

**IMPACT-INDUCED HYDROTHERMAL ACTIVITY AT CENTRAL-PEAK AND PEAK-RING CRATERS ON EARLY MARS.** O. Abramov and D. A. Kring, Lunar and Planetary Laboratory, University of Arizona, 1629 E. University Blvd., Tucson, Arizona 85721-0092. ([abramovo@LPL.arizona.edu](mailto:abramovo@LPL.arizona.edu))

**Introduction:** Impact events locally increase the temperature of a planetary crust, initiating hydrothermal activity if water or ice is present. Impact-induced hydrothermal activity is responsible for mineralogically and morphologically modifying many terrestrial craters [e.g., 1], and has been suggested for Martian craters [2, 3].

While there are probably no active impact-induced hydrothermal systems today, they may have been prevalent at ~3.9 Ga, during an intense period of bombardment lasting 20 to 200 Ma [4, 5]. This cataclysm likely affected Mars, because meteorites from the asteroid belt, as well as the only sample of the ancient Martian crust (meteorite ALH 84001), show effects of impact-induced metamorphism at ~3.9 Ga [6, 7]. Thus, we are focusing on an early Martian environment because it coincides with a sharply higher impact rate, and also because liquid water was likely stable in the subsurface and perhaps on the surface as well.

*Goals of this work:* One of the goals is to constrain the lifetimes of impact-induced hydrothermal systems on early Mars. Conductive crater cooling models suggest that the lifetimes of hydrothermal systems in craters 20 to 200 km in diameter are  $\sim 10^3$  to  $10^6$  years [e.g., 8, 9]. The present work seeks to evaluate the additional effects of heat transport by water and steam.

Another goal is to further understand the mechanics of post-impact hydrothermal circulation, with a focus on locations of near-surface activity. Together with estimates of system lifetimes this allows the prediction of the type, location, and extent of alteration. This in turn can aid in spectroscopic and visual identification of hydrothermal vents and hydrothermally altered minerals at Martian craters.

Finally, we are seeking to understand the biological potential of these systems in terms of their habitable volume, or the rock volume within the temperature range of thermophilic microorganisms that has fluid flow.

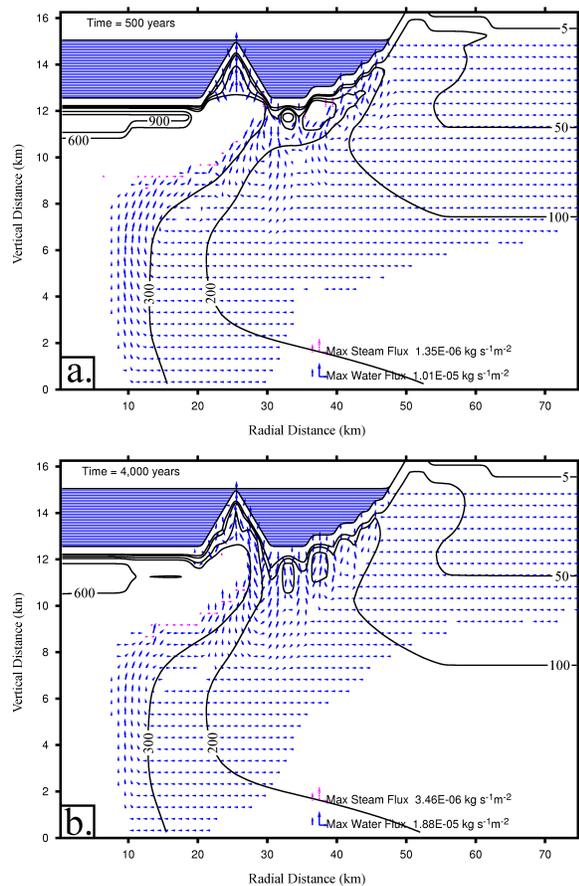
**Modeling Technique:** Hydrothermal activity in early Martian craters 30, 100, and 180 km in diameter was modeled using a modified version of a publicly available program HYDROTHERM [10], a three-dimensional finite difference code developed by the U.S. Geological Survey. For the present work, the program's radial mode is used. HYDROTHERM has been previously applied to hydrothermal systems at Martian craters [11].

HYDROTHERM requires input of topography and temperature distribution, in addition to rock properties, gravity, atmospheric pressure, and the basal heat flux. The surface topography is reconstructed using laser altimetry-derived Martian crater dimensions [12] and morphometry of lunar craters [13]. The temperature distribution underneath Martian craters is obtained from hydrocode simulations [e.g., 14]. Rock properties appropriate for Martian basalts are used, with a density of  $2600 \text{ kg/m}^3$ , thermal conductivity of  $2.5 \text{ W/(m K)}$ , and heat capacity of  $800 \text{ J/(kg K)}$ . The surface porosity is conservatively estimated at 20% [15] and decreases exponentially with depth, while the permeability has a maximum surface value of  $10^{-2}$  darcies and is a function of depth and temperature. The effect of other permeability values is also evaluated. The early Mars geothermal gradient and atmospheric pressure are estimated to be  $13 \text{ }^\circ\text{C/km}$  [16] and 0.5 bars, respectively.

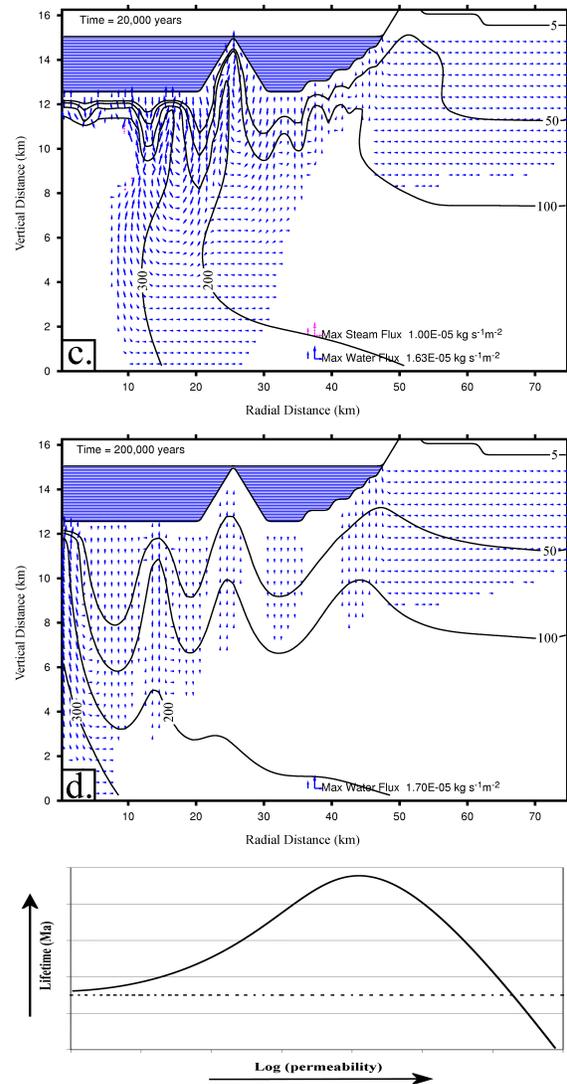
**Results:** Our modeling (e.g., Fig. 1) suggests the evolution of a post-impact hydrothermal system on early Mars proceeded as follows. The first step was the gravity-driven rapid draining of the rim and the flooding of the crater cavity by groundwater and any other available water source. The interaction between the incoming water and the hot interior of the crater may have produced large quantities of steam. Eventually, a crater lake should have formed in the basin of the crater, changing the flow of water from a gravity-driven to a hotspot-driven state. Newsom et al. [3] argued that the thermal energy of the impact melt and the central uplift can keep a lake from completely freezing for thousands of years under a thick sheet of ice, even under the current climatic conditions. Our model simulations, plus observations at terrestrial impact sites [e.g., 1, 17], suggest that the most extensive hydrothermal alteration would have occurred in the central peak (for smaller craters) or the peak ring (for larger craters), and the modification zone where fluid flow is facilitated by faults. The region of active hydrothermal circulation extends laterally almost to the crater rim and to a depth of several kilometers. The habitable volume for thermophilic organisms (volume of rock that has water flow and a temperature between 50 and  $100 \text{ }^\circ\text{C}$ ) reaches a maximum of  $\sim 6000 \text{ km}^3$  in the 180 km crater.

The average lifetimes of impact-induced hydrothermal systems on early Mars are estimated at  $\sim 0.065$  Ma for the 30-km crater,  $\sim 0.29$  Ma for the 100-km crater, and  $\sim 0.38$  Ma for the 180-km crater, and depend strongly on assumed ground permeability (Fig 2).

These long lifetimes are partly explained by the most vigorous circulation taking place near the surface and the hotter parts of the models being impermeable due to the brittle/ductile transition at about 360 °C. Thus, conduction remains the dominant form of heat transport in much of the model, especially for larger craters. Another consideration is vertical heat transport by flowing water, which can increase the temperature of near-surface regions and prolong the lifetime of the system. Finally, convection is less vigorous on Mars due to lower gravity, resulting in less heat removal compared to similar systems on Earth, but this is partly balanced by a higher overall permeability. In general, the combination of relatively long lifetimes and long-lived upwellings suggest that impact-induced hydrothermal systems on early Mars would have resulted in a significant mineralogical alteration of the crust.



**Figure 1.** Results of a numerical simulation of the hydrothermal system at a 100-km impact crater on early Mars. Surface permeability is  $10^{-2}$  darcies. Black lines are isotherms, labeled in degrees Celsius, and blue and red arrows represent water and steam flux vectors, respectively. The length of the arrows scales logarithmically with the flux magnitude, and the maximum value of the flux changes with each plot. Panels a to d show the state of the system at 500 years, 4,000 years, 20,000 years, and 200,000 years, respectively.



**Figure 2.** General dependence of system lifetime (defined by near-surface temperatures) on the average permeability of the subsurface. The dashed line indicates the lifetime in the absence of water.

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