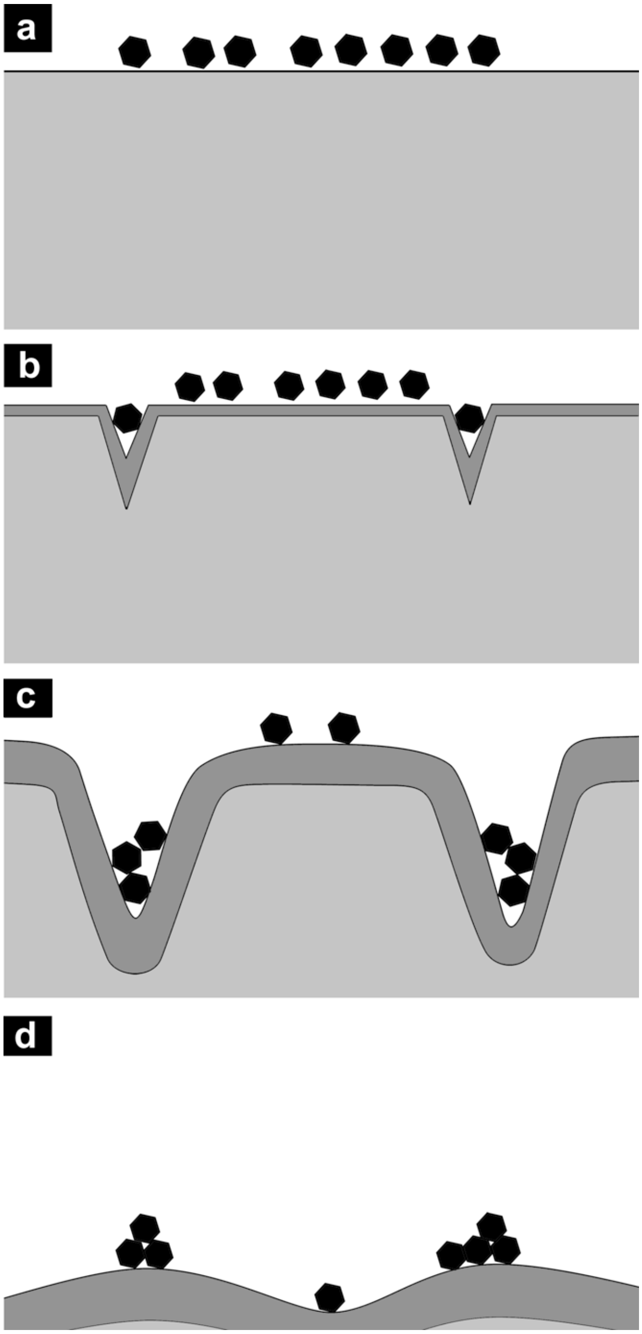

Fig. 12. Schematic illustration of possible boulder positioning sequence on LDM surfaces to create rubble piles. (a) Boulders (dark hexagons) are emplaced on the ice-rich LDM (light gray) by impact excavation of rocky basement. (b) Thermal contraction cracks open in the LDM and are widened by enhanced sublimation along fractures. A sublimation lag deposit (dark gray) begins to develop. Boulders present over growing troughs may be caught in the troughs, although they may be too large to be winnowed into underlying wedge material. (c) Larger, more steeply dipping troughs develop as enhanced sublimation at polygon fractures removes ice from polygon margins, causing more boulders to slump into troughs (particularly concentrated at junctions between troughs). (d) Continuing removal of subsurface ice by sublimation lowers the LDM surface, however, concentrations of wedge sediments and slumped boulders along former troughs protects underlying ice-rich mantle, resulting in preservation of high topography along former troughs (now rubble-pile-surfaced, polygonally-patterned mounds).

ratio at 80% ice to 20% lithic fines by volume. This implies ice volume exceeding pore space (McKay et al., 1998; Fisher, 2005; Sizemore and Mellon, 2006, 2008), and is sufficient to produce sublimation subsidence of polygonally-patterned features. This yields a global permafrost ice reservoir of ~3.9×10^5 km^3, comparable to ice volume estimates of the martian LDM made by Head et al. (2003). Taking a 90% volumetric conversion from ice to liquid water yields a globally averaged water layer of ~2.5 m deep for the martian LDM ice reservoir. This estimate is most strongly sensitive to the spatial extent of polygonally patterned, ice-rich mantle material, which is well-constrained by global thermal contraction crack polygon surveys (e.g., Mangold, 2005; Levy et al., 2009d), rather than to the precise ice/lithic mixing ratio. For comparison to other ice reservoirs, the ice volumes of the north and south polar caps are 2–3 $\times 10^6$ km^3 and 1.2–1.7 $\times 10^6$ km^3, respectively (Smith et al., 1998; Zuber et al., 1998), yielding a globally averaged water depth of ~30 m. Compared to known global ice reservoirs, the volume of ice required to produce polygonally-patterned LDM deposits with a mixing ratio approaching 100% ice (e.g., 98% pure water ice observed at Phoenix, Smith et al., 2008, 2009) is quite small, and is consistent with the mid-latitude deposition of destabilized polar ice during periods of high obliquity, formation of protective sublimation tills as surface soils desiccated and ice returned polewards (Head et al., 2003), and subsequent modification of the remaining ice-rich LDM into its present, polygonally patterned state (Head et al., 2003; Schorghofer, 2007).

4.3. The role of liquid water

Liquid water has clearly played a role in the physical and chemical development of the martian surface, particularly in its early history (Squyres, 1989; Baker et al., 1991; Carr, 1996; Baker, 2001; Bibring et al., 2006). But how recently has liquid water interacted with polygonally-patterned surfaces on Mars, in what volumes, over how extended an area, and with what observable results? The presence of geologically recent gully–polygon systems on Mars (Head et al., 2008; Levy et al., 2008a, 2009d) suggests that very locally derived liquid water may have interacted with polygonally patterned ground ("gullygons") as recently as ~1–2 Ma, the age of the youngest dated gullies on Mars (Riess et al., 2004; Schon et al., 2009a). In these gully–polygon systems, polygonally patterned ground pre-dates the presence of gullies, appears to have modified gully formation, and has subsequently disrupted gully fan deposits through ongoing thermal contraction cracking (Levy et al., 2008a, 2009d). In gully–polygon systems, channel-like features are observed that are (1) continuous and sub-linear; (2) present in widened, curved, and down-slope-oriented polygon troughs; and (3) present in proximity to larger, traditional gully channels. Such "annexed channels" are interpreted to be remnants of polygons troughs through which liquid water flowed (Marchant and Head, 2007; Levy et al., 2009d). The propagation of fractures upward through younger fan deposits emplaced on top of these polygons suggests that some gullygons may have actively undergone seasonal thermal contraction and wedge growth during periods of active gully flow, channel erosion, and fan deposition (Levy et al., 2009d). The reemergence of polygons through some gully fans suggests that periods of gully activity were microclimatically warm enough to permit localized water ice melting in gully alcoves and surface flow through gully channels, but not so warm as to produce widespread saturated active layer activity (Kreslavsky et al., 2008), or complete destruction of previously emplaced polygons. On the basis of these observations, polygons present in martian gully–polygon systems have been interpreted to be analogous to composite-wedge polygons (Fig. 2) present in the relatively clement inland mixed zone of the Antarctic Dry Valleys (Marchant and Head, 2007; Levy et al., 2009c,d). Composite-wedge polygons are characterized by localized, peak-seasonal contact between meltwater and the ice table of the polygonally patterned surface. However, in the martian case, rapid sublimation of frozen meltwa-