Hydrological modeling of outflow channels and chaos regions on Mars

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Studies of martian outflow channel origins assume bankfull, peak discharge conditions

- Results in overestimates of discharge
  - 7 orders of magnitude greater than the largest terrestrial groundwater springs
  - 2 orders of magnitude greater than terrestrial catastrophic floods

This study numerically models the formation and evolution of outflow channels, assuming a pressurized aquifer

- Reinvestigate implications for the number, duration, evolution of discharge, and erosional history of outflow channel floods

Formation of chaos terrain

- Fluid pore pressure within a confined aquifer reached or exceeded the lithostatic pressure at the base of the cryosphere.
- Excess pore pressure expanded fractures within the aquifer, propagate upward through 1-3 km thick cryosphere.
- Valleys/fissures between mesas represent hydrofractures that served as conduits for the flow in the outflow channel events (spacing of ~1 km consistent with representing cryosphere thickness of 1-3 km).
- Flow in aquifer (narrow aperture fractures/joints) is laminar; flow in hydrofractures is turbulent

Flood termination

- Discharge decreases with time as a power law
- The waning stages of the flood are limited by freezing within the channel and hydrofractures
- According to the paper this occurs before water is evacuated from the aquifer, and recharge rebuilds pressure required to facilitate another outflow event
  - Flood volume of ~1000 km$^3$ requires a recharge period of ~$10^4$ years
- Model Results

![Figure 5](image-url) Discharge as a function of time in the early stages of a flood from a 200 km radius chaos region for different cryosphere thicknesses and aquifer overpressures (baseline model represented by the solid line), as well as for a model in which the permeability and compressibility of the aquifer are held constant in time.

- **Individual Floods**
  - 20 km thick aquifer, 2 km thick cryosphere, pore overpressure 5 MPa
  - For low or decreasing permeability, there is a sharp decrease in discharge rates after an initial peak in discharge rates
  - For maintained high permeability, discharge rates decrease more slowly: the outflow event lasts for a longer period of time at elevated discharges
  - Depths of ~6 km within the aquifer are affected by the change in hydraulic head
  - Results indicate a maximum discharge of $10^3 - 10^4$ m$^3$ s$^{-1}$, and a flow depth of 54 m
  
  $\Rightarrow$ Flood volumes are too small to carve Ares Valles in a single flood event.

- **Multiple Floods**
  - Following termination of flood by freezing, the aquifer remains pressurized
  - Once recharge repressurizes the aquifer sufficiently, another flood event can occur
    - Erosion within the chaos region and reduction in the thickness and strength of the cryosphere reduces overpressure required
    - Recharge can occur from
      - Precipitation/melting of ice deposits on Tharsis (Harrison and Grimm, 2004, 2005)
      - A combination of passive drainage of aquifers and steady flux of water from buried Tharsis aquifers (Hanna and Phillips, 2006)
      - Recharge of global aquifer from basalt melting of polar ice caps (Clifford, 1993)
      - Others?
    - Recharge rates could be on the order of $\sim 1$ m$^3$ s$^{-1}$

![Figure 7](image-url) Evolution of the (a) discharge, (b) flood volume, and (c) subaqua pore pressure as a function of time for periodic floods from a 200 km radius chaos region representative of Iani Chaos at the source of Ares Valles. Note the different timescales used in each plot and discontinuities along the time axis in Figures 7a and 7b.
To achieve estimated minimum flood volume from Iani Chaos, 6 – 49 individual floods must have occurred (more if sediment loads < 0.4)

- Peak discharges are expected to have reached $10^6 – 10^7 \text{ m}^3 \text{ s}^{-1}$.

⇒ Outflow channels were likely carved by a large number of floods over long periods of time

Questions:

- Is the overpressure in the aquifer that is assumed to be required for outflow channel generation (2-10 MPa) reasonable?
  - 5 MPa of pressure corresponds to ~1300 m of hydraulic head, meaning that 1300 m of substrate beneath Tharsis (above Iani Chaos) would have to be saturated to generate this overpressure.

- Is a 40% sediment load in the flood fluid reasonable?

- What aquifer volume corresponds to the water volume required for each eruption (2000 km$^3$)? Is this geologically reasonable?