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TERRESTRIAL GLACIAL ESKERS: ANALOGS FOR MARTIAN SINUOUS RIDGES;

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Introduction. Last year we introduced a glacial model for the Argyre region [1], a concept which we now extend [2], and which we recently integrated with a Global Hydrologic Model incorporating many other aspects of martian geology [3]. The original insight for the glacial interpretation came from an unusual system of sinuous ridges in Argyre (Figs. 1,2). Similar ridges occur in many areas of Mars, mostly at middle to high latitudes (Figure 3). Very few geologic mechanisms can form such ridge systems, inasmuch as they have distinctly fluvial planimetric structures, yet are ridges, not valleys or channels. Proposed origins as sand dunes, wrinkle ridges, lava flows, dikes, clastic dikes, or beach ridges [4-7] have no observational support in our view, since they are unsatisfactory in explaining ridge morphologies, planimetric structure, scale, and regional landform assemblages. Despite wide agreement that the martian ridges strongly resemble glacial eskers, this hypothesis has been presented with great equivocation due to a perceived lack of other glacial landforms [5,8]. Quite to the contrary, we have shown that the martian ridges actually do occur in logical ordered sequences with many other types of characteristically glacial-appearing landforms [1,2]. Here, we further support the esker hypothesis in isolation from considerations of regional landform assemblages.

The esker model. Glacial meltwater streams flowing on the surfaces of stagnant glaciers or in subglacial tunnels collect coarse sediment on their beds, as most streams do, but leave these deposits as elevated ridges, termed *eskers*, after the ice ablates (Figs. 4,5). Eskers are among the most abundant, widespread, and most clearly diagnostic features indicating Pleistocene glaciation [9]. Terrestrial eskers occur on almost as wide a range of scales as normal streams, from several m to over 400 km long, from a few cm to 200 m high, and from 25 cm to 6 km wide [9,10]. Landsat images show hundreds of eskers 300-1200 m wide extending in well-integrated systems across much of Canada [11,12].

Terrestrial eskers sometimes occur as lone, sinuous ridges, in alignments of disconnected bead-like hills, or in complex systems (Figure 6). Common dendritic and anastomosing planimetric structures of complex esker systems [9,11,13] may reflect normal meltwater drainage, or can be inherited from preglacial fluvial valleys on the glacier bed. Dendritic distributary patterns are also known [14]. These patterns can be modified by ice shear, producing en echelon patterns. Rectilinear and orthorhombic esker systems can be generated by drainage through glacial crevasses. Eskers can be deposited across subglacial topographic divides and may cross-cut other eskers. Eskers commonly grade longitudially into or occur on the floors of subglacially-eroded fluvial valleys ("tunnel valleys") formed during catastrophic bursts of subglacially stored meltwater [14]. Terrestrial eskers can be sharp-crested, rounded, flat-topped, or double-ridged, and commonly have axial depressions (kettles) on their crests [9]. Axial depressions and double-ridged structures are collapse features formed when ice cores melt.

Terrestrial eskers are composed mostly of sand and gravel, but also boulders and clay, sometimes all in one vertical section. Sediments are usually well-sorted as they are in most other fluvial deposits (Fig. 4), and both normal and reverse grading are common, indicating large variations in water discharge. Fig. 4 shows a large faceted boulder embedded in otherwise well-sorted esker sediments; the boulder apparently fell in from the roof or wall of the ice tunnel in which the esker was deposited. Slumping and other minor mass wasting commonly occurs as ice tunnel walls melt and withdraw their support. Planar subhorizontal bedding and cross-stratification are common in eskers; the scale of these layerings ranges from centimeters to tens of meters.

Martian eskers. Every aspect of terrestrial eskers and esker systems is matched by analogs on Mars. Martian esker systems are up to 800 km long; individual ridges are typically 100-200 km long, 600-2400 m wide, and on the order of 40-160 m high. They occur as lone, sinuous ridges; in cross-cutting and en echelon sets; in anastomosing, dendritic, rectilinear, and distributary-type systems; they occur in associations with tunnel valleys, braided outwash, and many other glacial landforms; and, martian eskers include sharp-crested, flat-topped, rounded, and double-ridged varietes, and display internal bedding.

Conclusions. Martian sinuous ridges are similar in every respect to terrestrial eskers: scale, morphology, planimetric pattern, and associations with other probable glaciogenic landforms. In sum, we find the esker hypothesis well supported. Eskers are glaciofluvial structures, and owe their existence to large-scale melting of stagnant temporate glaciers. Thus, eskers are indicators of an ameliorating climatic regime after a protracted episode of cold, humid conditions. We infer from the apparent existence of eskers on Mars that large areas of that planet were formerly heavily glaciated; that Mars underwent climatic variations similar to those of the Pleistocene on Earth; and that the martian atmosphere was formerly moist, dense, and warm.

References. 1. J.S. Kargel and R.G. Strom, 1990, Lun. Planet. Sci. XXI, 597-598. 2. Other abstracts, these volumes, by Kargel et al., Johnson et al., Strom et al., and Baker et al. 3. V.R. Baker, R.G. Strom, V.C. Gulick, J.S. Kargel, G. Komatsu, and V.S. Kale, 1991, submitted to Nature. 4. M.H. Carr et al., 1980, Viking Orbiter Views of Mars, NASA SP-441, p. 122; and M.H. Carr in The Geology of the Terrestrial Planets, NASA SP-469, p 232. 5. S.W. Ruff and R. Greeley, Lun. Planet. Sci. XXI, 1047-1048. 6. K.L. Tanaka and D.H. Scott, 1987, USGS Map I-1802-C. 7. T. Parker, 21st Lun. Planet. Sci. Conf., personal communication. 8. A. Howard, 1981, Repts. Planet. Geol. Prog. - 1981, NASA TM 84211, 286-287. 9. R.J. Price, 1973, Glacial and Fluvioglacial Landforms, Hafner Publ. Co., New York, 242 pp. 10. H. Lee, 1965, Geol. Surv. Canada Pap. 65-14, 1-17. 11. glacial map of Canada. 12. G.S. Boulton and C.D. Clark, 1990, Nature 346, 813-817. 13. R.L. Shreve, 1985, Quat. Res. 23, 27-37. 14. H.E. Wright, 1973, Geol. Soc. Amer. Mem. 136, 251-276.

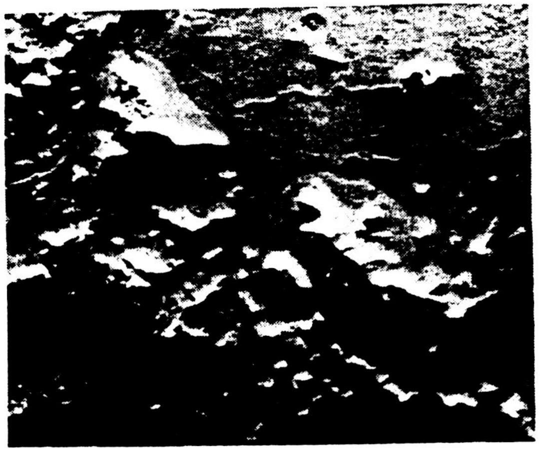

Figure 1. Portion of martian Argyre Basin showing features supportive of glaciation, including anastomosing system of esker, glaciolacustrine plains, and associated cirques, aretes, rock glaciers, and other glacial/periglacial landforms. Scene width about 300 km, illumination from top right.

Figure 2. Close-up of esker ridge system in Argyre. Scene width about 50 km, illumination from top.

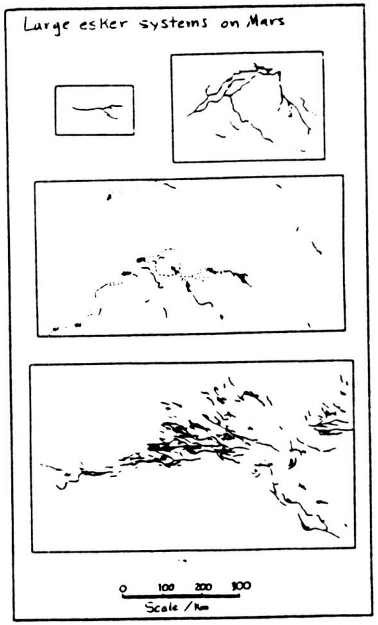

Figure 3. Planimetric patterns of esker systems on Mars.

Figure 4. Glaciofluvial sediments in an esker in Minnesota. Keys for scale.

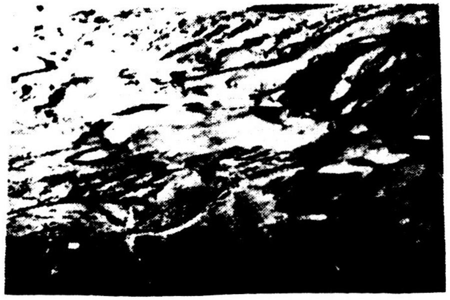

Figure 5. Esker emanating from subglacial meltwater channel at the front of the Woodsworth Glacier (upper right, very dirty) in Alaska and terminating in an outwash fan (lower left). Note also striated till and kettles.

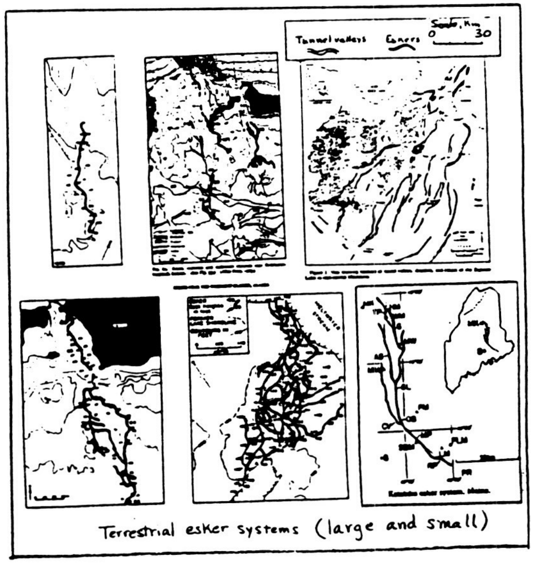

Figure 6. Planimetric patterns of terrestrial esker systems.