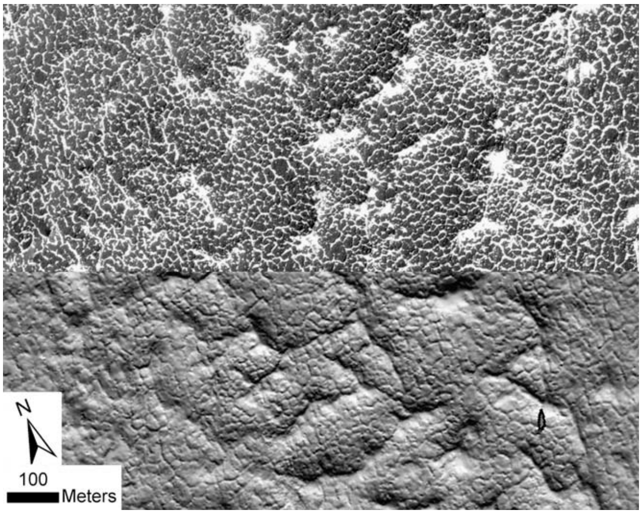

Fig. 10. Sublimation polygons and "megagons" (larger, ~100 m, topographically high mounds covered in sublimation polygons) in Beacon Valley, Antarctica (Marchant et al., 2002). Image top: air photograph of polygons and megagons. Image bottom: LIDAR digital elevation model hillshade (illumination from image top) of adjacent groups of polygons and megagons. Antarctic air photographs and LiDAR topography data kindly made possible in part through a joint effort from the NSF and the USGS.

morphic processes. Likewise, raised shoulders on some mixed-center polygons have been accounted for by a two-stage sublimation process occurring in very ice-rich LDM deposits. In this two-stage process, sublimation is initially focused at thermal contraction cracks (Marchant et al., 2002; Kowalewski and Marchant, 2007; Kowalewski, 2009), but shifts to polygon interiors as dry (desiccated and/or windblown) sediment accumulates at the polygon trough, sealing off underlying ice and building sediment-rich wedges that remain topographically high relative to the collapsed polygon centers (Levy et al., 2009b). Thus, rather than indicating recent, wet active layer or thermokarst modification (surface depression caused by melting of ground ice, Washburn, 1973) of the latitude-dependent mantle, these mixed-center polygon surfaces form in extremely dry conditions (no melting) and also strongly indicate the presence of abundant excess ice in LDM deposits (interpreted to originate from a primary precipitation source, e.g., Head et al., 2003). This ground ice is of sufficient purity to leave depressions tens of meters deep in locations experiencing locally intense sublimation.

Another polygonally patterned feature present on the martian surface that may provide information about ice concentration in the cracking LDM medium is "basketball terrain" rubble piles (Kreslavsky and Head, 2000; Malin and Edgett, 2001; Levy et al., 2008b, 2009c; Mellon et al., 2009). Basketball terrain rubble piles are accumulations of <~1 m boulders, locally concentrated in piles ~3–5 m in diameter, that are commonly perched atop topographically high mounds surfaced by smaller-scale thermal contraction crack polygons (Levy et al., 2008c, 2009c; Mellon et al., 2009). Rubble piles are typically spaced 20–30 m apart, in staggered or linear patterns, and are connected by sparse strings of boulders in some locations (Levy et al., 2008c, 2009c; Mellon et al., 2009). Levy et al. (2008b) proposed that many of the observed boulders may have been excavated by impacts (e.g., Heimdall crater near the Phoenix landing site, Arvidson et al., 2008) from the Hesperian ridged plains surfaces interpreted to underlie the LDM surfaces and the Vastitas Borealis Formation (Fig. 11) (Head et al., 2002; Kreslavsky and Head, 2002); however, the possibility remains that some boulders were also brought to the surface by geographically-limited and ancient (>5–10 Ma old) active layer processes (particularly on steep slopes) described by Kreslavsky et al. (2008). Levy et al. (2008b) and Mellon et al. (2008b) have proposed that the arrangement of boulder piles is consistent with a previously extant network of larger (~30 m diameter) thermal contraction crack polygons. Mellon et al. (2008b) suggest several mechanisms that could concentrate boulders in paleo-polygon troughs, ranging from gravitational or aeolian sorting and slumping (e.g., Rosato et al., 1987), to surface creep, to a complex (water-free) dry cryoturbation process cycling boulders through troughs to polygon interiors (see Section 2.4 for a discussion of closed-cell cryoturbation).

In the Antarctic Dry Valleys, boulders commonly accumulate in sublimation polygon troughs due to gravitational sliding, rolling and slumping due to over-steepening of polygon troughs by enhanced sublimation of buried ice along polygon margins (Marchant et al., 2002; Kowalewski and Marchant, 2007; Kowalewski, 2009). Polygon troughs are typically at their steepest and deepest at junctions between troughs, and accordingly, act as loci of boulder accumulation, concentrating slumped cobbles and boulders from the corners of several polygons (Levy et al., 2006). Boulders accumulated in old polygon troughs and at polygon junctions would overlie and armor finer, winnowed sediments (Marchant et al., 2002), eventually burying ice deeper, and thereby protecting it from enhanced sublimation. If ice removal continued from the centers of these large polygons, topographic inversion similar to that described above (for mixed-center polygons) could occur, resulting in accumulations (at former polygon junctions) of boulders on topographically high piles of sediment overlying protected ice, linked by chains of boulders localized to former polygon troughs. This potential sequence of events is illustrated schematically in Fig. 12.

Mellon et al. (2008b) propose aeolian deflation of sediments that have lost cementing pore ice, concentrated between rubble piles, as a mechanism for raising rubble pile mounds relative to surrounding terrain. In contrast, we point out that any inversion process responsible for removing polygons large enough to shed boulders by gravitational slumping would require the removal of several meters of excess subsurface material from beneath the polygon interiors, without producing noticeable drifts of sedimentary material. Accordingly, we interpret this hypothetical series of events to imply the vertical removal of several meters of excess ice from the ancient polygonally-patterned substrate by sublimation. If this older polygonal surface is comparable to the current polygonally-patterned LDM, significant volumes of excess ice are strongly implied, distributed uniformly throughout the medium (e.g., not in a "cryo-shell" as described by Fisher, 2005). This process strongly favors precipitated ice deposits for constituting LDM surfaces (Head et al., 2003), rather than vapor-diffusion-emplaced ice (Mellon et al., 2008a,b), and is consistent with the infilling of "boulder halo" craters (Fig. 11) with LDM material. Accordingly, the presence of "rubbles piles" on Mars suggests that similar sublimation polygon-like processes (e.g., gravitational sorting of clasts into polygon troughs and fractures) may have occurred in the recent geological past. Polygons resulting in "rubble pile" formation may be strongly analogous to terrestrial sublimation polygons, in which minor changes in sediment sorting within and above the polygon wedge drive enhanced sublimation along polygon troughs; alternatively, high-centered polygons for which minimal sediment transport is observed may represent enhanced sublimation along polygon fractures due to increased ice surface area contact with the martian atmosphere (e.g., Marchant et al., 2002; Kowalewski and Marchant, 2007; Kowalewski et al., 2006).

Is there other morphological evidence for high ice content of the polygonalized portion of the latitude-dependent mantle? At both high (~68°N) and middle (~45°N) latitude locations, terrace- or step-like layering in LDM deposits is visible (Fig. 13) (Arvidson