

MICROCLIMATE ZONES 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 Earth's polar deserts make for compelling comparisons to a dry and cold Mars. Among polar deserts on Earth, the Dry Valleys region of Antarctica has long been featured as the most Mars-like. Classified broadly as a cold and hyper-arid region, the valleys feature a diverse suite of surface landforms that provide a geomorphological framework for interpreting features on Mars.

New climate and geomorphological data from the Dry Valleys show that the region is best subdivided into a series of narrow climatological zones. Each microclimate zone differs from the next by slight variations in atmospheric temperature and soil-moisture. Along microclimate boundaries, subtle variations in temperature and soil-moisture are sufficient to produce remarkable variations in surface topography. As is the case for most polar deserts, the geomorphic impact of minor variations in moisture and temperature is disproportionately large when compared to similar shifts in atmospheric temperature and soil moisture in humid-temperate latitudes. Insight gained from the distribution and temporal migration of microclimate zones in the Dry Valleys may help shed light on the origin and, in particular, the evolution of periglacial features and climate change on Mars.

Division of microclimate zones. Changes in relative humidity and soil-moisture content in the Dry Valleys, both of which are strongly influenced by atmospheric temperature and wind speed/direction [1], regulate salt weathering, frost action, and soil development [2]. These processes in turn control rates of downslope movement, fan development, gullying, polygon morphology/evolution, and rock weathering. We distinguish three microclimate zones 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. At issue here is not the precise geographical boundary of each microclimate zone, but rather the identification of equilibrium landforms produced within each zone. We note that temperature measurements alone are insufficient in delineating microclimates and in predicting the style of equilibrium landforms in each zone. For example, temperature oscillations about the freezing point in dry soils (< 5% soil moisture) may not produce observable landforms; but similar temperature fluctuations in saturated soils may produce significant change.

Zone 1: Coastal thaw zone (subxerous). Soils in the coastal thaw zone exhibit seasonally saturated active layers. The zone descends from about 1000-m elevation near the coast to about 100 m elevation 75 km inland on low-lying valley floors. Relative humidity during summer months averages about 75% and reflects the dominance of southeasterly, coastal winds. Snowfall likely exceeds 80 mm of water equivalent per year. Mean annual air temperature averages about -17°C [3], although due to changes in surface albedo, wind speed and direction, near-surface temperature changes significantly over horizontal distances of ~10 m.

The relatively mild climate of the coastal thaw zone permits development of gelifluction lobes, solifluction terraces, ice wedges, rills, channels, debris flows, levees, ephemeral

ponds, and intermittent rivers. Soils developed in the coastal thaw zone are subxerous and contain salts enriched in sodium chloride [4]. Low-centered, ice-wedge thermal-contraction polygons form in this zone (Fig. 1). The seasonal influx of liquid water (ice) into thermal contraction cracks leads to the development of raised polygon rims [5, 6]. Glaciers show some surface melting (about 10%, the rest by sublimation [7]; in places, this meltwater has cut channels 3-to-5-m deep.

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 -30°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]. Apart from regions alongside ephemeral streams and isolated snow patches, near-surface soils contain less than 10% soil moisture.

Gelifluction lobes and debris flows are rare and probably active only during extreme climatic events [7]. Ephemeral streams, which do not erode the land surface significantly, form where glaciers and snow banks terminate on dark-colored rocks. In places, small amounts of meltwater may migrate through soils at temperatures well below 0°C, facilitating slumps and down-slope movement on otherwise stable slopes. This phenomenon is not widespread, and consequently the land surface of the inland mixed zone is not everywhere dynamic. Instead, dry climatic conditions in this zone favor the development and preservation of extensive desert pavements and sand-wedge polygons (Fig. 2). 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.

Zone 3: Stable upland frozen zone (ultraxerous). Soils in the stable upland frozen zone are ultraxerous. Relative humidity averages less than 45% and reflects the predominance of dry katabatic winds. Mean annual temperatures are below -30°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. Flowing meltwater is absent from this microclimate zone and near-surface soils contain < 3% soil moisture. Glaciers and snow banks lose mass entirely by sublimation.

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. A typical moisture profile may show a near surface dry layer from 20 cm to 60 cm thick (< 3% moisture by weight) overlying concentrated ice (>90% moisture by weight). Where sand-wedge polygons form in sublimation tills over buried glacier ice, differential sublimation of subsurface ice exaggerates the size of marginal troughs, the result being the

development of high-centered, sublimation polygons (Fig. 3) [8]. Ultraxerous soils contain salts enriched in nitrates, reflecting the influence of westerly katabatic winds from the polar plateau [4, 9]. There is no active layer in this zone.

Spatial distribution of microclimate zones and the role of geomorphic overprinting. The three-fold geographic distribution of ice-wedge, sand-wedge, and sublimation polygons in the Dry Valleys has remained remarkably consistent throughout the last several million years. For example, there is no evidence for ice-wedge casts in surficial sediments of the stable upland frozen zone. In addition, there is no evidence for debris flows, gullying, or the development of widespread fans in surface sediments in this zone as well. Rather, unconsolidated sediments 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.

Beneath the thin veneer of surficial sediment in the Dry Valleys, however, bedrock landforms (10 m-100 m baseline) do show considerable evidence for marked climate change. The fact that such change is not recorded in the morphology of Pliocene- and Miocene-age surface sediments attests to the antiquity of such change. Bedrock walls in the stable upland frozen zone show well-developed gullies and channels, which today form only intermittently in the coastal thaw zone. The transition from a warm and wet inland climate (i.e., from conditions likely analogous to the modern coastal thaw zone) occurred > 10 million years ago in the Dry Valleys. Bedrock landforms in the stable upland frozen zone have been little modified (if at all) during the last 10 million years. Because climate on Mars likely shifts between extremely cold conditions (during which bedrock landscapes are largely paralyzed) and warmer conditions when true active layers form in small microenvironments, we postulate that a geomorphic record of Amazonian climate change may similarly be preserved on Mars [10, 11].

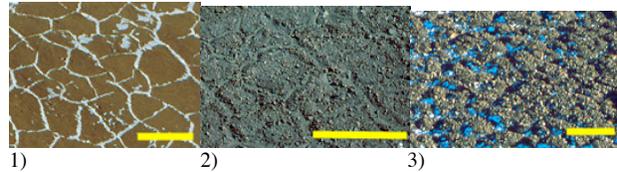
Because the spatial distribution of glacial landforms is in itself a clear and unequivocal record of climate change, moraines in the Dry Valleys can be used to mark the style and severity of climate change. For example, if all microclimate zones showed marked glacier fluctuations, then one could surmise that climate change was significant. If, however, glacier fluctuations were restricted to one or two zones, or to a few localities within one microclimate zone, then one could infer that climate change was less severe.

Alpine glaciers in all microclimatic zones in the Dry Valleys have been remarkably stable over the last several million years. Maximum ice-marginal fluctuations in the coastal thaw zone have been ≤ 2 km, whereas expansion/recession of alpine glaciers in the stable upland frozen zone has been ≤ 0.75 km. In Beacon Valley (stable upland frozen zone) spoon-shaped hollows at the head of debris-covered glaciers attest to a change in microclimate that favors sublimation over snow deposition. Moraines within these hollows show the pattern of lateral retreat. Elsewhere in the stable upland frozen zone, modern alpine glaciers seem to be advancing. As ice advances down-valley in these regions, and merges with slow-flowing or stagnant debris-covered glaciers, rumpled ridges and oversteepened lobes of sublimation tills mark accelerated subsurface ice flow. This complex pattern of alpine glacier fluctuation in the stable upland frozen zone appears to be modulated by the level of the

adjacent East Antarctic Ice Sheet and the distribution of snow-bearing katabatic winds off the polar plateau. Currently, for example, wind-blown snow off the ice sheet favors growth of alpine glaciers on the southwest side of Beacon Valley, but not on the northeast side.

Implications and Conclusions. Each microclimate zone in the Dry Valleys features a unique assemblage of landforms. We test for climate change in the Dry Valleys by looking for evidence of geomorphic overprinting on base landforms. Such overprinting could be detected from the emplacement of a short-lived active layer (solifluction, gelifluction, and meltwater channel) on partially degraded landforms. The preservation of Pliocene-age sublimation polygons in the stable upland frozen zone of the Dry Valleys indicates that climate conditions of the coastal thaw zone and inland mixed zone, both of which permit downslope movement, active layers, and flowing meltwater, have not advanced inward for at least the last 5 Ma. Minor variations in the size of alpine glaciers, however, attest to some climate change in the upland zone.

Because polygon morphology varies considerably from zone to zone in the Dry Valleys, the spatial distribution and morphology of polygons on Mars may help in defining martian climate zones [e.g., 12]. Furthermore, evidence of apparent overprinting on these forms, for example as degradation associated with the emplacement of solifluction lobes, fans, and channels associated with a near-surface active layer, can shed light on the sign and magnitude of recent climate change on Mars [e.g., 10, 13]. Similar studies will be valuable for other landforms as well, for example on the distribution and overprinting of gullies, fans, and lobate flow features on the martian landscape [e.g., 13].



Figures 1-3. Polygons the Dry Valleys region. 1. Ice-wedge polygons of the coastal thaw zone; 2 sand wedge polygons of the inland mixed zone; 3 sublimation polygons of the stable upland frozen zone. Yellow bar is 20 m across in all figures.

References: [1] J.R. Keys, Wellington Geol. Dep. Publ. 14, NZ., 1980. [2] I.B. Campbell and G.G.C. Claridge *Geoderma* 28, 221-238, 1982. [3] W. Schwertfeger, *Develp. in Atmos. Sci.* 15, 1984. [4] I.B. Campbell and G.G.C. Claridge, Antarctica: soils, weathering processes, and environment (*Devel. Soil Sci.* 16) 368 pp., 1987. [5] T.E. Berg and R.F. Black, *Ant. Res. Ser.* 8, 61-108, 1966. [6] R.F. Black, *Quat. Res.* 6, 3-26, 1976. [7] T.J. Chinn, Proc. Riederlap Workshop; IAHS-AISH Publ. 126, 237-247, 1980. [8] D.R. Marchant *et al.*, *Geol Soc. Am. Bull.* 114, 718-730, 2002. [9] J.G. Bockheim, *Geoderma* 47, 59-77, 1990. [10] M. A. Kreslavsky and J. W. Head, LPSC 35, #1201, 2004. [11] J. W. Head *et al.*, *Nature*, 426, 797-802, 2003. [12] N. Mangold, 3rd Mars Polar Conf., #8044, 2003. [13] D. R. Marchant, J. W. Head and M. A. Kreslavsky, 3rd Mars Polar Conf., #8106, 2003.