prediction of ice table depths at polygonally patterned sites (Sizemore and Mellon, 2006; Bandfield, 2007; Mitrofanov et al., 2007a; Mellon et al., 2008a).

Perhaps the most striking result to arise from MGS/MO/MEx observations of martian permafrost terrain was the observation that ice-related landforms on the martian surface (e.g., polygons, scalloped depressions, pits) are not randomly distributed, but rather are found concentrated in latitude-dependent deposits (Kreslavsky and Head, 2000; Mustard et al., 2001; Head et al., 2003; Milliken et al., 2003; Kostama et al., 2006; Soare et al., 2007). Polygonally-patterned surfaces on Mars are typically geologically recent units (less than several Ma) that drape underlying terrain, smoothing topography, and typically span continuously from high latitudes equatorwards to ~60°, growing patchier and more dissected from ~60° to ~30°, equatorwards of which they vanish (Kreslavsky and Head, 1999, 2000, 2002; Mustard et al., 2001; Head et al., 2003; Milliken et al., 2003; Mangold, 2005; Kostama et al., 2006; Levy et al., 2009c). These collected observations have been interpreted to indicate the presence of a martian latitude-dependent mantle (LDM) (Kreslavsky and Head, 2000; Mustard et al., 2001; Head et al., 2003).

The unprecedented increase in the coverage and resolution of spacecraft image and topographic data provided by MGS/MO/MEx led to multiple opportunities to test hypotheses regarding the physical state of martian polygonally-patterned permafrost, addressing critical questions regarding the role of a martian active layer (the portion of permafrost that is seasonally warmer than 0 °C). Although observations of degraded martian craters and slopes strongly suggest the presence of a martian active layer during obliquity highs more than 5–10 Ma before the present (Kreslavsky et al., 2008), climate and surface temperature balance models (Ingersoll, 1970; Haberle et al., 2001; Forget et al., 2007) indicate currently frigid global conditions (Kreslavsky et al., 2008) and appear at odds with reports of recent (<~2 Ma) active layer or thermokarst processes in LDM-related terrains (e.g., Page, 2006). Isolating the evidence for or against active layer processes in the polygonally-patterned portions of the martian LDM is critical for determining the role of liquid water in geologically recent surface processes.

Combined analysis of polygon morphology (Mangold, 2005; Levy et al., 2009c), water-equivalent-hydrogen (Boynton et al., 2002; Feldman et al., 2002; Kuzmin et al., 2004; Mitrofanov et al., 2007a,b), surface thermal response (Bandfield, 2007; Bandfield and Feldman, 2008; Feldman et al., 2008), and Phoenix lander soil data (Smith et al., 2008, 2009) all strongly indicate the presence of ice in the martian latitude-dependent mantle (LDM). But what is the origin of the martian LDM and how did it become so ice-rich? Morphological and stratigraphic evidence strongly indicates that the LDM formed through the atmospheric deposition of dusty ice during recent "ice age" periods of high obliquity, producing beds of potentially massive, dirty ice (Mustard et al., 2001; Head et al., 2003; Laskar et al., 2004; Schon et al., 2009b) that have subsequently partially sublimated to produce protective lag deposits (Head et al., 2003; Schorghofer and Aharonson, 2005; Schorghofer, 2007). In contrast, ongoing modeling of average-climate-driven martian water/ice stability indicates that global water ice deposits observed by MGS/MO are broadly (although not entirely) in diffusive equilibrium with the martian atmosphere, raising the possibility that martian permafrost is dominated by diffusively emplaced pore ice (Jakosky and Carr, 1985; Mellon and Jakosky, 1995; Mellon et al., 2004; Hudson et al., 2009a; Mellon et al., 2009), or possibly near-surface shells of diffusively-emplaced excess ice (ice volume exceeding dry pore space) (Fisher, 2005). Distinguishing between these two end-member ice-depositional modes (primary precipitation versus diffusive emplacement) is critical for understanding the magnitude and significance of martian ice-rich, polygonally-patterned terrains.

4. New observations and results from MRO/HiRISE

The High Resolution Imaging Science Experiment (HiRISE) has provided enhanced viewing of martian polygonally patterned ground at a spatial resolution up to an order of magnitude greater than that of previous instruments (McEwen et al., 2007a,b), permitting viewing of polygonally patterned ground with a clarity previously found only in lander-based image data (Mutch et al., 1976; Smith et al., 2008, 2009). Meter-scale resolution data provide links among local sites observed around landers to broader-scale martian environments, and permit unprecedented comparison of martian terrain with terrestrial analog field observations. HiRISE image analyses have addressed several of the most pressing questions raised by previous studies of martian polygonally patterned ground. Here we address advances in the current understanding of small-scale (<~25 m) martian thermal contraction crack polygon morphology, the nature of the ice component in martian permafrost, the role of water in martian polygon development, the age and distribution of polygonally-patterned surfaces on Mars, and insights derived from analysis of interactions between polygons and other ice-related martian landforms.

4.1. Polygon morphology

The high spatial resolution of HiRISE image data (25 cm/pixel) (McEwen et al., 2007a) has greatly increased the detail discernable in images of martian thermal contraction crack polygons (Fig. 1). Not all polygons observed in HiRISE images have been interpreted to form from the thermal contraction of ice-rich permafrost. For example, Page (2006) interprets Marte Valles patterns to indicate sorted polygon formation, while Osterloo et al. (2007) interpret chloride-related fractures as desiccation cracks. All the features subsequently identified as martian thermal contraction crack polygons in this paper meet the criteria outlined by Levy et al. (2009c) for distinguishing thermal contraction crack polygons from other natural network features (such as desiccation cracks, lava-related cooling cracks, or bedrock jointing) (see also Fig. 7).

A variety of morphological components of thermal contraction crack polygons, including surficial troughs, mounded centers, and raised shoulders (where present), are discernable in HiRISE images (Figs. 1 and 5), permitting detailed analysis of polygon characteristics (McEwen et al., 2007b; Mellon et al., 2007; Levy et al., 2008c, 2009b,c; Mellon et al., 2009). Polygonally patterned ground featured in HiRISE data is more clearly resolved than in MOC data, permitting the identification of a range of small-scale thermal contraction crack features <~25 m in diameter. For example, polygons typical of northern polar regions near the Phoenix lander average ~3–6 m in diameter as measured by GIS (Levy et al., 2009c; Mellon et al., 2009) and automated methods (Pina et al., 2009). These features are very similar in size to terrestrial thermal contraction crack polygons (Lachenbruch, 1961; Marchant et al., 2002; Marchant and Head, 2007), and represent the smaller end of the range of polygon diameters observed at MOC resolution (e.g., Mangold (2005) reports a size range for "small" polygons of 10–50 m). Martian polygon troughs have been shown through HiRISE stereo image analysis (and confirmed by Phoenix lander data) to be typically less than several tens of cm deep (Arvidson et al., 2008; Smith et al., 2008, 2009).

Beyond yielding single morphometric properties such as size, low sun-angle HiRISE image data have revealed the complex three-dimensional morphology of martian polygons in exquisite detail (McEwen et al., 2007a), comparable to air photographs used to map terrestrial polygons (Black, 1952). Across the latitude-dependent mantle (Head et al., 2003), martian thermal contraction crack polygons are overwhelmingly high-centered (Fig. 1) (Levy