tributaries that originate in alcoves at or near the base of the rock layer and merge together downslope to form single channels (~80 m wide) that open up into depositional fans (Fig. 5). Within the gully channels, smaller scale ~10 m wide internal channels are present, which at HiRISE resolution (sub-meter) can be seen to contain fine-scale fluvial-like features, including terraces and braided channels (Fig. 5c). These features are similar to those observed to form in the active gullies in the Antarctic Dry Valleys (compare Fig. 1c with Fig. 5c), and suggest that fluvial erosion was involved in the formation of the gullies (e.g. Morgan et al., 2008). Abandoned channels and distinctive fan stratigraphy (Fig. 5) suggest that multiple episodes of activity have been recorded in the gully morphology.

In contrast to the PF gullies, the gullies on equator-facing (EF) slopes have smaller, thinner (~20 m wide) channels that branch out from the apex of well-defined 200–500 m wide, cuspate alcoves that occur in the exposed rock layer at the summit of the slopes (Fig. 6). EF slopes are steeper than PF slopes, suggesting that the latter have experienced more erosion. Large amounts of debris (including 10 m diameter boulders) are visible within the alcoves and spread out down slope forming talus cones into which the gully channels are eroded. This suggests that dry mass-wasting processes in the form of rockfalls and debris slides may have accompanied gully activity along the EF slopes. Nevertheless, the prominence of the multiple channels that meander around topographic obstacles (Fig. 6a) argue for the involvement of a fluid agent. The occurrence of levees are similar to terrestrial debris flows that have been invoked to explain some martian gully formation (Costard et al., 2002; Hartmann et al., 2003; Levy et al., 2010). Together, these characteristics argue for the involvement of lower volumes of water in the erosion of the EF gullies relative to that involved in gullies on the PF slopes. It is likely that mass-wasting processes in addition to gully erosion also contributed to the shallower PF slopes we see at present. However, the difference in scale between the two gully types argues for the greater significance of PF gully erosion. Similar slope asymmetry is found within the ADV, with gentler slopes resulting from a greater availability of liquid water (Marchant and Head, 2007). This suggests that the same may hold true for Asimov. The east and west-facing gullies are morphologically similar to the PF gullies in terms of the level of incision, although they do not exhibit the same degree of complexity or finer-scale bedforms.

Pole-facing gullies appear fresher and more well-developed than equator-facing gullies (Fig. 5), suggesting that the PF gullies have been active more recently than the EF gullies. Determining an absolute age for the two gully systems using crater size–frequency distribution data is difficult due to the small sample areas involved; furthermore, the steep angles on which the gullies have formed (>15°) makes them prone to failure and thus degradation resulting in the loss of impact craters. Nevertheless, two equally sized survey areas corresponding to slopes only containing either PF or EF gullies were defined and a crater counting survey of all available MOC (22) and HiRISE (8) images was conducted. This revealed ~70 craters with a diameter >5 m (including six craters with a diameter of >100 m) are present on EF gullies in the EF survey area relative to only ~15 on the PF gullies in the PF survey area. Thus the PF gullies display a lower crater density than the EF gullies. This suggests that the EF facing gullies have not been active as recently as the PF and is therefore consistent with the morphological interpretation.

What are the causes of orientation-dependent differences in gully morphology? Examination of the circular valley systems shows that the aspect-dependence of gully morphology was maintained regardless of whether the gullies were eroded into the lava-capped crater fill material or the opposite valley side, along the interior of the Asimov crater walls (Figs. 5-7). The southern valley of Asimov is the widest and deepest (>2 km relative to ~500 m for the north valleys) and so it has the largest scale and number of gullies along its walls. However, the same gully asymmetry consisting of multiple tributary fed PF gullies relative to the more linear channels and cuspate alcoves of the EF gullies is still maintained in the northern valleys (Fig. 7). This suggests that insolation (through its effect on the stability of a surficial water source), not slope composition, was the critical factor in the development of gullies of different morphology.

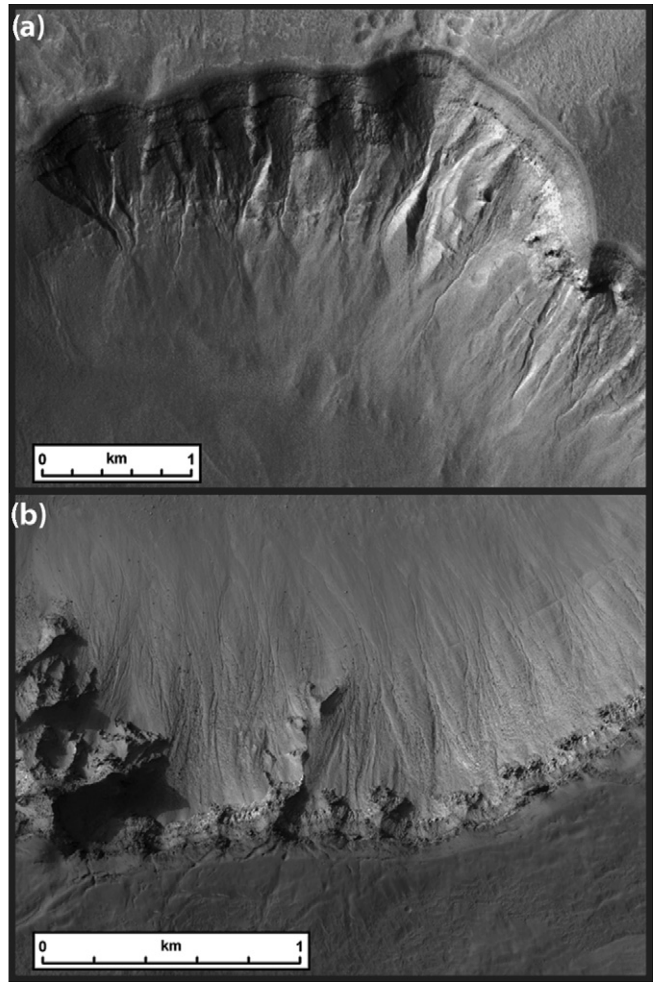

Fig. 7. Examples of PF (a) and EF (b) gullies within the northern valleys of Asimov. Note that the same gully morphology asymmetry is preserved between the two gully types as is seen in the southern valley (Figs. 5 and 6) despite the fact the slope composition has switched. (a) PF gullies consist of multiple branching tributaries as noted in Fig. 5 except that these gullies are carved into the crater wall instead of the interior crater fill material. (b) EF gullies displaying cuspate alcoves and linear channels. Compare with Fig. 6, except these gullies are eroded into interior fill material instead of the crater wall. (a) CTX: P05_003102_1327 and (b) HiRISE: PSP_002179_1330.

4. Model results and geologic interpretation

In order to investigate the differential insolation conditions related to aspect we employed the one-dimensional version of the LMD GCM developed by Costard et al. (2002). Within the model the diurnal and seasonal surface temperatures are derived from the balance between the radiative and turbulent fluxes, thermal conduction into the regolith and CO_2 condensation and sublimation. Insolation is a function of obliquity, orbit eccentricity and longitude of perihelion. Therefore, in order to investigate the potential for melting to occur in the past, Laskar et al. (2004) simulation of Mars orbital dynamics can be used to provide the inputs for these