MODELLING ESKER FORMATION ON MARS

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Introduction

Eskers are sinuous sedimentary ridges that are widespread across formerly glaciated landscapes on Earth (Figure 1), [e.g. 1]. They form when sediment in subglacial tunnels is deposited by meltwater, and are exposed when ice retreats.

Some sinuous ridges on Mars have been identified as eskers; some are thought to have formed early in Mars' history beneath more extensive ice sheets [e.g. 2], but smaller, younger systems (Figure 2) associated with extant glaciers in Mars' mid latitudes have also been identified [3, 4].

Elevated geothermal heating and formation during periods with more extensive glaciation have been suggested as possible prerequisites for esker deposition [3, 4]. Numerical modeling [5, 6] also supports geothermal heating as a possible cause of the area of assumed liquid water beneath Mars' south polar ice cap [7].

Figure 1. High resolution (25 cm/pixel) vertical aerial imagery of the Flemington eskers near Nairn, Scotland. The eskers can be seen as a series of wooded ridges running E-W through the centre of the image. Illumination is from the south; the image is 1 km x 2 km. Image centred on 57.55 °N, 3.93 °W. Image tiles nh8553 and nh8453 [JPG geospatial data], Updated 5 November 2017: EDINA Aerial Digimap Service, https://digimap.edina.ac.uk, Downloaded: 2019-01-21 14:55:07.866, © Getmapping Plc.

Figure 2. High Resolution Imaging Science Experiment image ESP_044804_2130 of the glacier-linked esker in Phlegra Montes identified by [3].

Methods

Here, we adapt [9] with *g* and other constants adapted to Martian values. We use the model to investigate:

a) the impact of Martian conditions on subglacial tunnel systems using a series of model experiments with constant water discharge (50 m^3s^{-1}) varying:

   i. assumed liquid density (ρ_w) from 1000 kgm^{-3} to 1980 kgm^{-3} (the density of saturated perchlorate brine)

   ii. ice hardness (A) from $2.4x10^{-24}$ $Pa^{-3}s^{-1}$ to $5x10^{-27}$ $Pa^{-3}s^{-1}$ (a temperature range of 0°C to -50°C)

b) the impact of variable water discharge on esker formation by simulating very simply a possible release of meltwater from an assumed geothermal event beneath a Martian glacier or ice cap.

Our overall aim is to begin to estimate the water discharge which could have led to recent Martian esker formation. This could help constrain Martian geothermal heat flux and recent mid-latitude ice extent and thickness.

Subglacial Hydrology and Esker Formation

The physics of water flow beneath glaciers is well understood and has been extensively modelled. Subglacial water can flow in several types of system:

- thin films of water
- poorly-linked subglacial cavities
- efficient subglacial tunnels

Eskers form in tunnels, making them of most concern here.

Subglacial tunnels exist in a dynamic balance between:

- ice deformation which tends to close them
- heat released by the flowing water melting tunnel walls tending to open them

Tunnels are generally larger, and have lower water pressure where:

- water discharge is high
- ice is thin

These conditions are typical near the ice margin. Two recent models [8, 9] of esker formation on Earth find that sediment deposition in subglacial tunnels is most likely near the margin as lower water pressure and larger tunnel cross section lowers the sediment carrying capacity of water flow. Deposition also tends to occur during periods of decreasing water discharge as tunnels tend to close more slowly than discharge falls, leading to effectively 'under-fit' streams.

Results

A key aspect of model behaviour is the decrease in sediment carrying capacity towards the ice margin due to increased conduit size as ice thins [8, 9].

Martian parameters emphasise this effect, with lower gravity having the largest impact (Figure 3). Tunnel diameter increases, leading to a reduction in water pressure, velocity, and flow shear stress.

Higher water density reduces these effects somewhat, and harder ice increases them.

These effects should make deposition more likely over a greater length of the conduit.

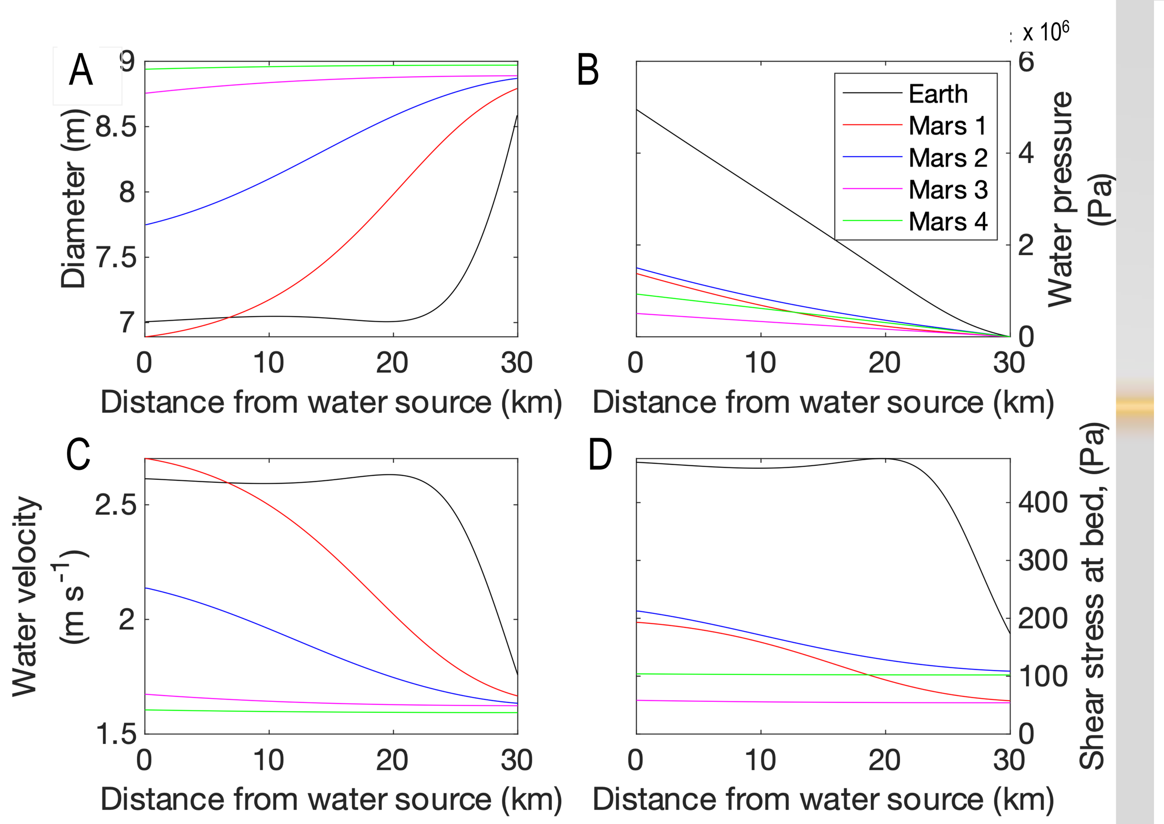

Figure 3 . Impact of Martian parameter values. A. Tunnel diameter (m). B. Tunnel water water pressure (Pa). C. Tunnel water velocity (m s^{-1}). D. Shear stress exerted at base of water flow (Pa). Mars 1 = Mars *g* only; Mars 2 = Mars *g*, ρ_w = 1980 kg m^{-3}; Mars 3 = Mars *g*, A = $5x10^{-27}$ Pa^{-3} s^{-1}; Mars 4 = Mars *g*, ρ_w = 1980 kg m^{-3}, A = $5x10^{-27}$ Pa^{-3} s^{-1}.

Unless stated, ρ_w = 1000 kg m^{-3}, A = $2.4x10^{-24}$ $Pa^{-3}s^{-1}$.

Results (continued)

This effect is borne out by the the variable discharge experiments.

Figure 4 A,B (Earth *g*) show relatively rapid tunnel closure after peak discharge, with conduit enlargement confined to the distal ~ 8-10 km of the tunnel (as in Figure 3). Sedimentation is confined to the last ~ 2 km of the tunnel as water flow power stays high due to conduit closure even as discharge falls.

By contrast, Figure 4 C,D (Mars *g*) shows much slower conduit closure after peak discharge, the conduit is enlarged over most of the model domain (and especially in the last ~ 10 km, as in Figure 3). Sedimentation occurs ~ 10 km upstream of the tunnel mouth as flow power is lower, and begins earlier due to the larger tunnel size.

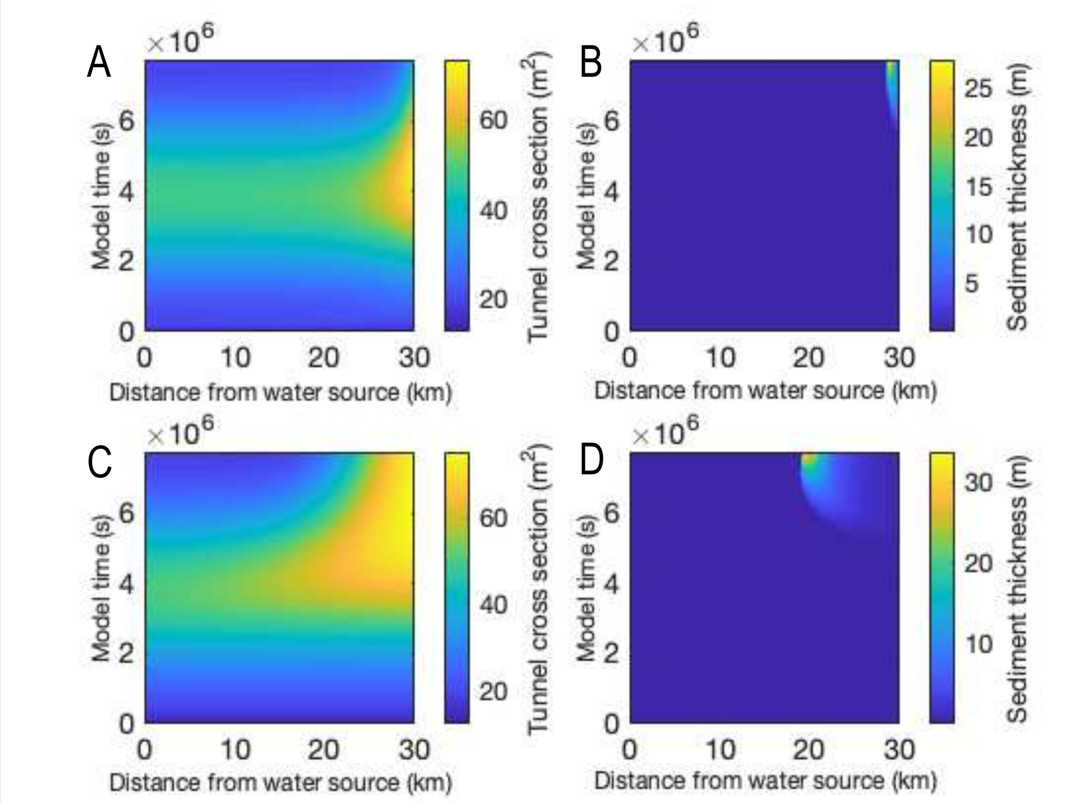

Figure 4. Time/space diagrams for evolution of tunnel cross section and sediment thickness. Discharge forcing is symmetric through time; peak discharge of 200 m^3 s^{-1} is half way through run. A: Earth *g*, tunnel cross section. B; Earth *g*, sediment thickness. C. Mars *g*, tunnel cross section. D. Mars *g*, sediment thickness. ρ_w = 1000 kg m^{-3}, A = $5x10^{-26}$ Pa^{-3} s^{-1}

Conclusions and Future Work

Our results suggest that esker formation within a subglacial meltwater tunnel would be more likely on Mars than Earth, primarily because subglacial tunnels tend to be larger for equivalent water discharges, with consequent lower water flow velocities. This allows sediment deposition over longer lengths of tunnel, and to greater mean depths, than for terrestrial systems.

Future work will use measured bed topography of a mid-latitude esker to assess the impact of topography on deposition patterns and esker morphology. We will also expand the range of discharge regimes investigated by adapting a model of Antarctic subglacial lake drainage [10] to simulate possible Martian subglacial lake drainage events driven by subglacial geothermal events of the type postulated as a possible cause of the inferred liquid beneath Mars' South Polar Ice Cap [7].

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