ARSIA MONS FAN-SHAPED DEPOSIT RIDGED FACIES AS COLD-BASED GLACIER DUMP MORAINES: James W. Head* and David R. Marchant†, †Dept. Geol. Sci., Brown Univ., Providence, RI 02912 USA, *Dept. Earth Sciences, Boston University, Boston MA 02215

Introduction and Background: Arsia Mons contains a distinctive and unusual lobe, or fan-shaped deposit on its western flank [1,2] that displays three facies: 1) An outermost ridged facies, consisting of a broad thin sheet characterized by numerous ridges, 1->10 km in length, and spaced a few hundred meters to several kilometers apart, that extend over topographic barriers without apparent deflection. 2) A knobby facies, which forms an extensive area of chaotic terrain that consists of subrounded several-kilometer-diameter hills; some hills are elongated downslope, and others form chains that are parallel to subparallel to the ridges in the ridged facies. 3) A smooth facies, which contains arcuate lineations and diffuse to lobate margins; the smooth facies appears to overlie areas of the knobby facies. In this contribution we focus on the nature and origin of the ridged facies.

Ridged Facies Description: Scott and Zimbelman [1] described the ridged facies of the fan-shaped deposit as a "broad, thin sheet marked by abundant ridges that extend over topographic barriers without apparent deflection. Individual ridges are about 1 to more than 10 km long, spaced a few hundred meters to several kilometers apart; ridges [are] connected in places by shorter crossribs."

The superposition of the ridged facies over the ejecta of an impact crater is shown in Fig. 1. In this example, the individual narrow parallel ridges cross the ejecta facies and extend right up to the rim crest of the crater. There is no apparent offset in the underlying ejecta deposit or modification or shortening of the crater itself that might suggest that deformation of the surface by landsliding or folding of an upper surface might have occurred. Instead, the relationships strongly suggest that the ridges are depositional features and the process of deposition was one in which the underlying crater and lava flow substrate was undisturbed by the emplacement of the ridged terrain.

The ridged facies consists of several different scales of ridges (Fig. 2), the largest of which appears to be the outermost ridge. The different sized ridges are not randomly distributed in ridge sequence and there appear to be somewhat systematic changes in size. Ridges also change character along strike. Comparison of Fig. 2 and Fig. 3 shows that the outermost ridge changes from a straight to mildly sinuous ridge to one which is somewhat discontinuous and has somewhat cuspatelike echelon sections. Another characteristic of the ridged terrain is that ridges with one orientation can overlie ridges with another orientation. In Fig. 4, ridges of the outermost part of the ridged facies can be seen to extend beneath ridges of a more inner set of parallel ridges. This second set ranges from subparallel up to about 45 degree orientations relative to the outermost, older set. Examination of the relationship with the next innermost hummocky facies (Fig. 2, 3) shows that these ridges underlie at least the outer part of the hummocky facies. Evidence for multiple events is also seen in Fig. 5, where a large sinuous ridge snakes across the surface, at an angle to, and apparently overlying, the more systematic set of smaller ridges below. Similarly, in Fig. 6, a set of larger ridges crosses the finer set of ridges at angles of from 45 degrees up to almost 90 degrees. Examination of the relationships between the ridged facies and the next innermost knobby or hummocky facies shows that at least in some areas, the knobby facies is superposed on the ridged facies. This is apparent in Figs. 2 and 4 where ridges of the ridged facies can be seen protruding through the superposed knobby facies.

MOC images show evidence for abundant dunes in the vicinity of ridges suggesting that the ridges are composed of fine-grained material that is subject to eolian erosion. MOC images also show that the outermost ridge is asymmetrical with its steep side facing outward. Morphology of the smaller ridges varies, ranging from peaked, rounded, to flat-topped. Few distinctive associated features are seen in the ridged facies. If the interpretation of Scott and Zimbelman [1] that these features represent glacial moraines is correct, then one might expect to see various features associated with glaciers, their movement and their melting. However, we found no evidence for the extensive development of striated radial ridges (drumlins), melt-related features (e.g., sinuous channels, lake deposits, or eskers). In addition, analysis of dressed MOLA topography shows clear evidence that the lava flows of Arsia Mons that exist beyond the outer margin of the ridged facies extend underneath the ridged facies virtually unmodified by the development of the ridged facies.

In summary, the ridged facies consists of a series of parallel linear ridges that surround the fan-shaped deposit as a whole and which show: 1) a striking continuity and parallelism, 2) variation in the width and height of individual ridges, 3) no evidence of interaction with underlying topography, 4) no evidence for significant scour or melt-related features, 5) evidence for superposition of some ridge sets on others, 6) evidence for superposition of at least the outer part of the knobby facies on the ridged facies, and 7) modification by eolian processes.

Ridged Facies Interpretation: On the basis of their superposition on lava flows and a large impact crater, the facies was interpreted by Scott and Zimbelman [1] as recessional moraines, resulting from the emplacement of "glacial drift deposited long the margins of an ice sheet during successive stages in its ablation and retreat.” On the basis of the new characterization using MGS data, we do not find support for a landslide or volcanic origin for these features. The very distinctive substrate preserved below the surface (lava flows and impact craters), the blanket-like nature, together with the extreme regularity of the ridges, contrasts distinctly with the landslidelike features seen in the Olympus Mons aureole, for example. Similarly, although dunes and ridges can be produced during pyroclastic flow emplacement, the regularity of these and their great lateral extent would require an unexpected homogeneity in turbulent flow [3].

In summary, we support the interpretation of [1] and explore more specific glacial environments in which such features might form. As previously described a simple classification of glaciers [4] includes: 1) Temperate glaciers, which are generally everywhere at the Tm (wet-based), 2) Polar glaciers, which are below the Tm throughout, and are frozen to underlying beds (cold-based), and 3) Subpolar glaciers, which are temperate in their inner regions, but have cold-based margins. On the basis of present surface temperatures on Mars, the vast majority of the surface is likely to be such that any glaciers will be cold-based. Recently, the nature and evolution of terrestrial cold-based glaciers have become much better known, particularly through the Antarctic exploration program and research in the Antarctic Dry Valleys [e.g., 5, 6], which repre-
sent conditions on Earth that are likely to be most similar to those of the cold, hyperarid regions of Mars.

Cold-based glaciers have two fundamental characteristics: 1) they show little to no interaction with the underlying terrain at the scales described here, and 2) they show little to no evidence of extensive melting and drainage processes. As cold-based glaciers retreat by sublimation of ice, their margins are characterized by the deposition of any entrained debris. In stationary or slowly changing ice margins, gravitational processes deposit debris as ice-contact aprons of scree or debris flows, or as linear ridges (dump moraines) where the ice margin remains stationary during debris accumulation. Dump moraine size is related to supraglacial debris volume and length of the standstill. For example, on Earth, small dump moraines form when glaciers remain stationary during winter but retreat during summer, with each moraine marking an increment of debris accumulation during one winter [4]. Dump moraines are abandoned during glacial thinning and their inner facies are subject to collapse and reworking [7]. As the glacier reestablishes at a new position a new dump moraine will be formed within the older one. Arctic and polar glaciers accumulate by a combination of dry calving and limited melting at the base of steep terminal ice cliffs. Aprons have steep ice-contact slopes, with gentler ice-distal slopes (determined by properties of the debris), and are subject to modification following deglaciation, sometimes due to ablation of incorporated ice blocks [7-10]. Dump moraines are superposed on the substrate with virtually no modification of the substrate.

We thus interpret the ridged facies as a series of dump moraines, each representing a period of standstill of a cold-based ice sheet followed by a phase of retreat. The very even distribution of the ridges and their continuity means that the debris distribution must be extremely homogeneous and that the ice-meltback must have been very even and symmetrical. The evenness of debris distribution favors widespread fine debris emplaced by pyroclastic eruptions or dust deposited from the atmosphere, as opposed to debris scoured from below the glacier or deposited locally on top of the glacier by rockfalls.


Figures 1-6. Viking Orbiter examples of characteristics of the ridged facies.