COLD-BASED GLACIERS IN THE WESTERN DRY VALLEYS OF ANTARCTICA: TERRESTRIAL LANDFORMS AND MARTIAN ANALOGS: David R. Marchant[1] and James W. Head[2], [1]Department of Earth Sciences, Boston University, Boston, MA 02215 marchant@bu.edu, [2]Department of Geological Sciences, Brown University, Providence, RI 02912

Introduction: Basal-ice and surface-ice temperatures are key parameters governing the style of glacial erosion and deposition. Temperate glaciers contain basal ice at the pressure-melting point (wet-based) and commonly exhibit extensive areas of surface melting. Such conditions foster basal plucking and abrasion, as well as deposition of thick matrix-supported drift sheets, moraines, and glacio-fluvial outwash. Polar glaciers include those in which the basal ice remains below the pressure-melting point (cold-based) and, in extreme cases like those in the western Dry Valleys region of Antarctica, lack surface melting zones. These conditions inhibit significant glacial erosion and deposition. An intermediate classification of subpolar glaciers includes those with wet-based interiors and cold-based margins.

Results from our field-based research in Antarctica show that ancient landscapes are preserved beneath cold-based glacier ice. These results, along with new insights from quantitative measurements of glacial abrasion [e.g., 1], have prompted us to re-evaluate some Martian landforms in terms of glacial processes. As background, we here summarize the formation of drop moraines, sublimation tills, and rock glacier deposits associated with cold-based glaciers in the Dry Valleys of Antarctica, and then [2] outline the case for similar glacial landforms along the western flanks of the Tharsis Montes.

Background: Basal sliding, basal entrainment, and transport of basal debris towards the glacier base are three fundamental requirements for significant glacier erosion. Basal sliding requires subglacial meltwater, a property controlled largely by the thermal regime of the glacier. At the base of wet-based glaciers, debris is entrained chiefly through regelation, a process whereby basal meltwater is frozen onto the glacier base. Regelation normally occurs where the basal-ice temperature fluctuates about the pressure-melting point. In such cases, small bedrock obstacles yield pressure variations that induce basal-ice melting and refreezing. Refreezing of "dirty" meltwater entrains basal debris. At sites of persistent pressure melting, the continued downward transport of basal debris towards the bedrock interface results in elevated rates of bedrock erosion. Such processes result in overdeepened basins found commonly beneath cirque and valley glaciers. Although simplified, the above represents the classic scenario for wet-based, subglacial erosion [3-7]. Recent studies show that some basal debris may also be entrained beneath cold-based ice [8]. Debris may be entrained through rotation of loose bedrock by glacier flow [6] or by freezing of interfacial meltwater films (<<1 mm thick) at subfreezing temperatures [1, 9]. Theoretical and empirical studies show that liquid water at the base of glaciers can exist in stable equilibrium at subfreezing temperatures [9]. The magnitude of erosion capable from freezing of such subglacial meltwater, for example where measured in Antarctica, is as little as 9×10^{-7} to 3×10^{-6} m yr^{-1} [1]; typically less than the rate of aeolian erosion.

Although cold-based glaciers do not erode their underlying substrates appreciably, they do deposit characteristic landforms [10]. The material within these landforms originates from supraglacial debris, commonly rockfall and/or volcanic ejecta that falls onto the glacier surface. Angular and lacking evidence for subglacial abrasion, these rockfall and volcanic particles flow passively through the ice toward glacier margins. The resulting landforms (e.g., drop moraines, sublimation till, rock-glacier deposits) are perched on existing topography. Sharp basal contacts and undisturbed underlying strata are hallmarks of cold-based glacier deposits [11].

Drop moraines: The term drop moraine is used here to describe debris ridges that form as supra- and englacial particles are dropped passively at margins of cold-based glaciers (Fig. 1a and 1b). Commonly clast supported, the debris is angular and devoid of fine-grained sediment associated with glacial abrasion [10, 12]. In the Dry Valleys, such moraines may be cored by glacier ice, owing to the insulating effect of the debris on the underlying glacier. Where cored by ice, moraine crests can exceed the angle of repose. In plan view, drop moraines closely mimic the pattern of former ice margins, though moraine width may vary spatially, owing to the characteristic inhomogeneity in the distribution of supraglacial debris (excepting volcanic airfall debris). Debris is generally thickest in regions near (or down ice flow from) bedrock cliffs.

Sublimation till: Sublimation along the ice/atmosphere interface may bring englacial debris passively to the ice surface. The rate of ice sublimation slows as the evolving sublimation till thickens, eventually insulating the underlying ice by retarding vapor diffusion and thermal change. Many sublimation tills in the western Dry Valleys region of Antarctica are underlain by glacier ice, even though some are in excess of 8.1 Ma [13,14] (Fig. 2a and 2b). Differential flow of underlying glacier ice may result in distinct surface lobes of sublimation till (see also below). In addition, thermal contraction near the surface of the buried glacier commonly initiates a network of surface polygons that cut the till, the relief of which is controlled in part by variations in till porosity and permeability [14].

Rock-glacier deposits: In the western Dry Valleys region of Antarctica, rock glaciers form as sublimation concentrates debris on the surface of active glaciers. Continued flow of the underlying glacier through internal deformation produces ridges and lobes of sublimation till atop the glacier (Fig 3a and 3b). The thickness of this debris increases down ice flow, as material is continually added to the base of the sublimation till as it moves down valley. In general, rock-glacier formation is favored by high debris accumulation rates and low ice velocities, conditions common in an advanced state of glacial retreat [15]. Spoon-shaped hollows that commonly form at the head of many terrestrial rock glaciers [16, 17] likely arise as incomplete debris covers there facilitate excess sublimation over that beneath more extensive tills down valley.

Martian analogs: An Amazonian-aged deposit covering ~180,000 km^2 of the western flank of Arsia Mons displays several features diagnostic of deposition from cold-based ice (details are outlined in [2]). Foremost are: 1) an outermost zone of over 100 arcuate and parallel raised ridges (drop moraines), each up to 10 meters high and 100 km long; 2) a medial zone of rough, hummocky topography (sublimation till) superposed on intact lava flows; and, 3) a proximal zone abutting the upper flanks of Arsia consisting of several individual lobes and superposed parallel raised ridges. The latter closely resemble terrestrial rock glaciers. None of the deposits are associated with geomorphic features indicative of meltwater. Collectively, these features suggest glaciation of western Arsia Mons and open up the possibility that relict glacier ice may remain there in extant rock glaciers.

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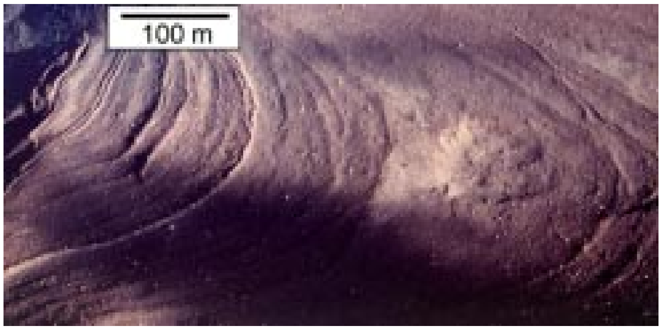

Figure 1a. Drop moraines, on the floor of lower Arena Valley, deposited from former fluctuations of Taylor Glacier. The oldest moraines are > 1.2 Ma [10].

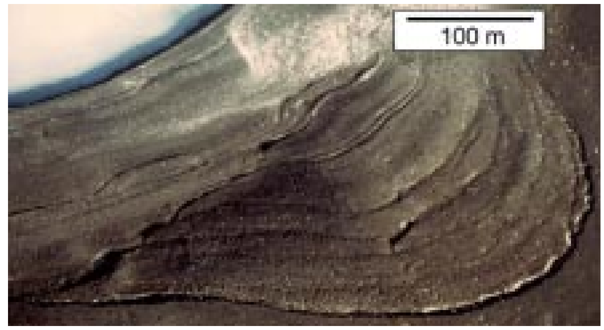

Figure 1b. Close-up view of drop moraines in lower Arena Valley (Taylor Glacier in upper right-hand corner). The outermost moraine stands 3 m above the surrounding valley floor.

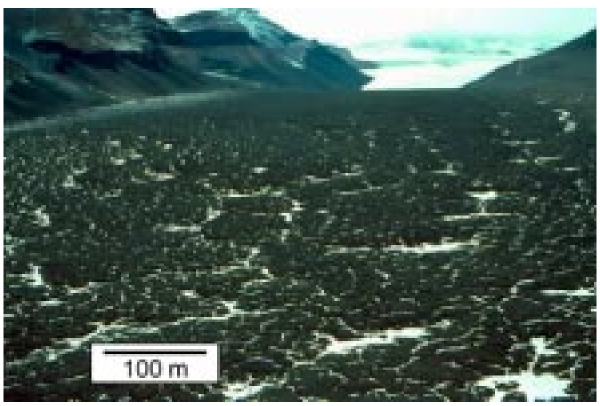

Figure 2a. Oblique air view of central Beacon Valley. The flat valley floor, lined with polygons, in underlain by glacier ice > 8.1 Ma [13, 14].

Figure. 2b. Glacier ice, > 8.1 Ma [13, 14], buried beneath 50-cm-thick sublimation till on the floor of central Beacon Valley.

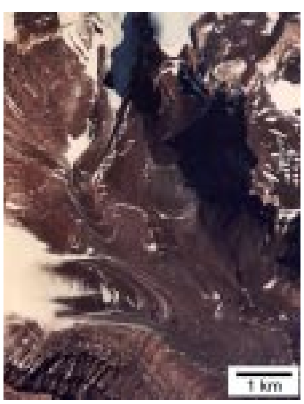

Figure. 3a. Rock glaciers at the head of Beacon Valley, Antarctica. The dolerite-rich drift that covers these glaciers is < 1 m thick.

Figure. 3b. The Mullins Valley rock glacier, upper Beacon Valley. This rock glacier, about 6 km in length, is as much as 700 ka near its distal end.