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Thermal contraction crack polygons on Mars: A synthesis from HiRISE, Phoenix, and terrestrial analog studies

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ABSTRACT

Thermal contraction crack polygons are complex landforms that have begun to be deciphered on Earth and Mars by the combined investigative efforts of geomorphology, environmental monitoring, physical models, paleoclimate reconstruction, and geochemistry. Thermal contraction crack polygons are excellent indicators of the current or past presence of ground ice, ranging in ice content from weakly cemented soils to debris-covered massive ice. Relative to larger topographic features, polygons may form rapidly, and reflect climate conditions at the time of formation—preserving climate information as relict landforms in the geological record. Polygon morphology and internal textural characteristics can be used to distinguish surfaces modified by the seasonal presence of a wet active layer or dry active layer, and to delimit subsurface ice conditions. Analysis of martian polygon morphology and distribution indicates that geologically-recent thermal contraction crack polygons on Mars form predominantly in an ice-rich latitude-dependent mantle, more likely composed of massive ice deposited by precipitation than by cyclical vapor diffusion into regolith. Regional and local heterogeneities in polygon morphology can be used to distinguish variations in ice content, deposition and modification history, and to assess microclimate variation on timescales of ka to Ma. Analyses of martian polygon morphology, guided by investigations of terrestrial analog thermal contraction crack polygons, strongly suggest the importance of excess ice in the formation and development of many martian thermal contraction crack polygons—implying the presence of an ice-rich substrate that was fractured during and subsequent to obliquity-driven depositional periods and continually modified by ongoing vapor equilibration processes.

1. Introduction

Thermal contraction crack polygons are a key element of cold and polar landscapes on Earth and Mars (Figs. 1 and 2). A century of research by polar scientists has demonstrated the importance of polygonally patterned ground—and in particular, of thermal contraction crack polygons—in the interpretation of climate history, glacial and periglacial stratigraphy, polar hydrology, and cold desert ecology (Leffingwell, 1915; Lachenbruch, 1962; Black and Berg, 1963; Péwé, 1963; Washburn, 1973; French, 1976; Marchant et al., 1993, 2002; Sugden et al., 1993, 1995; Marchant and Denton, 1996; Murton, 1996; Yershov, 1998; Virginia and Wall, 1999; Bockheim, 2002; Doran et al., 2002; French, 2003; Fortier et al., 2007; Kowalewski et al., 2006; Kowalewski and Marchant, 2007; Marchant and Head, 2007; Murton and Bateman, 2007; Levy et al., 2008a; Kowalewski, 2009). Theoretical considerations of martian permafrost (Wade and De Wys, 1968; Mellon, 1997; Mellon et al., 2009), coupled with combined exploration of polygonally-patterned terrain by landers and orbiters has revealed Mars to be a permafrost-dominated planet with a rich surface history of thermal contraction cracking (Mutch et al., 1976, 1977; Malin and Edgett, 2001; Seibert and Kargel, 2001; Kuzmin and Zabalueva, 2003; Milliken et al., 2003; Mangold, 2005; Kostama et al., 2006; Smith et al., 2008, 2009; Levy et al., 2009c).

Several critical questions remain outstanding regarding the use of martian polygons as a paleo-climate indicator. (1) What has increasing image resolution revealed about the morphology of martian thermal contraction crack polygons and what does this indicate about polygon-formation conditions? (2) What is the distribution of martian polygons—are they present in random patches, or do zonal climate conditions affect their distribution? (3) What do polygons indicate about the origin, composition and ice content of the martian permafrost: is it dominated by snow and ice deposition producing massive ice or by cyclical vapor diffusion into regolith producing pore ice? (4) What does polygon morphology indicate about the presence, absence, and role of liquid water in recent martian permafrost terrain evolution? (5) What are the rates and duration of climate conditions permitting thermal contraction

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