ENVIRONMENTAL CONDITIONS OF ORIGIN OF SURFACE MORPHOLOGIES OF MARTIAN GLACIER-LIKE FLOWS. J.S. Kargel[1], Rick Wessels, and Brice Molnia[3], [1]U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001, U.S.A., jkargel@usgs.gov, [2]Arizona State University, rwessels@usgs.gov, [3]U.S. Geological Survey, bmolnia@usgs.gov

Introduction: Glacier-like flows are among the most characteristic landforms in the latitude belts between ± 30°-60° on Mars. These features include what are termed lineated valley fill (or striped valleys), lobate debris aprons, and concentric crater fill [1], so named depending on the geometry of the flows and the topographic features they are associated with. They exhibit many characteristics of terrestrial debris-covered glaciers and rock glaciers, and there have been no compelling models that would indicate that they are something other than these types of features. Here we explore details of lineated valley fill and other elongated Martian icy flows. While there are many striking similarities to valley glaciers on Earth, there are also major differences, especially in that the Martian glacier-like features lack the degree of hierarchical structure of tributaries that are common among terrestrial alpine valley glaciers. There are other differences as well. Our emphasis here is on the development of longitudinal lineations that are roughly parallel to valley sides. The analog is terrestrial medial moraines. We find that this analog serves well in some cases, but not so well in many others. In addition, there are many fine details of the ablated surfaces of Martian glacier-like flows, resolved in spectacular MOC and THEMIS imagery, that need explanations either in the context of terrestrial meltwater-driven ablation or sublimation-dominated ablation.

Background: It is generally assumed that water ice is the principal (or sole) icy constituent of Martian glacier-like flows, a fact that is supported by theoretical models that indicate the stability of buried ground ice at latitudes poleward of ± 30° to 40°. This interpretation gained ground when Mars Odyssey neutron spectrometer results confirmed that ground ice is present at shallow depths (mostly within the top few decimeters) poleward of about ±50°. The difference between the minimum latitude cutoff of the theoretical distribution of ground ice and the minimum for observed distribution of ground ice is consistent with the modeled increase of the minimum depth of burial as latitude decreases—at about ±30° to 40°, ground ice is thought to be stable but exists beneath a meter to several tens of meters of desiccated material, whereas poleward of ±50° ground ice may exist within centimeters to a meter of the surface; the neutron spectrometer is sensitive to hydrogen (ice or other forms of H_2O) only in roughly the top meter.

The modeled occurrence of ground ice stable zones is consistent with high-resolution MOC imaging of permafrost and icy flow surfaces, which have small-scale pitting that is considered indicative of destabilized or partly sublimated icy deposits prevailing in the region ±30° to 40°, but a comparative absence poleward of ±50°, suggesting that the ground ice there. As well as landforms and deposits containing large amounts of ice, are stable. In both models and observations, the latitude belt between ±40° to 50° is transitional, in that details of slope, slope aspect, surface albedo, and elevation affect whether stable ground ice can be shallow or must be deeply buried.

The nature of pitting and other degradation features begs the question of what environmental conditions are responsible. Clearly there was a change of environment, but what were those conditions? Was melting of ground ice involved, or only sublimation? Was water ice the only volatile, or was carbon dioxide or clathrate also involved? If melting occurred, was it ordinary liquid water, or hypersaline water, liquid carbon dioxide, or CO_2-saturated liquid water?

Observations:

Longitudinal striping. A ubiquitous feature of Martian glacier-like landforms is that they are entirely debris covered. They lack, at present, accumulation zones, unless accumulation occurs by underground spring discharge into talus. The dominant longitudinal striping (ridges and furrows) of fretted canyon flows and many other icy flows on Mars is in some cases unquestionably similar to the medial moraines on Earth. In other cases, the striping is unquestionably *not* the same phenomenon, but rather is more like the transverse rumples typical of rock glaciers. More often, the situation is ambiguous for lack of sufficient image coverage. Mainly lacking are indications of nonsteady flow, such as seen in the contorted medial moraines of terrestrial surge-type glaciers; however, some instances of such contortions have been identified on Mars.

Surface pitting. A variety of surface pits are observed in the Martian glacier-like flows. These features commonly are structurally controlled and oriented along medial moraines and other longitudinal stripes; the same is often observed in terrestrial glaciers, where the presence of rock debris is thought to plug drainage conduits, making surface ponds stable; the surface ponds absorb and transmit to underlying

ice more thermal energy than in adjacent unwetted spots on the glacier's surface, so the ponds tend to grow until they intersect a conduit that cannot be plugged. Such ponds often are asymmetric, even crescentic, and commonly have preferred orientations produced by glacier structure and solar insolation. It is tempting to attribute the common pitting in Martian debris-covered glaciers to the same type of melt-pond phenomenon. However, we lack on Earth adequate examples of debris-covered glaciers whose ablation regime is overwhelmingly due to sublimation.

Whether they have grown by melting or sublimation, many of the pits on lineated valley fill and lobate debris aprons have preferred orientations that probably represent the etching of ice-tectonic features, such as shear crevasses and extension crevasses, which underlie the debris cover. This is very commonly observed on terrestrial debris-covered glaciers.

Local melt features. Gullied glacier surfaces are common in the southern hemisphere but absent in the northern hemisphere; in fact most of the small-scale gullies globally are associated with one of two types of landforms—lobate debris aprons and apparent nonglacial alluvial fans. Debris flow activity appears to be a major if not the dominant cause of gullies. Water-saturated debris would appear the likeliest cause. In both associations, the source of water would appear to be either surface melting or near-surface underground melting. Such debris flows and gullies are ubiquitous in alpine glacial settings of Earth.

Compelling (though not unequivocal) cases of proglacial outwash valley trains occur but are rare and have been identified only in the southern hemisphere. The drainage appears to be largely or entirely subglacial and exits at the glacier snouts—a very common feature on Earth. Apparently lacking on Mars, however, are extensive supraglacial drainage networks.

Flat, smooth, sharp-edged plains that may be glacier-marginal lake basins (kilometer-size) also occur, but are rare, and appear also to point to melting as a locally important process in glacier ablation. Some glacier-marginal lakes have been identified in the fretted terrain.

A spectacular partial analog to the glacier-carved basins and interconnected waterways of the Boundary Waters Canoe Area (Minnesota) occurs in the northern fretted terrain and will be discussed in detail. This water drainage/storage system is perplexing for its specific implications, which would seem to be that a large crater filled to overflowing, with no external water source, and emptied into a fretted channel, where the drainage contributed ice mass.

Conclusions: We have not yet arrived at definitive answers to the questions in the "Background" section, but we have identified some new observations and Earth analogs that bear on these issues. It seems that sublimation is involved in the ablation in most instances of Martian glacier-like features, but a compelling case for melting also can be made in many instances. Evidence of melt contributions to glacier ablation seems stronger in the southern hemisphere than in the northern hemisphere. Since the distribution of glacier-type landforms and possible melt- and sublimation-related ablation features pretty well matches the latitude belts where ground ice is predicted thermodynamically and where any near-surface ice should have become unstable, we must conclude that H_2O is overwhelmingly the major volatile. In the majority of cases sublimation appears to have been the dominant ablation process, as there are no melt features in evidence, though locally melting did occur. Whether CO_2 and or high salt concentrations may have contributed to melting at low temperatures is another finer, but important issue that needs to be resolved.

For all the spectacular new evidence, much work remains in analyzing MOC and THEMIS imagery and examining landforms in the context of detailed topographic data from MOC. A more definitive assessment of the environmental indicators present on Mars also awaits further scrutiny of terrestrial analogs.