2.6. Applying terrestrial polygon knowledge to Mars

Before proceeding further with discussion of martian thermal contraction crack polygons, it is important to take full stock of the limitations inherent in applying terrestrial analog analyses to features observed on Mars (e.g., Marchant and Head, 2007); by fully understanding the differences between terrestrial analogs and planetary subjects, we gain a greater appreciation of many similarities between the two (Fig. 3). Field access to terrestrial Arctic and Antarctic thermal contraction crack polygons provides considerable accumulated experience with, and insight into, polygon surface morphology, subsurface structure, and development over time. In contrast, analysis of martian polygonally patterned ground is limited to remote observations (Mangold et al., 2004; Mangold, 2005; Levy et al., 2009c) and to a small number of widely spaced surface experiments with capabilities to trench and explore the upper ~20 cm of dessicated surface soils, but with limited ability to vigorously excavate through entire polygon structures (Mutch et al., 1976, 1977; Smith et al., 2008, 2009).

Extrapolating from terrestrial examples to martian conditions comes with the inherent risks associated with applying insights from familiar environments into alien conditions. This challenge is compounded by the possibility of observing preserved relict landforms on the martian surface that formed under conditions different from those currently prevailing (e.g., Marchant and Head, 2007). Even under current conditions, the precise role of seasonal CO_2 frost deposition (e.g., Smith et al., 1998) in polygon-related processes is only beginning to be understood, and may have profound effects on soil microphysics (compaction or agitation of clasts), water vapor diffusion (limiting fluxes in or out of soils), and seasonal thermal response (insulating surfaces until CO_2 frost is removed).

Beyond exploration constraints, the differences in the physical environment between terrestrial and martian thermal contraction crack terrains necessitates careful application of models—particularly models containing any empirically-derived constants that may be applicable under terrestrial polar conditions (e.g., Hobbs, 1974) but which lose accuracy under the extreme cold and low pressures of martian circumpolar terrains. For example, Mellon (1997) is judiciously conservative in extrapolating from terrestrial to martian conditions, taking account of factors requiring extrapolation, such as lower mean annual temperatures on Mars leading to more brittle permafrost (less thermally-activated viscous relaxation) that generates higher thermal contraction stress per Kelvin cooling than would be expected on Earth. Likewise, recent improvements to vapor diffusion modeling have expanded the treatment of the effects of Knudsen diffusion of water vapor through martian till, which is critical for constraining rates of sublimation of water ice present beneath martian regolith—effects that are more important in martian permafrost modeling than on Earth (where Fickian diffusion dominates, e.g., Kowalewski et al., 2006; Kowalewski and Marchant, 2007; Kowalewski, 2009) due to low martian atmospheric pressure (Helbert et al., 2009; Ulrich, 2009). Additionally, detailed physical treatment of the mechanical properties of a range of martian polygon-forming substrates is only just beginning to expand from models of regolith cemented with pore ice (Mellon et al., 2009) into understanding of the interactions between pore-ice-cemented sediments, potential massive ice deposits, etc. (e.g., Head et al., 2003; Schorghofer, 2007). Even when modeling and observational work are done with the utmost care, terrestrial field experience cautions that microclimatic and even meter-scale heterogeneities in permafrost ice content, soil composition and origin, ice distribution, proximity to related landforms (e.g., streams, lakes), and age can have pronounced effects on polygon morphology and development (Bockheim, 2002; Marchant et al., 2002; Bockheim et al., 2007; Gooseff et al., 2007; Marchant and Head, 2007; Levy et al., 2008a). Many of these properties are not easily detected in orbital observations, underlining the importance of correlating observations of polygonally patterned ground on Mars between multiple high-resolution datasets.

An alternative approach to investigating landform processes occurring under current Mars conditions (e.g., exceptionally low mean annual temperature and low atmospheric water vapor pressure) is to use observed landforms to drive interpretations of past climate conditions (e.g., Seibert and Kargel, 2001; Page, 2006; Soare et al., 2008). This relict morphology approach is particularly effective when combined with detailed analyses of martian orbital-element-driven climate history (e.g., Laskar et al., 2002; Forget et al., 2006) and can be used to infer the past occurrence of surface conditions different from the present over 10–20 Ma timescales, such as active layer processes (Kreslavsky et al., 2008).

3. A brief summary of patterned ground on Mars

Exploration of martian permafrost, and martian polygonally patterned ground in particular, has occurred at an ever-accelerating rate as spacecraft observations have improved the resolution, coverage, and variety of observations of the frozen martian surface. Beginning with early theoretical, telescopic, and terrestrial analog investigations (e.g., Lowell, 1907; Wade and De Wys, 1968; Ingersoll, 1970; Anderson et al., 1972; Morris et al., 1972), research has focused on assessing the age, origin, distribution, and ice-content of martian permafrost— in order to assess its geological, hydrological, and biological implications (Lederberg and Sagan, 1962; Gilichinsky et al., 1992, 2007; Mellon, 1997; Feldman et al., 2002; Dickinson and Rosen, 2003; Mitrofanov et al., 2007a,b; Kreslavsky et al., 2008; Levy et al., 2009c, 2009d; Marchant and Head, 2010).

Early results, driven largely by the Viking landers and orbiters, established the presence of a range of permafrost and polygonally-patterned landforms on Mars, including potential frost cracks, ground ice, sorted sediments, gelifluction lobes, and glacial features (Mutch et al., 1976, 1977; Squyres, 1978, 1979; Lucchitta, 1981; Squyres and Carr, 1986). Large-scale fracture patterns, such as those observed in Utopia Planitia, hinted at the possibility of widespread thermal contraction crack activity on the martian surface, however, some large-scale (hundreds of meter) fracture features have been shown to not be ice-related (Hiesinger and Head, 2000; Lane and Christensen, 2000), while others remain as candidate frost features (Abramenko and Kuzmin, 2004).

The arrival of the Mars Global Surveyor (MGS) (1997–2006), Mars Odyssey (MO) (2001-present), and Mars Express (MEx) (2003-present) spacecraft in martian orbit initiated a revitalized age of exploration of martian permafrost. High resolution image data from the Mars Orbiter Camera (MOC) (Malin and Edgett, 2001) produced unprecedented views of martian polygonally patterned ground (Malin and Edgett, 2001; Seibert and Kargel, 2001; Milliken et al., 2003; Mangold, 2005; Kostama et al., 2006), supported by a range of topographic (Zuber et al., 1998; Jaumann et al., 2007) and geophysical datasets such as neutron spectrometer/gamma-ray spectrometer water-equivalent hydrogen measurements (Boynton et al., 2002; Feldman et al., 2002; Kuzmin et al., 2004; Mitrofanov et al., 2007a,b) that directly implicated the presence of water ice in the upper meter of martian polygonally-patterned surfaces (Mangold et al., 2004). Global-scale water–ice distribution has been refined using thermal inertia and surface temperature data (Bandfield, 2007; Bandfield and Feldman, 2008; Feldman et al., 2008), broadly confirming the detection of near-surface water ice (ice-rich permafrost) and permitting the accurate