sequence and are the same age as the host medium) (MacKay, 2000).

Can similar processes operate on sand-wedge polygons forming in the absence of a seasonally saturated active layer? A "dry active layer" is a permafrost soil horizon that is seasonally warmed to above 0 °C under arid climate conditions that do not result in the saturation of the warmed soil with meltwater (e.g., Marchant et al., 2002; Marchant and Head, 2007; Kreslavsky et al., 2008). Major differences between the ice-wedge case and the sand-wedge case include: (1) the sand-wedge polygons lack a wet active-layer that can be shuttled along on top of an expanding and melting ice table (the "piggyback" process of MacKay, 2000); (2) the sand-wedge polygons typically form in ice-cemented permafrost with a significantly lower ice content and thermal expansion coefficient than ice-wedge polygons in wet, peat-rich environments; and (3) a convective return flow (closed-cell cryoturbation) has been proposed for such sand-wedge systems, resulting in the elevation of the height of polygon centers (Sletten et al., 2003). In contrast, material transported wedge-wards in the ice-wedge case accumulates as raised shoulders or within the troughs, with any measured polygon center height or volume increases attributed to frost-heave of markers relative to subsidence of melting ice-wedges (MacKay, 2000).

The closed-cell cryoturbation process can be tested by examining cross-sections of active and relict sand-wedges. Excavations into active Antarctic sand-wedge polygons show a wedge cross-section characterized by massive or foliated sands and cuspate, upturned polygon margins, typical of the raised-shoulder morphology observed in ice-wedge polygons, rather than looped horizons generated by closed-cell convection (Péwé, 1959; Murton et al., 2000; Marchant et al., 2002; Marchant and Head, 2007; Murton and Bateman, 2007; Kowalewski, 2009). Well-defined sand-wedges, rather than fully mixed sediment horizons, are typical of active sand-wedge polygons found at high latitudes (e.g., Antarctic examples reported by Sugden et al., 1995; Marchant et al., 2002; Marchant and Head, 2007; Kowalewski, 2009; Swanger, 2009) as well as of relict sand-wedges present at low latitudes (Murton, 1996; Maloof et al., 2002; Murton et al., 2000; Kovacs et al., 2007).

In contrast to extensively disturbed sediments, some sublimation polygons form on extremely stable sediment surfaces. Although some lateral movement of sediments by slumping can occur at the margins of sublimation polygons (Berg and Black, 1966; Marchant et al., 2002), the vertical ablation of underlying massive ice results in a stable lowering of the permafrost surface dominating the pedogenic profile (Marchant et al., 2002; Bao et al., 2008). The un-churned nature of sediments atop sublimation polygons in Beacon Valley, Antarctica, is evidenced by profiles of cosmogenic ^{3}He obtained from cobbles in till overlying buried glacier ice; measured concentrations in subsurface clasts are deficient in ^{3}He relative to values expected by taking only shielding from overlying till into account (Marchant et al., 2002). This deficiency indicates that clasts have moved upwards relative to the ground surface as overlying ice sublimes; rates of ice sublimation calculated from these data (e.g., Schaefer et al., 2000) are on the order of $\sim$10–50 m Ma^{-1}. Had cryoturbation occurred during this process, clasts at the surface and at depth would likely show similar ^{3}He abundances, reflecting the up and down vertical movement of sediment in a cryoturbated soil column (Marchant et al., 2002). Evidence for stable surfaces in regions with sublimation polygons also comes from the observation and radiometric dating of in situ volcanic ash trapped in polygon troughs—some of which has escaped cryoturbation for up to 8.1 Ma (Sugden et al., 1995; Marchant et al., 1996). Morphological evidence for stable surfaces may even apply to regions with sand-wedge polygons in Beacon Valley: evidence comes from the long-term preservation of meter-scale moraines of Quaternary and Pleistocene age (Fig. 6) emplaced atop sand-wedge polygons. Together, these lines of evidence suggest that the surfaces of sublimation polygons and even sediment-starved sand-wedge polygons may be exceptionally stable, and may not be rapidly reworked by "dry" cryoturbation processes (e.g., Marchant et al., 2002; Marchant and Head, 2007; Kreslavsky et al., 2008). We will return to this concept in analysis of ongoing research at the NASA Phoenix landing site (Section 5).

2.5. Polygons and polar hydrology

Although the occurrence of ice-wedge polygons in well-developed lacustrine and riparian systems has been extensively documented in the Arctic (Leffingwell, 1915; Hopkins, 1949; Lachenbruch, 1962, 1966; Plug and Werner, 2002), the role that polygons themselves play in the initiation of polar fluvial systems is only beginning to come to light (and is of particular interest on Mars, where geologically recent, fluvial gully systems are present) (e.g., Malin and Edgett, 2000; Dickson and Head, 2008; Head et al., 2008). Fortier et al. (2007) have documented the rapid growth of Arctic fluvial drainages or streams, in which ice-wedges melt to form ice caves, and then open channels, resulting in the incision of streams up to 750 m long over the span of four years. These channels may continue to expand, collecting and transmitting regional runoff as part of an integrated hydrological system (Fortier et al., 2007). Analogously, composite-wedge polygons in the Antarctic Dry Valleys have been shown to enhance the formation of gullies, promoting the accumulation of snow (that melts during peak summer heating), in addition to accumulation and transport of gully-related water (channeling melt through polygon troughs) (Levy et al., 2008a). In the Antarctic case, the melting of ground ice is not a significant contributor to gully stream flow (Head et al., 2007b; Morgan et al., 2007; Dickson et al., 2008; Levy et al., 2008a; Morgan, 2009). Rather, ice-cemented sediments provide a meters-thick impermeable substrate over which gully-related liquid water flow occurs during peak summer conditions (Head et al., 2007b; Levy et al., 2008a). This recent work suggests that thermal contraction crack polygons are not merely passive landscape elements, but rather, are important parts of developing cold desert landsystems, providing positive feedbacks to the formation of a range of features of geological, hydrological, and astrobiological interest (Levy et al., 2008a, 2009d).

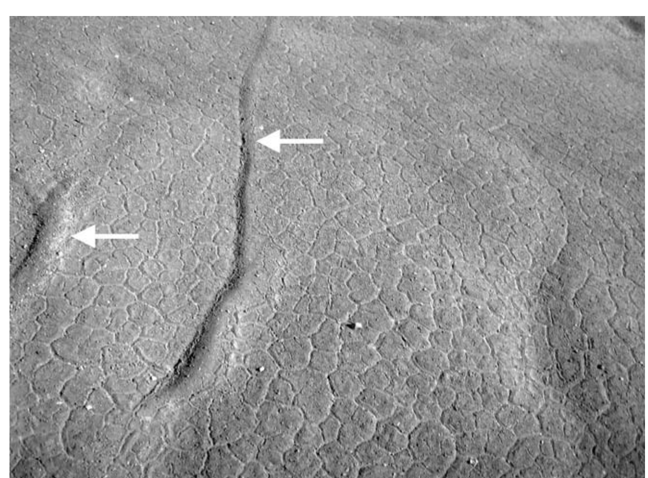

Fig. 6. Moraines (arrows) and sand-wedge polygons in lower Beacon Valley. Moraines are Pliocene and younger (Marchant et al., 2002). Field of view ~200 m wide.