**MARTIAN POLAR ICE SHEETS AND MID-LATITUDE DEBRIS-RICH GLACIERS, AND TERRESTRIAL ANALOGS.** J.S. Kargel[1], B. Molnia[2], and K.L. Tanaka[3], [1]U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001, U.S.A.; Email: jkargel@usgs.gov; [2]USGS, Email: bmolnia@usgs.gov; [3]USGS, Email: ktanaka@usgs.gov.

**Introduction:** Glaciers are commonly defined as perennial masses of ice and snow that exhibit morphologic indications of significant flow down-slope under its own weight (under the influence of gravity). This definition does not imply a particular origin or flow mechanism, and in the broadest sense it does not even require that the ice is $H_2O$. Thus, terrestrial rock glaciers are a type of glacier by this definition, as are Earth's snow-fed alpine glaciers, ice caps, and polar ice sheets; Martian lobate debris aprons, lineated valley deposits of the fretted terrain, and the south polar cap are also glaciers. Martian glaciers apparently include both $H_2O$-dominated and $CO_2$-rich icy flows; the ones being rich in $CO_2$-rich are restricted to the south polar cap. Debris-covered snow-fed glaciers and periglacial rock glaciers provide the closest terrestrial analogs to lobate debris aprons and lineated valley deposits of the fretted terrain.

**Martian glacier types and terrestrial analogs:** Among Martian glaciers and their Earth analogs, we observe many indications of both brittle and ductile flow behavior. Scarps and troughs in Mars' carbon dioxide-covered south polar cap locally expose intense deformation— buckles, folds, boudins, crevasses, thrust faults and elastic flexural bulges; and in outlying areas of polar layered deposits faults are common. Although there are profound differences between the Martian polar caps and terrestrial polar ice sheets, many of the morphologic characteristics of the Martian south polar cap are similar to characteristics of Earth's ice sheets.

Crevasses, faults, folds, medial moraines, and pressure ridges are commonly expressed on Martian valley and alpine glaciers as deeply etched surface structures whose relief is brought out by differential sublimation. These features are directly comparable to those of terrestrial valley and alpine glaciers. Only one good example comparable to braided glacial outwash systems on Earth has been identified on Mars. Small gullies and debris flows associated with Martian glaciers, like those widely observed for Himalayan debris-covered glaciers, are common. Indications of sublimation are widespread in precisely the geographic locations where sublimating ice is most expected based on Mars climate models.

Terrestrial glaciers are the closest landform analogs of the Martian glaciers, but some structural features of the Martian icy flows are mimicked by structures best known from high-grade metamorphic and plate tectonic systems on Earth. Terrestrial high-grade metamorphic complexes, where deep crustal spreading of hot plastic layered rocks occurred, offer insights relevant to boudins, folds, and faults in the south polar cap (Figs. 1 and 2). Ductile compressive shortening and the lobate forms of major polar flow lobes (Fig. 3) have good analogs in glacial ice sheets; pahoehoe lava flows exhibit some of the same morphologies. Also in the south polar cap we observe elastic plate flexure, where good process analogs include oceanic plate flexure due to the loads of ocean islands and magmatic arcs. In lobate debris aprons of Deuteronilus Mensae, wrinkle-ridges (similar to those of lunar maria and Martian volcanic plains) and plate obduction (Fig. 4) are observed, but more common are surface buckles, flowlines, and medial moraines (Fig. 5) similar to those of Earth's rock glaciers and debris-covered glaciers.

**Conclusions and Implications:** The implications of these analogs, along with insights drawn from analytical models, are that (1) the Martian cryospheric flows are composed of a flowing, faulting, folding substance; (2) it is a substance capable both of sublimating and melting at conditions near the Martian surface; and (3) the flow features are generally rheologically layered. This layering in the subpolar glaciers is probably due to differential debris/ice contents as well as vertical thermal stratification. In the south polar cap rheological layering is probably due both to thermal stratification (offering many orders of magnitude variation in effective viscosity) and differential amounts of water ice, dry ice, clathrate hydrate, and minor constituents (salts, acids, and inert dust components).

In contrast with the southern perennial $CO_2$-surfaced cap, the north polar cap and icy deposits around the southern perennial cap have only rare ductile behavior, folding, and other evident indications of a soft, glacier-like rheology.

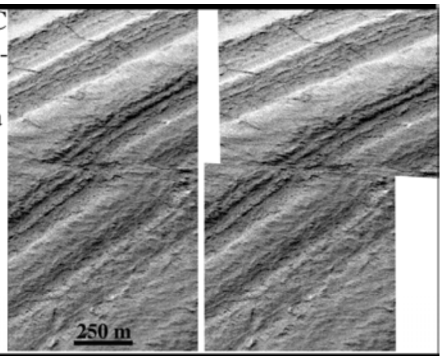
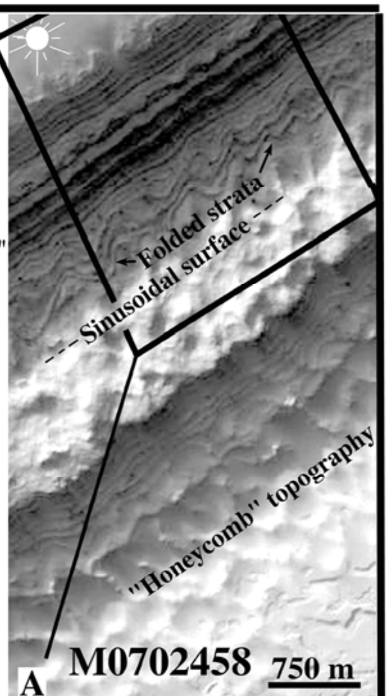



Fig. 1. MOC image M100-3514 shows faulted strata of South Polar Layered Deposits in actual image (left) and recontrsction (right).



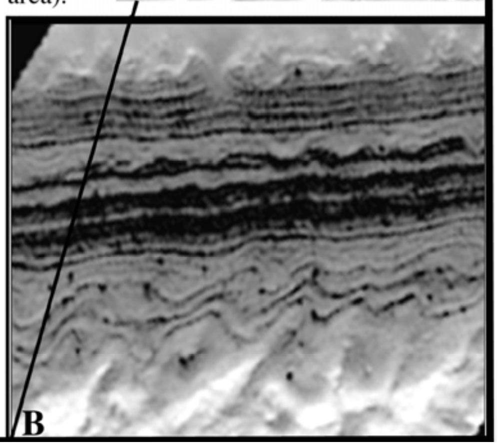
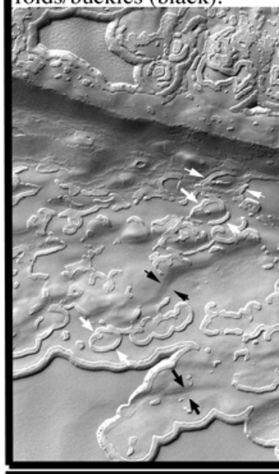




Fig. 2. MOC image M0702458 shows folds exposed in sublimating scarp face of the perennial south polar cap. (A) "Honeycomb" topography may be the eroded expression of boudin structure. (B) Details of folded outcrops (in shaded area) and what may be a folded bedding horizon (in area of direct solar illumination and at the edge of shadow area).

Fig. 3. MOC image m070-3801 shows compressed "swiss" (white arrows) and folds/buckles (black).



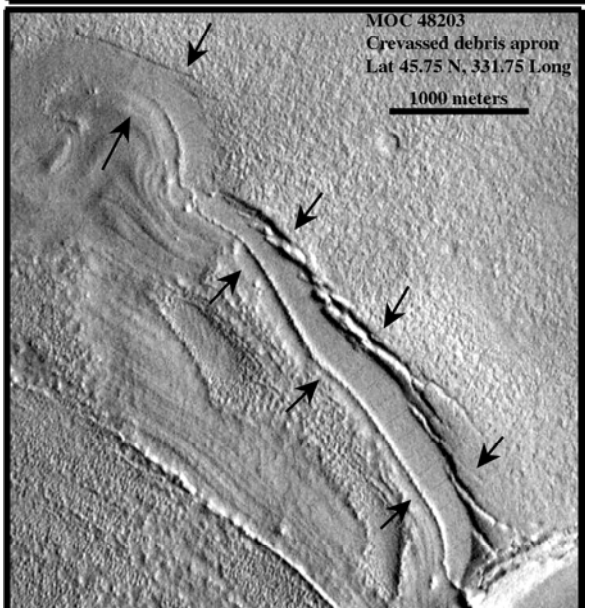




Fig. 4. Mutually obducting lobate debris apron 'plates.'

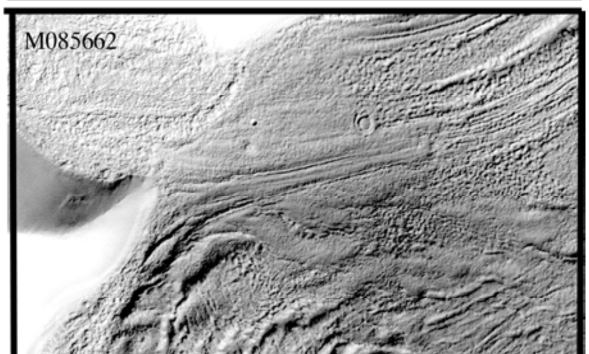



Fig. 5. Medial moraine and flow structure, Coloe Fossae.