IMPACT-INDUCED HYDROTHERMAL ACTIVITY 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)

Introduction: It is well known that impact events can locally increase the temperature of a planetary crust, initiating hydrothermal activity if water or ice is present. Impact-induced hydrothermal activity is well documented at terrestrial craters with alteration mineral assemblages [e.g., 1], and has been suggested for Martian craters [2,3].

While there are 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 may have also 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].

Importance of impact-induced hydrothermal activity on early Mars: Ancient valley networks, some of which are interpreted as surface runoff [e.g., 8], as well as chemical, mineralogical, and structural data from the Opportunity rover [9], suggest liquid water was present and stable on the surface (at least episodically) in the Noachian epoch, when the cataclysm took place. The cataclysm may have resurfaced Mars, forming most of the craters observed in the Martian highlands [6] and likely would have resulted in cycles of vaporization of any surface water or ice following large impacts [10], eliminating any life that may have existed at the surface. At the same time, new subsurface habitats were created [11] in the form of impact-induced hydrothermal systems, which may have provided sanctuary for existing life or provided the site of its origin. On Earth, phylogenies constructed from rRNA sequences imply a thermophilic or hyperthermophilic common ancestor [12], which, along with the earliest isotopic evidence of life at ~3.85 Ga [13] (coinciding with the cataclysm), suggest that impact-induced hydrothermal systems played an important role in the origin and evolution of early life. The same may be true for Mars.

Goals of this work: One of the goals is to constrain the lifetimes of impact-induced hydrothermal systems on early Mars. Crater cooling models suggest that the lifetimes of hydrothermal systems in craters 20 to 200 km in diameter are ~10^3 to 10^6 years if purely conductive cooling is assumed [e.g., 14,15]. 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. 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 [16], a three-dimensional finite difference code developed by the U.S. Geological Survey. For the present work, the program's radial mode was used. HYDROTHERM has been previously applied to hydrothermal systems at Martian craters [17].

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 [18] and morphometry of lunar craters [19]. The temperature distribution underneath Martian craters is obtained from hydrocode simulations [e.g., 20]. Rock properties appropriate for Martian basalts are used, with a density of 2600 kg/m^3, thermal conductivity of 2.5 W/(m K), and heat capacity of 800 J/(kg K). The surface porosity is conservatively estimated at 20% [21] 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 °C/km [22] 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., 1,23], 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 °C) reaches a maximum of ~5000 km^3 in the 180 km crater.

The lifetimes of impact-induced hydrothermal system on early Mars range from 50,000 years to 700,000 years for complex craters less than 200 km in diameter, and depend strongly on assumed ground permeability. 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 ºC. Thus, conduction remains the dominant form of heat transport in much of the model, especially for larger craters. Another important consideration is the 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 that on Earth. Overall, the combination of relatively long lifetimes and large habitable volumes suggest that impact-induced hydrothermal systems may have been suitable environments for life on early Mars.

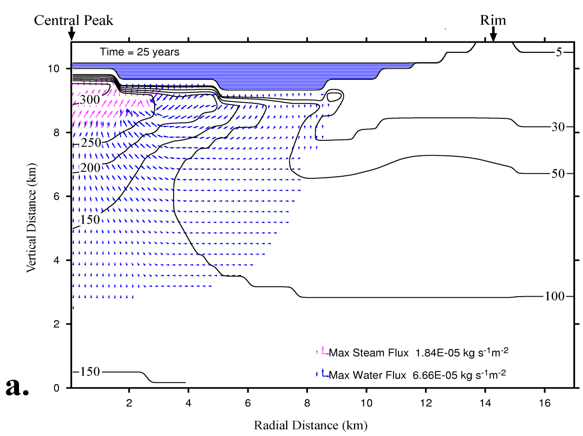
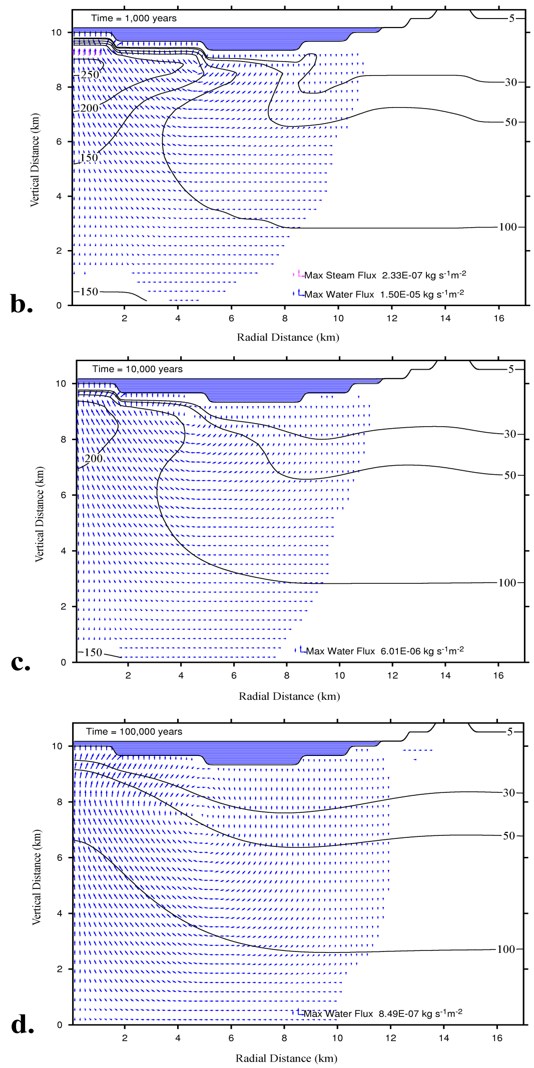


Figure 1. Results of a numerical simulation of the hydrothermal system at a 30-km impact crater on early Mars. Surface permeability is 10^{-2} darcies. Black lines are isotherms, labeled in degrees Celsius, and blue and red arrows represent water and steam flux vectors, respectively. The length of the 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 25 years, 1000 years, 10,000 years, and 100,000 years, respectively.



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