MODELS OF MARTIAN HYDROTHERMAL SYSTEMS AND IMPLICATIONS FOR GEOMORPHOLOGY. Kathleen Craft[1], Robert Lowell[1] and Erin Kraal[1], [1]4044 Derring Hall (0420), Department of Geosciences, Virginia Tech, Blacksburg, VA 24061, kcraft5@vt.edu, rlowell@vt.edu and ekraal@vt.edu.

Introduction: Many geomorphic features on the surface of Mars, such as gullies, fans, paleolakes, outflow channels, and deltas, were likely caused by flowing water; however, the source of that water is disputed. Possible water sources are hydrothermal systems driven by surficial lava flows and subsurface sills, impact events, and subsurface magmatic intrusions. Here we investigate systems driven by magmatic intrusions by first applying the boundary layer theory to obtain general results for heat and fluid fluxes and then use numerical modeling to explore other parameters including ice-melt contribution and brine formation.

Previous models for magma intrusion driven hydrothermal systems on Mars (e.g. [1-5],) employed coarse spatial and temporal resolutions that made temperatures and velocities close to the chamber difficult to observe. Results from Gulick's [3] model showed the importance of fluid behavior close to the chamber where a large change in temperature within < 100 m is evident. By employing the boundary layer theory, fluid behavior within close proximity to the chamber can be studied in detail. Additionally, our model improves upon previous models that considered intrusions and ice melting, but did not take hydrothermal circulation near the intrusion into account [4],[5].

Our analysis first developed steady state, two-dimensional, thermal boundary layer models. By making the assumption that convection occurs within a thin layer, the boundary layer theory, as described by Cheng and Minkowycz [6], was used to derive a general solution. Then, mass and heat fluxes near the quasi-vertical boundaries of magma intrusions with heights ranging from 1 to 10 km were determined. Figure 1 describes the model set-up and parameters.

The system's non-linear governing equations of conservation of mass (eqn (1)), conservation of momentum (eqns (2)&(3)), and conservation of energy, (eqn (4)):

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (1)$$

$$u = (-K/\mu)(\frac{\partial P}{\partial x} + \rho_f g) \quad (2)$$

$$v = (-K/\mu)\frac{\partial P}{\partial y} \quad (3)$$

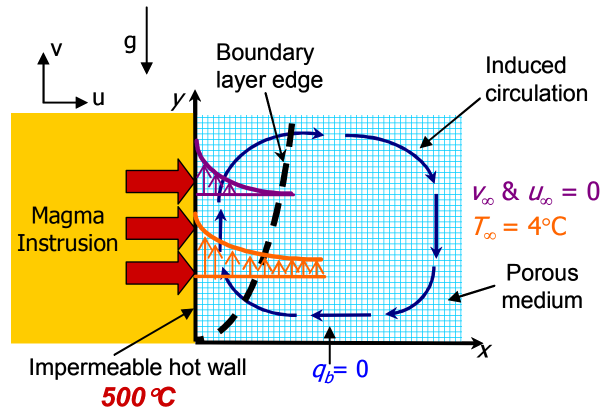

Figure 1. Sketch of boundary layer model area, boundary conditions and resuling boundary layer. Variable definitions: u: horizontal velocity, v: vertical velocity, g: gravitational acceleration, x: horizontal positions, y: vertical position, q_b= heat flux, T: fluid temperature, T_w fluid temperature at chamber wall, and T_∞ & v_∞ : fluid temperature and vertical velocity respectively, at an infinite distance from chamber wall

$$c_{p,f}\rho_f v.\nabla T = k\nabla^2 T \quad (4)$$

and boundary conditions of: at $y = 0$, $v = 0$; at $y = 0$, $T = T_w$; as $y \to \infty$, $u = 0$; and as $y \to \infty$, $T = T_\infty$, were formed into simplified, basic similarity equations:

$$\eta = Ra_x^{1/2}(y/x) \quad (9)$$

$$f(\eta) = \frac{\psi}{\alpha Ra_x^{1/2}} \quad (10)$$

$$\theta(\eta) = \frac{(T - T_\infty)}{(T_w - T_\infty)} \quad (11)$$

that relate Raleigh number, Ra_x, vertical and horizontal locations, y and x respectively, stream function, ψ, martian regolith thermal diffusivity, α, temperature of the wall, T_w, and temperature infinitely far from the heated wall, T_∞. The Raleigh number is defined as:

$$Ra_x = \frac{\rho_\infty g \beta K (T_w - T_\infty) x}{\mu \alpha} \quad (4)$$

From these equations, the thickness of the boundary layer (i.e. the thickness of the increased fluid temperature and velocity zone) can be shown to be a function of the Raleigh number:

$$\delta = y = \frac{\eta_\delta}{(Ra_x)^{1/2}} \quad (5)$$

where η_δ is the similarity value of position when θ = 0.01. Our analysis studied the effects of various permeabilities and intrusion dimensions on the heat and mass fluxes generated by hydrothermal flow.

Volume flux to the surface was calculated as the amount of fluid that upwells adjacent to the hot wall. Results from our simulation for 1 or 10 km deep dikes with surrounding porus medium permeabilities ranging from 1E-8 to 1E-14 m^2 are shown in Figure 2 [7],[8].

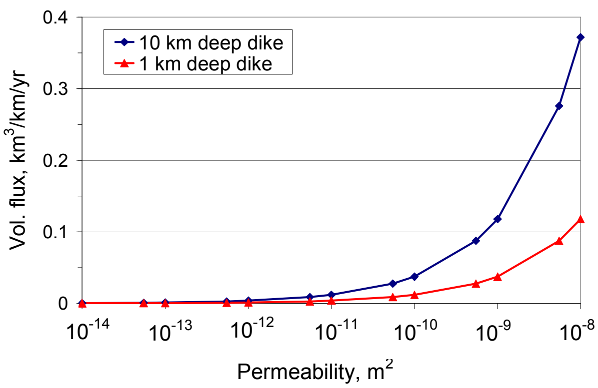

Figure 2. Volume flux for 1-km- and 10-km-deep dikes over a range of possible Martian crustal permeabilities. Permeability range covers reasonable values for consolidated basaltic regolith (≤ 1E-08 m^2) and that allow fluid movement (≥ 1E-14 m^2) [7],[8].

The results indicate, for example, that a 10 km long dike with a depth of ~ 5 km injected into a highly permeable rock would produce ~10^{18} J/yr of heat and transport ~1 km^3/yr of fluid. Mass flux results were compared with estimates for the volumes of fluid outflow and durations of flow needed to form various observed geomorphic features. Figure 3, depicts this information in a martian hydrograph by Kraal [9].

The hydrograph comparisons indicate that an unreasonable amount of time is required to produce enough flow to form observed surface morphologic features. Another possibility though, is that additional fluid may be provided by the melting of subsurface ice as a result of hydrothermal heat transport. There is considerable evidence of water ice below the Martian surface, e.g. [10],[11].

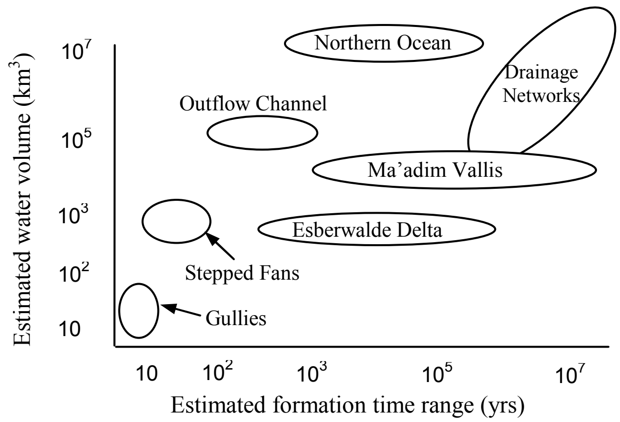

Figure 3. Martian hydrograph, depicting ranges of time and mass flow required to form certain geomorphologic features [9].

The possibility of ice-melt providing additional water to the hydrothermal system along with other considerations are being modeled in improved numerical, time-dependent simulations using a NaCl-H_2O, two-phase, control-volume code named FISHES (Fully Implicit Seawater Hydrothermal Event Simulator) [13]. The code simulates more realistic physical behavior including the existence of liquid and vapor phases, the formation of saline brines, and the transport of high enthalpy heat and fluid during the early stages of hydrothermal flow when the melting of subsurface ice might be most efficient. FISHES has the capability to calculate temperatures, velocities, and boundary layer thicknesses that are then used to determine heat output and fluid mass flux. Since brines are more stable than ordinary water under Martian low pressure and temperature conditions, estimates of the volumes of brine produced during hydrothermal circulation may have important implications for subsequent water storage in the Martian crust.

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