

FIRE, WATER AND ENERGY - HYDROTHERMAL HABITABLE ZONES ON MARS, A PRELIMINARY NUMERICAL MODEL ANALYSIS

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Introduction: Evidence of magmatic activity on Mars is abundant and has likely been occurring throughout the planet's history [1,2]. Many features also exist on the surface that indicate this magmatic activity interacted with water in both its liquid and solid forms [e.g. 1,3]. Out of the fire and ice, hydrothermal systems are born that circulate chemicals, fluids and heat. Mid-ocean ridge hydrothermal systems, which have been suggested as a possible location for the first life on Earth [e.g.4], and continental systems [e.g. 5] show biological communities taking advantage of the chemical energy provided by the fluid circulation and redox reactions occurring between the water and crust. Through numerical hydrothermal circulation models, we can predict where similar environments are likely to occur on planetary bodies and can determine fluid circulation volumes, flow rates and resulting temperature regimes through time. Rock alterations and mineral precipitations can then be calculated and used to estimate the crustal regions most conducive to habitability, if life ever arose on the planet.

Hydrothermal Model: Magmatic intrusions into water saturated crust will induce fluid circulation and result in water-rock interactions and alterations. Analytical analyses by [6] and [7] investigated possible Martian dike- and sill-driven hydrothermal systems, respectfully, beneath a layer of permafrost. Certain features observed on Mars suggest these systems occurred, such as Aromatum Chaos, a depression at the head of the Ravi Vallis channel system, postulated by [8] to have formed through sill-driven permafrost melting and aquifer release. Whether driven by a dike or sill, hot fluid circulating beneath a layer of permafrost would act to melt overlying ice and provide fluid flow to the surface. Through application of the boundary layer theory for 1 to 10 km tall dikes, with crustal permeabilities of $K=10^{-13} \text{ m}^2$ and $K=10^{-14} \text{ m}^2$, respectively, the analytical dike-driven hydrothermal model by [6] determined that, before convection begins in the melt layer, temperatures range fairly linearly from about 250°C at the base to 0 at the top, indicating high temperature rock alteration will occur primarily near the base of the melt layer. Once convection begins, these high T alterations will be overprinted with lower T alterations. These results are approximate, however, as permafrost will begin to melt and the dike will begin to cool before the steady state boundary layer is established. Considerations of melt and the magma intrusion

cooling are similar for a sill-driven system.

To study the evolution of a sill-driven hydrothermal system convecting beneath an ice layer over time (Figure 1), we perform analyses with the finite control volume numerical code, FISHES (Fully Implicit Seafloor Hydrothermal Event Simulator), which has been applied to simulate time-dependent, high-temperature, multiphase flow of NaCl-H₂O fluids in a permeable medium at terrestrial mid-oceanic ridges [9,10]. FISHES is also applicable for simulating similar Martian hydrothermal systems at depths below about 1 km and provides improvements over previous models by enabling accurate determination of fluid flow and temperature regime evolution and development of brine and vapor phases over the system lifetime, while also implementing a range of crustal permeabilities and time-dependent heat sources. Through application of the numerical code, important insight is gained into fluid circulation and heat transfer in the early stages of hydrothermal flow, as this is when the melting of an overlying permafrost/ice layer is likely to be most efficient. We then apply characteristics of the resulting heat flow, such as convection cell distribution, to predict how the ice layer melts, melt rate and when convection begins in the melt layer.

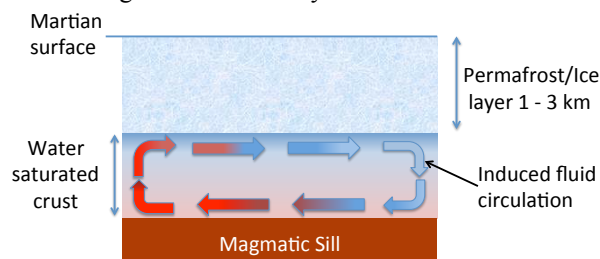


Figure 1. Martian sill-driven hydrothermal circulation beneath an ice/permafrost layer.

Habitable Zones: Building on the FISHES results, thermal profiles and their evolution over time within the subsurface permafrost melt region can be determined and incorporated into geochemical simulations of reactive transport reactions and secondary mineral formation. Crustal zones most conducive to life and preserving biosignatures can then be determined and targeted in future missions.

References: [1]Hamilton et al. (2011), *JGR*, 116, E3. [2]Neukum et al. (2004), *Nature*, 432, 971. [3]Burr et al. (2002), *GRL*, 29(1), 1013. [4]Baross and Hoffman (1985), *Orig. Life*, 15, 327. [5]Parenteau and Cady (2010), *Palaios* 25: 97. [6] Craft et al. (2015), *LPSC* 46, #2999. [7]Mercier and Lowell (2012), *LPSC* 43, #2275. [8]Leask et al. (2006), *JGR*, 111, E08071 [9]Lewis and Lowell (2009), *JGR*, 114, B05202. [10] Lewis and Lowell (2009), *JGR*, 114, B08204.