Site 3). Spatial point pattern reveals that trough intersection regularity is also a function of surface sediment distribution.

Derived values of spatial distributions from the Axel Heiberg field sites were compared to a subset of MOC images from Utopia Planitia, Mars, and a selection of MRO HiRISE images displaying polygonal geometry. These findings will be discussed.

Using this classification scheme, it may be posssible to infer sub-pixel characterstics of Martian terrain (e.g. sediment-size distribution) based on analysis of polygonal geometry. Given that trough intersection regularity is related to sediment size, and that ice wedge volumes are theorertically related to sediment distribution, it may later be possible to use polygonal geometric patterns to estimate subsurface ice content on both Earth and Mars. Smaller, uniform sediment mixtures should be more strongly cemented than would coarse, heterogeneous mixtures. Therefore, the thermal contraction stress required to overcome the strong cementation should be greater than that required to crack a weakly bound sediment mixture. Because greater stresses require larger cracks to relieve the stress [2], and larger cracks may be associated with enhanced ice accumulation [7], it is expected that ice wedge volumes will be greatest beneath polygonal terrain formed in small, homogeneous sediment mixtures.

Fig.1: *Subset of aerial photo mosaic for polygonal terrain sites (Site 2). Each image is approximately 120m in width.*

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