

**WEATHERING PITS IN THE ANTARCTIC DRY VALLEYS: INSOLATION-INDUCED HEATING AND MELTING, AND APPLICATIONS TO MARS.** R.L. Parsons<sup>1</sup>, J.W. Head III<sup>1</sup>, and D.R. Marchant<sup>2</sup>, <sup>1</sup>Department of Geological Sciences, Brown University, Providence, RI 02912, USA, <sup>2</sup>Department of Earth Sciences, Boston University, 675, Commonwealth Avenue, Boston, MA 02215, USA (Rebecca\_Parsons@Brown.edu).

**Introduction:** Coarsely pitted, 0.3-1 cm diameter, rocks have been observed on the surface of Mars since the observations made by the Viking Landers. These pits may be either vesicles formed by impact or volcanic processes, or the results of surface weathering processes. On Earth, weathering pits are common features on rocks throughout the Antarctic, where they have been attributed to both chemical and physical weathering processes. The hyper-arid, cold-polar desert environment of the Antarctic Dry Valleys (ADV) is commonly cited as the closest terrestrial analog to the Mars climate. It is hoped that further analysis of weathering pit morphologies in the ADV will provide a means to distinguish between the morphologies of vesicular rocks and non-vesicular rocks with weathering pits. The application of such a set of criteria to Mars could be important in furthering our understanding of the environment and processes occurring at its surface.

The work presented here is a preliminary assessment of data collected from the Beacon Valley region of the ADV during November and December of 2004. The results highlight two end-members of weathering pit development, and offer support for pit formation resulting from mineral breakdown by insolation-induced melting of snow that accumulates preferentially in pits during periods of limited snowfall.

**Previous studies of weathering morphologies in Antarctica:** The cause of tafonisation (formation of hollows with broad, rounded interiors) and alveolation (formation of small pits 0.5 cm to 5 cm deep) in rocks of the Antarctic has been the subject of considerable debate since the early 1960s. The particularly interesting point of this debate is that the evidence from the Antarctic seems to argue against freeze-thaw or wind abrasion as the predominant cause of these weathering morphologies (see [1] for summary of observations and references therein). Instead, early studies attribute these morphologies to salt crystallization, whereby damage to the rock and eventual pitting or undercutting occurs when the pressure exerted by the preferential growth of large salt crystals exceeds the tensile strength of the rock [2].

Observations that have led researchers to favour salt crystallization as the cause of these weathering pits include, (1) their occurrence on slopes of all aspects and at various altitudes, (2) a lack of preferred orientation, (3) the preservation and unaltered appearance of minerals from debris contained within pits, and (4) the accumulation of salts and salt crusts in and around pits [1].

Recent studies of weathered dolerite cobbles in the Dry Valleys region of Antarctica indicate that chemical weathering may play a more significant role than physical weathering processes (e.g. salt crystallization, freeze-thaw, wind abrasion) in pit formation [3,4,5]. In this scenario, snow melt that collects in pits due to the high heat capacity of the cobbles, quickly saturates a 1 mm thick weathering zone underlying the pit bottoms. It is in this zone that primary mineral breakdown and precipitation is thought to occur, resulting in pit advancement and accumulation of weathering products. Although

soluble salts have been found contained within this weathering zone, they are considered to be the remnants of secondary minerals precipitated during the latter stages of evaporation and largely removed by subsequent eolian erosion.

Despite the many studies of tafoni and alveolar weathering in Antarctica, the initiation of pits is often not considered and does not appear well-constrained. Similar studies of erosional marks in Antarctic rocks have highlighted the importance of defects in the rocks, such as inhomogeneities, irregularities, or discontinuities, as sites of mark development [6]. Weathering pits can themselves represent defects where erosional marks form, and similarly erosional marks can be transformed by weathering into irregular pits and may thus represent the initial site from which weathering pits develop [6]. The role of wind in pit formation is frequently regarded as limited to the removal of debris from basins after it has been loosened by other weathering processes [1]. However, Selby's [6] conclusions suggest a more complex story of pit formation in which the role of wind may be more instrumental than is commonly cited.

**Mullins field site and results of data collected during 2004 field season:** Mullins rock glacier originates at an altitude of ~1600 m, ~3 km to the east of Central Beacon Valley. The glacier ice surface is buried beneath a sublimation till layer up to 0.75 m thick constituting fine- to coarse-sand and decimeter to meter-sized boulders with the largest up to 5 m in diameter. This till surface can be divided into a series of zones that vary in morphology as a function of development and processing of the sublimation till. These zones also span a soil chronosequence that reflects a relative age increase in the down-valley direction.

Observations of weathered dolerite rocks throughout each zone reveal an extensive suite of weathering pit morphologies. At least four distinctive pit forms were identified (Fig. 1a-d), (1) honeycomb weathering, (2) well-developed, distinct etch pits, (3) pinnacle and hollow weathering, and (4) faceted pits. Honeycomb weathering tends to form on relatively flat surfaces within 10° of horizontal. It describes shallow etching of the surface to form irregularly shaped depressions rather than the near-circular to circular basins characteristic of etch pits. Etch pits also exhibit a more distinct form than honeycomb etching, typically displaying bowl-shapes in their cross-profile and inward protruding lips at their rims. Both honeycomb and etch pit weathering appears to be predominant in fine- and medium-grained dolerites. In contrast, coarse-grained dolerites form large hollows often with overhanging pinnacles of the original rock surface. The smooth, concave surfaces that remain appear morphologically akin to the cavernously weathered dolerites of Bull Pass, Antarctica [7]. A fourth weathering pit morphology develops coincident with eolian scour marks, the dimensions of which appear to initially control the size and spacing of the pits. These types of pits were observed on slopes more than 10° from horizontal and with tear-drop shaped scour marks elongated parallel to the slope of

the rock surface. Overdeepening and pit formation occurs in the wider part of the scour mark, which is commonly the down-slope end of the rock.

All forms of pits were observed to be preferential sites of snow accumulation during periods of light snowfall. Although snow remained in the valley for several days, snow within the pits was observed to quickly melt and remain as liquid water for several hours (Fig. 1d).

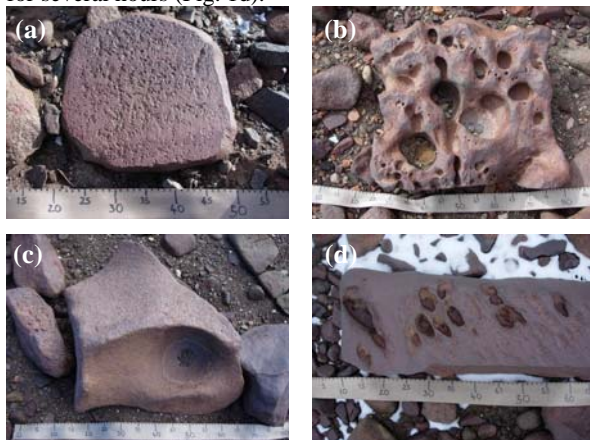


Figure 1: Dolerite rocks in Beacon Valley exhibiting varying weathering pit morphologies (scale is in centimeters); (a) 'Honey-comb' weathering, (b) Well-developed 'etch pits' (with debris and yellow precipitate coatings within pits), (c) 'Pinnacle and Hollow' weathering (with salt rim in hollow), and (d) 'Facetted pits' (larger ones containing snow melt).

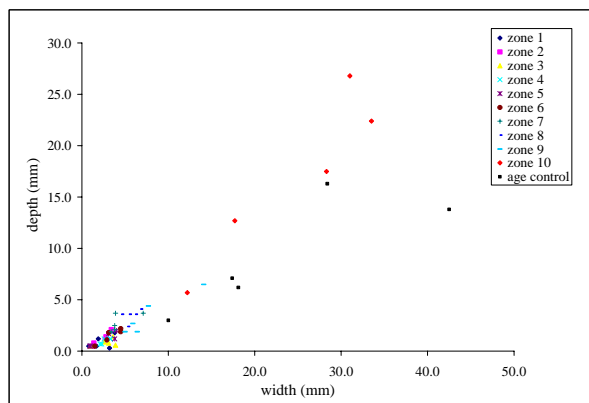


Figure 2: Graph of width versus depth of average-sized pits on dolerite rocks of morphological zones 1-10 on Mullins rock glacier. Pit dimensions of zone 10 are comparable with those recorded from the west side of Central Beacon Valley, where ages are known to exceed 7 Ma based on  $\text{Ar}^{40}/\text{Ar}^{39}$  dating of in-situ volcanic ashfall deposits [8].

In tracing pit development downvalley it appears that pit morphologies are best developed in older, more stable zones proximal to Central Beacon Valley (zones 8 and 9) and at the north side of the valley (zone 10). Measurements recorded from 20-30 rocks within each zone suggest a corresponding trend in pit dimensions (Fig. 2). The trend highlights two end-members of pit development with small (0.8-7.1 mm wide by 0.5-3.7 mm deep), poorly developed pock-marks dominating zones 1-7 contrasting with the large (12.2-33.5 mm wide by 5.7-26.8 mm deep), well developed pits dominating zone 10.

Between these two end-members an intermediate stage of pit development exists (zones 8 and 9), but the transitions between this and the two end-member stages are abrupt (Fig. 2). These transitions could indicate stratigraphic breaks in the soil chronosequence.

**Conclusions:** The results of preliminary analyses of field data collected on weathering pit morphologies in Beacon Valley suggest that well-developed pitting takes millions of years to form in the hyper-arid environment of the Antarctic Dry Valleys. Initial pit formation may be related to snow behaviour during peak summer months/days, and in some cases to pre-existing defects in the rocks, including wind abrasion marks. A variety of pit morphologies were observed, the differential development of which appears to be a function of grain size, local topography and relative exposure age of the surface on which they form.

On Mars, numerous comparable rock morphologies have been observed at the Viking landing sites, Chryse Planitia and Utopia Planitia, and more recently at the Spirit landing site, Gusev Crater (Fig. 3). Furthermore, ice was observed to have formed on the surface at the Utopia Planitia site during both winters in which Viking Lander 2 was active [2]. Hence, melt-water formed from insolation-induced melting of frost or snow could be instrumental in the formation of weathering pits on martian rocks in a mode that parallels their formation on Earth.

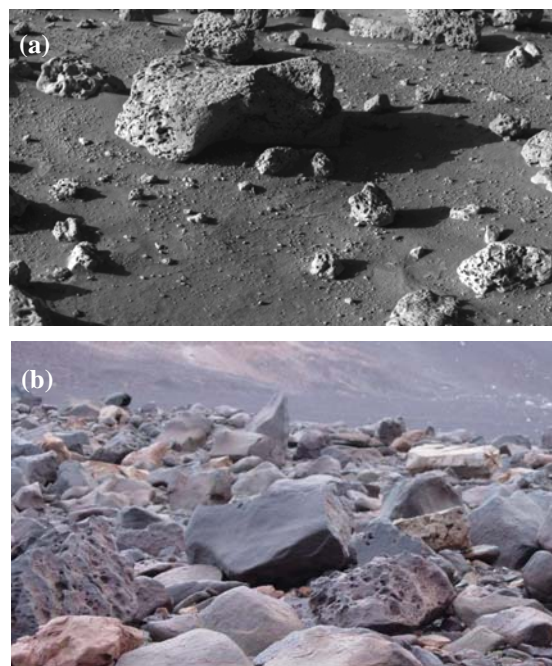


Figure 3: Pitted rocks tens of centimeters in diameter at (a) the Utopia Planitia landing site (Viking Lander 2 frame 21A044), and (b) the surface of Mullins rock glacier, Antarctica.

**References:** [1] Evans, I.S. (1969) *Revue de Geomorphologie dynamique*, 4, 1-177. [2] Wellman, H.W. and Wilson, A.T. (1965) *Nature*, 205 (4976), 1097-1098. [3] Allen, C.C. and Conca, J.L. (1991) *Proc. of LPS*, 21, 711-717. [4] Conca, J.L. and Malin, M.C. (1987) *Antarctic J. the U.S.*, 21, 18-19. [5] Conca, J. and Wright, J. (1988) *Antarctic J. the U.S.*, 22, 42-44. [6] Selby, M.J. (1977) *J. Geology and Geophysics*, 5, 949-969. [7] Conca, J.L. and Astor, A.M. (1987) *Geology* 15, 151-154. [8] Marchant, D. R. et al. (2002) *GSAB*, 114, 718-730.