

EQUILIBRIUM LANDFORMS IN THE DRY VALLEYS OF ANTARCTICA: IMPLICATIONS FOR LANDSCAPE EVOLUTION AND CLIMATE CHANGE ON MARS: David R. Marchant¹ and James W. Head. ¹Department of Earth Sciences, Boston University, Boston MA 02215 (marchant@bu.edu.) ²Department of Geological Sciences, Brown University, Providence, RI 02912

Introduction: The very low atmospheric temperatures and limited availability of liquid water in parts of the Antarctic Dry Valleys (ADV) makes them compelling analogs for current martian environments. Although classified as a single, hyper-arid, cold-polar desert, the ADV region is more appropriately divided into a series of narrow climatological zones. Each zone fosters a unique suite of equilibrium landforms [1]; in this context, equilibrium landforms are those unconsolidated features produced solely by geomorphic processes operating within a given microclimate zone. Of course some landforms in the ADV evolved over a range of climatic conditions, but many formed from processes operating at uniform rates and under non-changing climate conditions [1]. In this tectonically stable region then, evidence for partial dissection and/or unstable modification of equilibrium landforms may suggest variation in geomorphic processes brought on by interval(s) of climate change. Our study of the origin, evolution, and temporal migration of equilibrium landforms throughout the ADV may help shed light on the origin and evolution of similar-appearing landforms on Mars and may also help discern the magnitude and direction of recent climate change on Mars.

Division of ADV microclimate zones: We distinguish three microclimate zones in the ADV on the basis of varying temperature and soil-moisture content: a seasonally dynamic thawed coastal zone, a transitional inland mixed zone, and a stable upland frozen zone.

Zone 1: Coastal thaw zone (subxerous): Soils in the coastal thaw zone exhibit saturated active layers. Relative humidity during summer months averages about 75% [2-4]. Snowfall likely exceeds 80 mm of water equivalent per year. Mean annual air temperature averages about -17°C [3]. Equilibrium landforms of the coastal thaw zone include, solifluction lobes and terraces and ice-wedge polygons (Fig. 1). Soils are subxerous and contain salts enriched in sodium chloride [4].

Zone 2: Inland mixed zone (xerous): The transitional inland mixed zone includes moderate-to-low-elevation areas in the central Dry Valleys region and high-elevation areas near the coast. Alternating westward-flowing katabatic winds and eastward-flowing winds from the coast produce variable humidity, from 10% to 70%. Mean annual air temperatures are -21 to -25°C. Meltwater is rare, although some liquid water occurs down from snow banks and glaciers situated on favorable slopes. Snowfall is less than that of the coastal thaw zone [1, 3]. Apart from regions alongside ephemeral streams and isolated snow patches, near-surface soils contain less than 10% soil moisture. The dry climatic conditions of this zone favor the development and preservation of extensive desert pavements, gelifluction lobes, and sand-wedge polygons (Fig. 1). Sand-wedge polygons are similar to the ice-wedge polygons of the coastal thaw zone except that polygon troughs are filled with stratified sand-and-gravel rather than with ice [5, 6] (Fig. 1).

Zone 3: Stable upland frozen zone (ultraxerous): The relative humidity in the stable upland frozen zone averages less than 45% and reflects the predominance of dry katabatic winds [3, 4]. Mean annual temperatures are below -25°C. Precipitation is rare, but snow blown off the polar plateau accumulates on small glaciers and feeds perennial snow banks in the lee of

topographic obstacles. The distribution of snow and ice in the stable upland frozen zone is thus largely related to topography. Meltwater is essentially absent from this microclimate zone and near-surface soils contain < 3% soil moisture. Glaciers and snow banks lose mass by sublimation [7]. The hyper-arid and very cold conditions of the stable upland frozen zone favor the long-term preservation of buried glacier ice. Segregation or vein ice is not an important source of underground ice in this region due to the year-round absence of liquid water. Equilibrium landforms and features in this zone include dry sublimation till (atop debris-covered glaciers) and high-centered, sublimation polygons [8] (Fig. 1).

Spatial distribution of microclimate zones and the role of geomorphic overprinting: Landforms originating from thermal contraction in near-surface soils show marked variation among climate zones: ice-wedge polygons occur in the coastal thaw zone; sand-wedge polygons are common in the inland-mixed and stable upland frozen zones; and sublimation polygons are found only in areas where sublimation till rests on near-surface ice in the stable upland frozen zone (Fig. 1). This three-fold geographic distribution of polygon types has remained remarkably stable over the last several million years [1]. For example, there is no evidence for ice-wedge casts in surficial sediments of the stable upland frozen zone. In addition, there is little evidence for extensive debris flows, gully-ing, or the development of widespread fans (features common in the coastal thaw zone) in the upland frozen zone. Rather, unconsolidated sediments and sublimation polygons of the stable upland frozen zone contain ancient and *in-situ* ashfall deposits (5 to 10 cm from the ground surface) that are suggestive of a paralyzed landscape [1].

Evidence for subtle changes in microclimates: Because each microclimate zone in the Dry Valleys features a unique assemblage of equilibrium landforms, clues to subtle climate variation comes from geomorphic overprinting on base landforms. Examples of such overprinting could be the emplacement of a short-lived active layer (solifluction, gelifluction, and meltwater channel) on partially degraded landforms of the inland mixed or stable frozen upland zones. Similarly, ongoing fluvial dissection of gelifluction lobes in the inland-mixed zone (Fig. 2) is suggestive of current climate warming, bringing geomorphic processes common in the coastal thaw zone inland to the mixed zone. In general, however, the preservation of Pliocene-age sublimation polygons in the stable upland frozen zone of the ADV (without evidence for widespread emplacement of dynamic active layers) indicates long-term climate stability [1].

Applications to Mars: The recognition and documentation of three micro-climate zones within the ADV, the variation of temperature, humidity and soil water content among these microclimate zones, and the identification of equilibrium landforms within these zones, provides important insight into geomorphic processes operating within each ADV microclimate zone. In our opinion, similar climate zones exist on Mars and are largely distributed as a function of latitude-dependent insolation and soil-water content. The detailed knowledge of the processes derived from the ADV microclimates can clearly be

applied to Mars and will be helpful in deconvolving the signal of climatic zonation and climate change there.

There is indeed evidence that Mars has undergone major changes in climate in the recent geological past [9]. These are linked to variations in orbital parameters [10] that result in important variations in ice deposition and stability, and in the emplacement and degradation of 'ice age' deposits extending down to 30° latitude. As another example of recent climate change deduced from surface landforms on Mars, we are analyzing geomorphologic features displayed on crater interior walls in mid-latitudes (Fig. 3). In Fig. 3, the crater floor displays a rough-textured hummocky surface suggestive of sublimation polygons and eolian modification. At the base of the crater wall, a series of concentric crenulate ridges mark the transition to the crater wall, with the edge of the floor marked by a wall-facing scarp. The ridges become increasingly sinuous toward the crater wall. The main features of the crater wall are alcoves in which blocks and bedrock are exposed, and below this, shallow linear lobate depressions extending to the crater floor. Triangular talus cones form apices at the base of the alcoves, and broaden downslope, filling the shallow linear lobate depressions. We interpret these geomorphologic features as evidence for changing climate on Mars. In this scenario, in the relatively recent geologic past, the climate was sufficiently different to cause the accumulation of snow and ice in the alcoves, leading to the formation of debris covered glaciers that descended toward the crater floor.

Equally informative, and perhaps more analogous to the situation in the ADV, is the variation in "latitude-dependent" landforms on Mars, particularly those related to the dissection of near-surface icy deposits related to the last martian ice age [9]. In this regard, we note that dissection of ice-rich, near-surface debris poleward of 60° N produces features analogous to sublimation tills and sublimation polygons of the upland-frozen zone in the ADV. Equatorward of 60°, dissection of these same icy deposits takes on different characteristics, often resembling landforms common in the intermediate zone of the ADV such as lobate gelifluction lobes. At the current time, equilibrium landforms of the coastal thaw zone in the ADV are not well represented on Mars, but the discovery of prominent geologically young gullies in particular latitude bands [11] suggests that similar seasonal melting has occurred in the recent past.

In summary, in a manner analogous to evidence for climate changes discussed previously for the ADV, changing and superposed equilibrium landforms can be used to infer the sign of climate change on Mars. Mapping of similar microclimate zones and their superposition over the critical latitude-dependent transition zones on Mars hold promise for deconvolving the details of geologically recent climate change there (e.g., [9]).

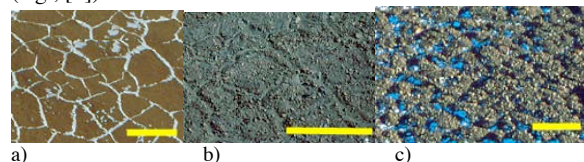


Figure 1. a) ice-wedge polygons of the coastal thaw zone; b) sand-wedge polygons of the inland mixed zone; c) sublimation polygons of the stable upland frozen zone. Yellow bar is 20 m across in all figures.

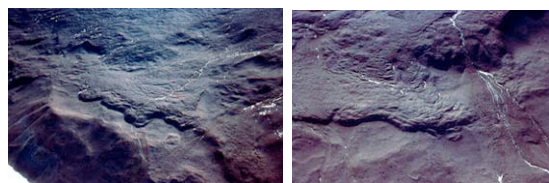


Figure 2. Gelifluction lobes in the inland mixed zone. View is 1 km across (top) and 0.8 km (bottom). Note dissection of lobes by streams. The lobes are > 500,000 yrs old and are now being eroded and incised at unprecedented rates.

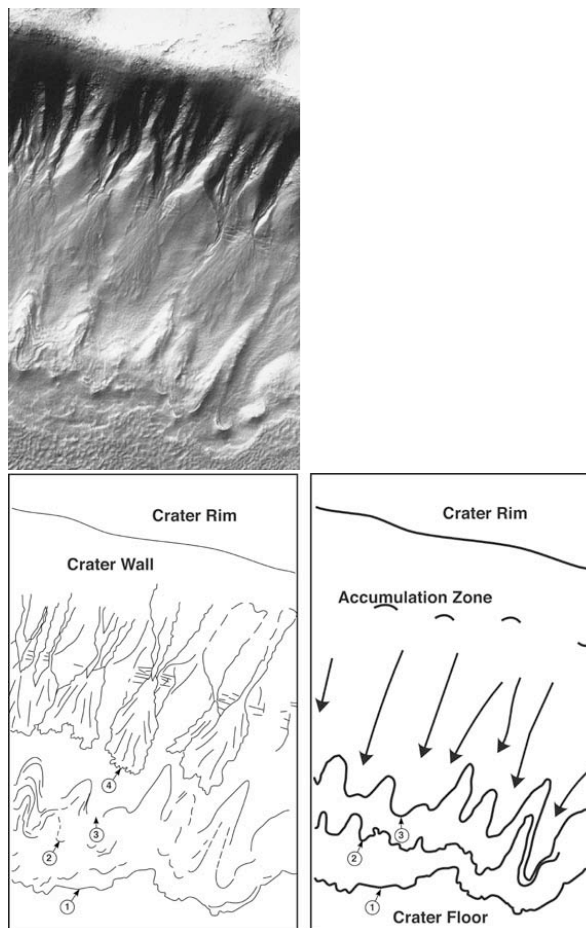


Figure 3. Portion of north (pole-facing) slope of impact crater at 33.35, 195.3W. Top, MOC Image E14 101929. Image is ~3 km width. Bottom left, sketch map of features in MOC image. Bottom right, interpreted directions and sequence of glacial advances represented by the deposits and structures.

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