Paleodischarge Modeling of the Argyre Ridge Esker Model. S.M. Metzger, Dept. of Geological Sciences, MS-172, University of Nevada, Reno, Reno, NV 89557

Throughout the past decade the sinuous ridges on the floor of the Argyre Basin have drawn considerable interest as potential remnants of processes that recorded key events in the ancient Martian climate. Although lake berms, aeolian dunes, and ice-shove ridges have all been energetically advanced, the glacial esker explanation has garnered the strongest reactions. The following exercise will strive to develop reasonable quantitative calculations of the flow discharge that would have been responsible for the Argyre ridges.

The ridges form a somewhat anastomising open network around the southern edge of the Argyre basin, at 55°S, 41°W. Based on MOLA, MOC and Viking image data, the following calculations will assume an average "standard" geometry for the ridges. Indeed, the striking feature of the sinuous ridges in Argyre is their apparent uniformity (which will be discussed later as one primary critique of their interpretation as eskers). They commonly maintain a uniform width of 1-2 km, a positive relief above the basin floor of several dozen meters, are capped commonly by flat or occasionally by multiple crests, and run unbroken (with 97% continuity) for hundreds of kilometers. Numerous randomly placed cross-sections indicate, for the sake of flow reconstruction calculations, that each ridge is conservatively defined as a trapezoid 1.3 km wide at the base, rising 52 m to a flat top crest 100 m across.

Eskers form when meltwater drainage tunnels develop along the base of stagnating glaciers. The condition of "stagnating glaciers" is crucial: the ice mass must be thick enough to actively deform and thus bring basal rock debris laterally into the subglacial drainage network but not deform so as to flow forward in a manner that would disrupt and destroy the tunnel sediments. Terrestrial eskers usually contain anticlinal sand and gravel layers that formed in situ and thereby record the transition into a deglacial period.

To conduct a paleoflow reconstruction of the drainage tunnel, it is necessary to estimate the shape of the conduit, its surface roughness, and the roughness of the materials deposited on its floor. Several authors have pointed out that hydrostatic pressures of full pipe flow measured in active subglacial tunnels are substantially higher than predicted by circular tunnel Rothlisberger and Shreve calculations. Consequently, this study assumes that the ice conduit takes the shape of a low broad arc 1.3 km wide and 60 m in height. Thus the ice tunnel is an overturned parabola covering a trapezoidal ridge. Although there is no report in the literature of measurements of the scalloped surfaces of ice tunnels, engineering flow roughness studies of similar pipe surfaces yield an estimate of Manning's roughness coefficient n of 0.016 for the ice conduit. Chow's fundamental work on the hydraulics of natural channels yeilds n = 0.040 for the gravel surface of the existing esker deposits. These roughness coefficients are simplistic and are likely to increase in the turbulence of a complex channel that includes boulders and countless tributary influx. Conversely, n may be reduced if the flow becomes more laminar due to a high concentration of suspended load.

Determining the conduit slope is difficult. The extent to which glacial ice covered the Argyre basin floor is conservatively estimated based on the presence of the sinuous ridges. Using MOLA data, this leads to a declivity of 300 m over a distance of 300 km, for a slope of 0.001. If ice extended further into the surrounding basin highlands, then the slope will be substantially greater and all of the following calculations will be more impressive.

The Manning equation (1889) computes mean velocity of flow:

$$V = \frac{KR^{\frac{2}{3}} s^{\frac{1}{2}}}{\left(\frac{n_i + n_e}{2}\right)} = 2.88\ \mathrm{ms^{-1}} \qquad (1)$$

where K = 1 (SI units)
n_i = ice wall roughness = 0.016
n_e= esker gravel roughness = 0.040
s = slope = 0.001
R = hydraulic radius = cross-sectional area A / wetted perimeter P = 4.0 m

Using the Continuity equation; An axiom stating that the rate of flow past one section of a conduit is equal to the rate of flow past another section of the same conduit plus or minus any additions or subtractions between the two sections:

$$Q = V \times A$$
$$= 2.88\ \mathrm{ms^{-1}} \times 8767\ \mathrm{m2}$$
$$= 2.53 \times 10^4\ \mathrm{m^3s^{-1}} \quad (2)$$

Discharge = Velocity x cross-sectional Area (mean velocity measured at 0.5 depth)

Reynolds number is a numerical quantity used as an index to characterize the type of flow (laminar vs. turbulent) in a hydraulic structure in which resistance to motion depends on the viscosity of the liquid in conjunction with the resisting force of inertia. It is the ratio of inertia forces to viscous forces, and is equal to the product of a characteristic velocity of the system (e.g. the mean, surface, or maximum velocity) and a characteristic linear dimension, such as diameter or depth, divided by the kinematic viscosity of the liquid; all expressed in consistent units in order that the combinations will be *dimensionless*. The number is chiefly applicable to closed systems of flow, such as pipes or conduits where there is no free water surface:

$$\mathrm{Re} = \frac{V \times d}{\upsilon} \qquad (3)$$

where V = flow velocity
d = internal diameter of the pipe
υ = kinematic viscosity of the fluid

υ

Using the same engineering calculations that yielded the Manning roughness coefficients n_I and n_e, a quasi-independent test of the above calculations is achieved by solving for the kinematic viscosity and comparing that value to independently derived value for brine (3.4 x 10^{-5} poise):

$$\upsilon = \frac{Vd}{\mathrm{Re}} = 2.47 \times 10^{-5} \text{ poise} \qquad (4)$$

where V = Velocity = 2.88 ms^{-1}
d = diameter of pipe = 40 m
Re = Reynolds number = 4.2 x 10^6

If the ridges are eskers, then given the ridge continuity, the esker ridges were formed concurrently. Therefore, flow entering the channel at one end would proceed to the far end along the entire ridge length. Travel time for a single water drop:

$$t = \frac{L}{V} = 300 \text{ km} / 2.88 \text{ ms}^{-1} = 10^5 \text{ secs}$$

$$= 29 \text{ hr} \qquad (5)$$

Over a period of 29 hrs. with a mean velocity of 2.88 ms^{-1}, a fluid volume of 2.63 x 10^8 m^3 would pass through this single "standard" drainage tunnel. In one week, approximately 2 km^3 of water is discharged through the conduit.

Problems associated with the esker model for the Argyre ridges have been discussed at length in the past []. Primary among them is the challenge of reconciling the high degree of uniformity in all aspects of Argyre ridge morphology with the highly variable nature of nearly every esker described in the terrestrial literature or directly studied by this author.

The flows calculated in this report are substantial. Like any natural river, subglacial tunnels experience wide fluctuations in flow characteristics with resulting variation in sedimentation. Like any natural river, depositional sections alternate with erosional sections and, given the velocity determined above, scour will develop on many existing deposits. No esker over 5 km in length reported in the terrestrial literature has greater than 67% continuity.

Thus several serious questions are raised. Why are the Argyre ridges so uniform? (Possible answer: very high suspended load [i.e. clay] suppresses turbulence and inhibits scour.) Was there sufficient ice to deliver enough water to the subglacial drainage network to form these features (versus returning to the atmosphere via sublimnation)? How far into the uplands did the ice extend and what effect would that have on these calculations? Where did all the liquid runoff go and can any outwash deposits be determined?

Refs: [1] Chow et al., 1988, Appl. Hydrol. [2] Graf, 1971, Hydraul. Of Sed. Trans. [3] US Bur of Reclam., 1965, Engin. Mono. #7 [4] Hooke et al., 1990, J of Glac. V36, #122 [5] Metzger, 1992, LPSC [6] Metzger, 1994, Thesis [7] Hauser, 1991, Prac. Hydraul. Hndbk