Lachenbruch, 1961; Maloof et al., 2002; Marchant et al., 2002; Kowalewski et al., 2006; Kowalewski and Marchant, 2007; Marchant and Head, 2007; Swanger and Marchant, 2007; Kowalewski, 2009) (Fig. 2). In relatively warm and wet climates, in which a typical, water-saturated active layer is seasonally present, ice-wedge polygons commonly develop as summertime meltwater seeps into seasonally open thermal contraction fractures and freezes (Berg and Black, 1966; Washburn, 1973). In cold and dry climates, in which soil conditions are too arid to develop traditional wet active layers (Bockheim et al., 2007), sand-wedge polygons may form as sand winnows into thermal contraction cracks (Péwé, 1959; Berg and Black, 1966). Composite-wedge polygons form in regions supporting a dry active-layer that receives localized additions of moisture (e.g., from gully-related flow, snowbanks, etc., Murton, 1996; Ghysels and Heyse, 2006; Levy et al., 2008a) and are characterized by subsurface wedges composed of alternating bands of sediment and ice or of ice-cemented sediment (Berg and Black, 1966). Sublimation polygons (Marchant et al., 2002) are a special type of sand-wedge polygon that form where excess ice (ice exceeding available pore space) occurs in the shallow subsurface and is preferentially removed along contraction cracks via sublimation to accommodate growing wedges of ice-free, fine-grained, and winnowed sediment (Marchant et al., 2002; Kowalewski et al., 2006; Levy et al., 2006; Kowalewski and Marchant, 2007; Marchant and Head, 2007; Kowalewski et al., 2008). This physical (climate) control of polygon morphology makes polygons useful indicators of current climate processes in varied polar terrains on Earth, as markers for paleoclimate reconstruction, and as analogs for polygonally-patterned landforms observed on Mars (Fig. 3) (Black, 1976; Gibson, 1980; Marchant and Head, 2007).

2.3. Thermal contraction crack polygon morphology

Each of the types of thermal contraction crack polygon outlined above has distinct morphological characteristics that can be identified during surficial or aerial observations, supported terrestrially by observations of polygon wedge morphology in excavated cross-sections (Figs. 2 and 5) (e.g., Black, 1952; Pewe et al., 1959; Berg and Black, 1966; Marchant et al., 2002; Marchant and Head, 2007). Ice-wedge, sand-wedge, composite-wedge, and sublimation polygons are all classified as "non-sorted polygons" (Washburn, 1973), meaning that wedge-filling material, wedge structure, and polygon micro-topography are more diagnostic of polygon-forming mechanical processes than of a re-distribution of grain sizes (from sand to boulders) by freeze–thaw cycling. Some sediment sorting may occur in ice-wedge and composite-wedge polygons (Péwé, 1959; Berg and Black, 1966; MacKay, 2000; Levy et al., 2008a), and boulders and cobbles may slump from polygon margins and collect in troughs associated with sand-wedge and sublimation polygons (Marchant et al., 2002) (see Section 2.4 for a more complete discussion of cryoturbation and resurfacing).

Ice-wedge polygons (Fig. 2) have a range of surface expressions that are tied intimately to the activity of the wedge, the thermal state of the host permafrost, and in arctic environments, the extent and variety of vegetation growing at the ground surface (MacKay, 2000). Incipient ice-wedges are commonly delineated by a network of fine surface fissures ("frost cracks") (Lachenbruch, 1962; MacKay, 2000). Active ice-wedge polygons are commonly outlined by troughs flanked by raised rims resulting from the lateral and upward displacement of soil or sediment by the growing ice wedge (Berg and Black, 1966; Black, 1982; Yershov, 1998), and are described as "low-centered" polygons accordingly (MacKay, 2000). Because ice-wedge polygons form towards the warmer limit of polygon-forming environments (Gold and Lachenbruch, 1973; Washburn, 1973; Yershov, 1998; Marchant and Head, 2007), the formation of thermokarst (surfaces

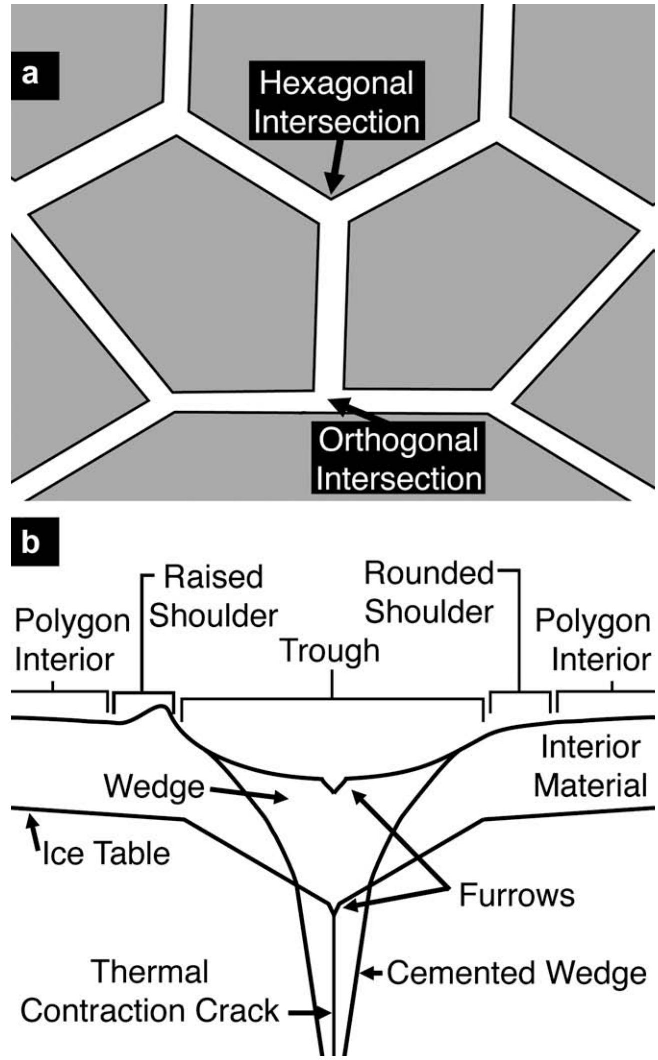

Fig. 5. Schematic illustration of polygon morphological components. (a) Map-view of polygon trough intersection angles. (b) Cross-sectional view of polygon morphological elements.

modified by the melting of ice-rich permafrost) can alter the appearance of degrading ice-wedge polygons, forming unstable, high-centered polygons as wedge ice melts and drains into local streams and ponds, or dramatically walled polygons (e.g., "fortress polygons," Root, 1975) in response to melting and drainage of excess ice in polygon interiors (MacKay, 2000). High-centered, decaying ice-wedge polygons can form in shaley soils in the arctic, where fluvial drainage removes poorly consolidated sediments from melted ice-wedge casts (Jahn, 1983), and are also described in the Transantarctic Mountains, where relict ice-wedges have sublimated away, leaving hollowed, slumping casts behind (Matsuoka and Hiraka, 2006).

Active sand-wedge polygons (Fig. 2) can be difficult to distinguish from active ice-wedge polygons, as sand-wedge polygons are commonly characterized by the presence of raised shoulders flanking polygon troughs (Fig. 5) that form due to the re-expansion of warming permafrost pushing against dry sediments that have fallen into open thermal contraction cracks (Péwé, 1959; Berg and Black, 1966; Yershov, 1998; Murton et al., 2000). Infiltration of fines into open cracks commonly produces surface furrows or sand funnels as fines infiltrate from the dry active layer into the subsurface (Berg and Black, 1966; Péwé, 1959). In the subsurface, raised rims initiate as cuspate, upturned strata