ORIGIN OF SINUOUS RIDGES IN THE DORSA ARGENTEA FORMATION: NEW OBSERVATIONS AND TESTS OF THE ESKER HYPOTHESIS: J. W. Head[1] and Bernard Hallet[2], [1]Dept. Geol. Sci, Brown Univ., Providence, RI 02912 USA, [2]Quaternary Res. Center, Univ. Washington, Seattle, WA 98195 USA, james_head@brown.edu

Introduction: In this analysis, we use MOLA altimetry data and various products derived from these data to test further the esker hypothesis for the origin of sinuous ridges in the Hesperian-aged Dorsa Argentea Formation (DAF) in the south polar region of Mars [summarized in 1-5]. In a companion analysis, we have reviewed the physical principles associated with esker formation from glacier physics and their corroboration through observations of a well-preserved esker system [6-8]. These observations and criteria [6] provide a basis for further testing of the esker hypothesis. Here we examine and compare map patterns, longitudinal profiles of sinuous ridges and relation to local slope, ridge cross-sectional profiles and their types, the relationship of ridge type and continuity to underlying topography, and ridge intersection and superposition relationships.

Observations and analysis: *1) Map patterns and scale*: The patterns and scale of the main ridges in a portion of the Dorsa Argentea Formation (Figure 1; see also Figure 1 [3] and 3 [5]) are very similar to those in the Katahdin esker system (Figure 1 [6]). Similarities include sinuosity, down-slope convergence, branching patterns, branching angles, width of systems and spacing between major eskers. They differ in total length, commonly being longer on Mars.

2) Longitudinal profiles of sinuous ridges and relation to local slope: A longitudinal profile of one of the ridges in Figure 1 (Figure 2; marked 1) shows that this ridge descends from an elevation of about 1320 m elevation to the bottom (~1080 m) of the valley (probably a ~100 km diameter very degraded crater in this part) and then continues up the other side of the valley to about 1200 m elevation, where it passes through a low in the valley wall (degraded crater rim?). This profile illustrates several properties of these ridges: 1) they rise and fall with regional topography (in contrast to river courses), 2) they cut across major topographic trends (the valley), 3) their height (and width) change along strike, and 4) their height is generally lowest at steepest background slopes (e.g., at the beginning and end of the profile). These properties are very similar to those of esker longitudinal profiles in the Katahdin region (Figure 2 in [6]) and other glacial environments.

3) Ridge cross-sectional profile types and distribution: We found several types of ridge cross-sectional profiles in our analysis (Figure 3): 1) simple symmetrical (inverted-v), 2) flat topped, 3) flat-topped with median troughs and ridges. Type 1 is by far the most dominant type (see Figure 1 [3] and 3 [5]), occurring throughout the region and concentrated in relatively flatter areas or areas of low regional slope. Types 2 and 3 occur primarily where Type 1 ridges climb locally steeper slopes or approach topographic barriers, such as other preexisting sinuous ridges, scarps, or crater rims (see below); locally asymmetrical profiles (e.g., second and fifth examples of Type 3, Figure 3) often occur where the ridge is climbing up the side of a regional slope. These three types of features are similar to terrestrial esker cross-sectional profiles (sharp crested, multiple crested, broad crested) in their morphological shape and relative abundance of occurrence [6-8].

4) Relationship of cross-sectional ridge types to underlying topography: A characteristic of terrestrial eskers (Figures 3, 4 in [6]) is their changing direction, morphology and continuity in relation to topographic obstacles [6-8]. We examined places where the sinuous ridges approach topographic obstacles and noted their behavior there (Figure 4). The ridges commonly passed through the lowest points in the topographic obstacle (usually a ridge or a crater rim); we also found that the ridges often became indistinct or were missing in the vicinity of the pass through the topographic obstacle. For example, in Figure 4 three sinuous ridges (marked by arrows) meander across the valley which extends from right (higher) to left (lower); a prominent ridge extends across the valley (arrow marked R). Sinuous ridge 1 becomes broader and more diffuse as it approaches one of the lower points in the ridge and disappears in the pass. Sinuous ridge 2, a distinctive inverted-v shape, approaches the ridge obliquely and broadens as it climbs the slope, and disappears in the pass. Both ridges 1 and 2 remerge on the other side of the ridge. Sinuous ridge 3 becomes indistinct in the pass, broadens in the second pass between the ridge and the valley wall, and then narrows and becomes a distinct Type 1 ridge on the valley floor. In all three of these cases, ridge morphology changes in the vicinity of the obstacle; ridges change from sharp-crested inverted v-shaped to broader flatter ridges as the gap is approached, and the sinuous ridge is either highly modified (3) or more commonly missing (1,2) in the immediate vicinity of, and in, the gap. These relationships are similar to those observed in the Katahdin region (Figures 3, 4 in [6]) and other glacial environments on Earth. These changes and gaps are attributed to depression of equipotential surfaces at regions of elevated pressure over the proximal slopes of hills at the base of the ice sheet, resulting in closer spacing of equipotentials at crests and local increases in the transporting capacity as the subglacial river crosses the pass [7,8].

5) Ridge intersection, cross-cutting and superposition relationships: Several sinuous ridges show branching relationships (Figure 1) where one ridge approaches the other obliquely and merges with it. Eskers are known to show these

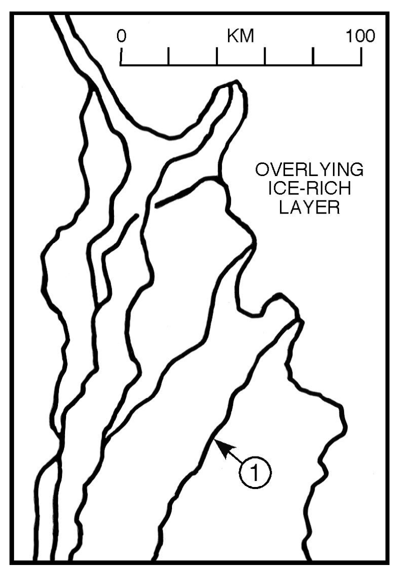

Figure 1. Map pattern of the main sinuous ridges in Dorsa Argentea (see also Figure 1 [3] and 3 [5]). Note the close similarity to patterns in the Katahdin region (Figure 1 [6]). Number 1 indicates ridge in Figure 2.

types of relationships when water-filled tunnels migrate laterally due to changes in shape and flow, causing tunnel capture [6-8]. In other cases (Figure 1) sinuous ridges appear to cross one another. Examination of a topographic map of two such examples (Figure 5) shows evidence that the ridges are actually superposed on one another. Ridge 1 extends NW-W across the map area, ridge 2 generally N, and ridge 3, NW. At the first intersection (A), ridge 1 is Type 1 as it approaches ridge 2, rapidly broadens in the upslope direction as it reaches ridge 2, continues over the top of ridge 2, being 20-40 m higher than ridge 2, and then narrows and decreases in elevation on the other side to return to Type 1. At intersection B, ridge 2 shows similar superposition relationships with ridge 3, suggesting that ridge 2 is younger that ridge 3. On Earth this type of behavior is not observed in subaerial river development, but is observed in esker systems [9]. It is consistent with the physics of flow in a water-filled channel below an ice body, as outlined in [6, 8], where the hydraulic head of the water-filled channel causes channels to migrate up and over pre-existing topography, such as the sedimentary ridges (eskers) of previous channels.

Summary and conclusions: In order to test further the esker hypothesis for the origin of sinuous ridges in the Dorsa Argentea Formation, we have outlined a set of predictions from the physics of glacier and water-filled channel behavior, and field observations of terrestrial eskers [6-9]. On the basis of the topographic characteristics of sinuous ridges in the DAF, we find that there are numerous similarities to those predicted and observed for terrestrial eskers (map patterns and scale, longitudinal profiles and relation to slopes, ridge cross-sectional profiles, relationship of ridge morphology to underlying topography and obstacles, and ridge superposition relationships). We conclude that these observations significantly strengthen the esker hypothesis for the origin of the sinuous ridges in the Dorsa Argentea Formation on Mars.

References: 1) K. Tanaka and D. Scott, *USGS Map I-1802C*, 1987; 2) A. Howard, *NASA TM-84211*, 286, 1981; 3) J. Head, *LPSC 31*, #1117, 2000; 4) J. Head, *LPSC 31* ,#1116, 2000; 5) J. Head and S. Pratt, *JGR*, in review, 2000; 6) J. Head and B. Hallet, *LPSC 32*, #1366, 2001; 7) R. Shreve, *J. Glaciology*, 11, 205, 1972; 8) R. Shreve, *GSAB*, 96, 639-646, 1985; 9) R. J. Price, *Glacial and Fluvioglacial Landforms*, Hafner Publ. Co., New York, 242 p., 1973; D. Benn and D. Evans, *Glaciers and Glaciation*, Wiley, New York, 734 p., 1998; W. Warren and G. Ashley, *J. Sed. Res*., 64, 433-449, 1994.

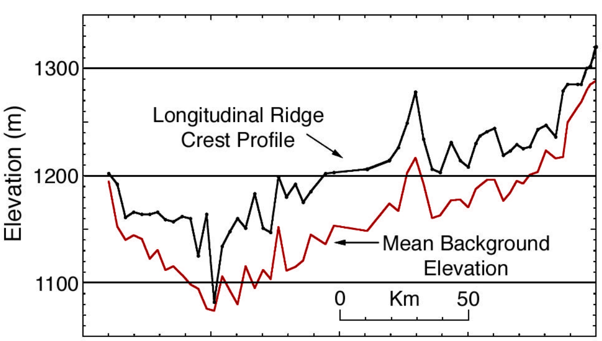

Figure 2. Longitudinal profile of a sinuous ridge. Compare to those in the Katahdin region (Figure 1 [6]).

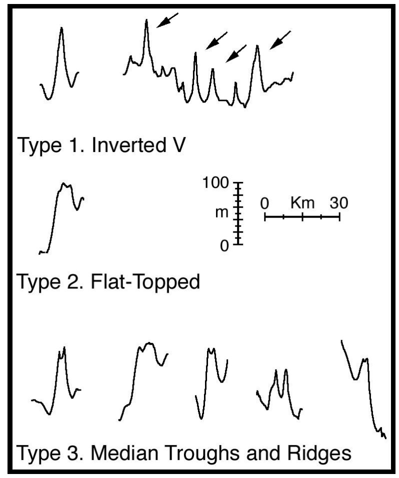

Figure 3. Cross-sectional profiles of sinuous ridges illustrating the main types detected.

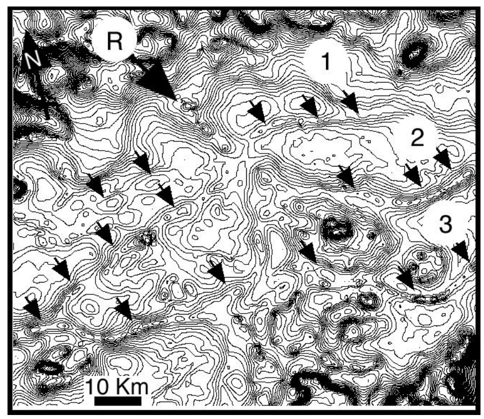

Figure 4. Contour map of sinuous ridges (1-3; delineated by arrows) and their relationship to positive topography (cross-cutting ridge, R). Contour interval is 10 m. Center of map is at 77°S, 18°W. Compare to those in the Katahdin region (Figures 3, 4 [6]).

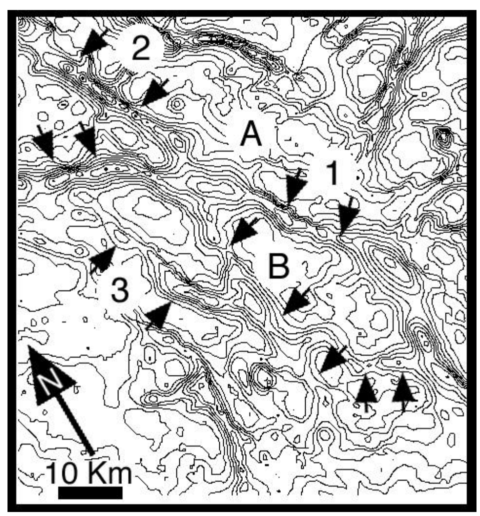

Figure 5. Contour map of sinuous ridge intersection relationships. Arrows indicate ridges 1-3, letters indicate intersections A and B. Contour interval is 10 m. Center of map is at 77.7°S, 35°W. Compare to those in the Katahdin region (Figures 3, 4 [6]).