FINITE-DIFFERENCE MODELING OF IMPACT-INDUCED HYDROTHERMAL SYSTEMS.

O. Abramov and D. A. Kring[1], [1]*Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721-0092, abramovo@lpl.arizona.edu*

Introduction: Current research indicates that impact-generated hydrothermal systems played an important role on early Earth. A dramatic increase in the number of impact events occurred at ~3.9 Ga [1,2], and coincides remarkably well with the earliest isotopic evidence of life at ~3.85 Ga [3]. This period lasted 20 to 200 million years, during which time hydrothermal heat generated by impact events may have exceeded that generated by volcanic activity. These impacts would have resurfaced most of Earth, and may have vaporized the Earth's oceans, virtually eliminating surface habitats while creating a abundance of subsurface habitats [4]. In addition, there is genetic evidence indicating a common ancestor comparable to present-day thermophilic organisms [5]. These lines of evidence suggest that impact-generated hydrothermal systems were important for the origin and evolution of early life, and deserve further study.

Several hydrothermal systems associated with terrestrial impact craters have been identified based on mineralogical evidence. Examples of known systems include the 35 km Manson crater [6], the 80 km Puchezh-Katunki crater [7], and the 250 km Sudbury crater [8].

The primary heat sources driving a hydrothermal system associated with a complex impact crater are the central uplift and the melt sheet, with the latter contributing ~10-100 times more energy [9]. The lifetimes of hydrothermal systems in craters 20 to 200 km in diameter are 10^3 to 10^6 years if conductive cooling is assumed [9]. In order to better constrain the expected lifetimes of these systems and further understand their mechanics, a finite-difference computer simulation is used to evaluate the effects of convection.

Modeling technique: For modeling impact-induced hydrothermal systems, a computer program HYDROTHERM was used. HYDROTHERM is a three-dimensional finite-difference model developed by the U.S. Geological Survey to simulate water and heat transport in a porous medium [10]. Its operating range is 0 to 1200° C and 0.05 to 1000 MPa. The code solves the mass and energy balance equations at every mesh element and time step. These strongly coupled and highly nonlinear equations are treated using the Newton-Raphston iteration, leading to a system of linear equations that are solved for each iteration.

HYDROTHERM has been successfully applied to hydrothermal systems of volcanic origin [11] and Martian impact craters [12]. In this paper, HYDROTHERM is used to model post-impact water and heat flow in several terrestrial impact craters. Preliminary results for the 250 km Sudbury crater, which shows extensive hydrothermal alteration of its impact melt sheet [13], are presented.

HYDROTHERM requires input in the form of topography and temperature distribution, in addition to rock properties and planet-specific parameters such as gravity, atmospheric pressure, and the basal heat flux. The surface topography and temperature distribution of Sudbury crater that are input into the simulation were previously calculated by a hydrocode simulation [14]. Rock properties appropriate for Earth are used, with a density of 3000 kg/m^3, thermal conductivity of 2 W/(m K), and heat capacity of 850 J/(kg K). The porosity has a surface value of 20% and decreases exponentially with depth, while the permeability has a maximum surface value of 10^{-3} darcies and varies with both depth and temperature.

Results: The results of the HYDROTHERM numerical simulation are shown in Fig. 1. The area shown extends to 150 km in radius and 16 km in depth, and includes the central peak and the crater rim. A 75 x 32 grid was used, resulting in a horizontal resolution of 2 km and vertical resolution of 0.5 km. The temperature fields are indicated by red contour lines, water flux vectors are represented by blue arrows, and steam flux vectors are represented by red arrows. Fig. 1 shows the state of the system at 25 years, 25,000 years, and 2.5 x 10^6 years.

The system at 25 years is characterized primarily by the draining of the rim, and some steam production beneath the melt sheet. No flow occurs in the melt sheet itself or the central peak, as the high temperatures in these areas make them virtually impermeable. Some of the water from the rim drains into the crater basin, contributing to the formation of an impact crater lake.

At 25,000 years, steam emerges from the edge of the melt sheet, potentially forming fumaroles on the crater floor near the rim. As the steam escapes from the edge of the melt sheet, water is drawn in to resupply the steam flow, establishing circulation in that area. The temperatures in this region range from 100 to 300 °C. This process continues until at least 2.5 x 10^6 years.

Thus, our model predicts that an impact-induced hydrothermal system associated with a Sudbury-sized impact crater can remain active for well over 10^6 years.

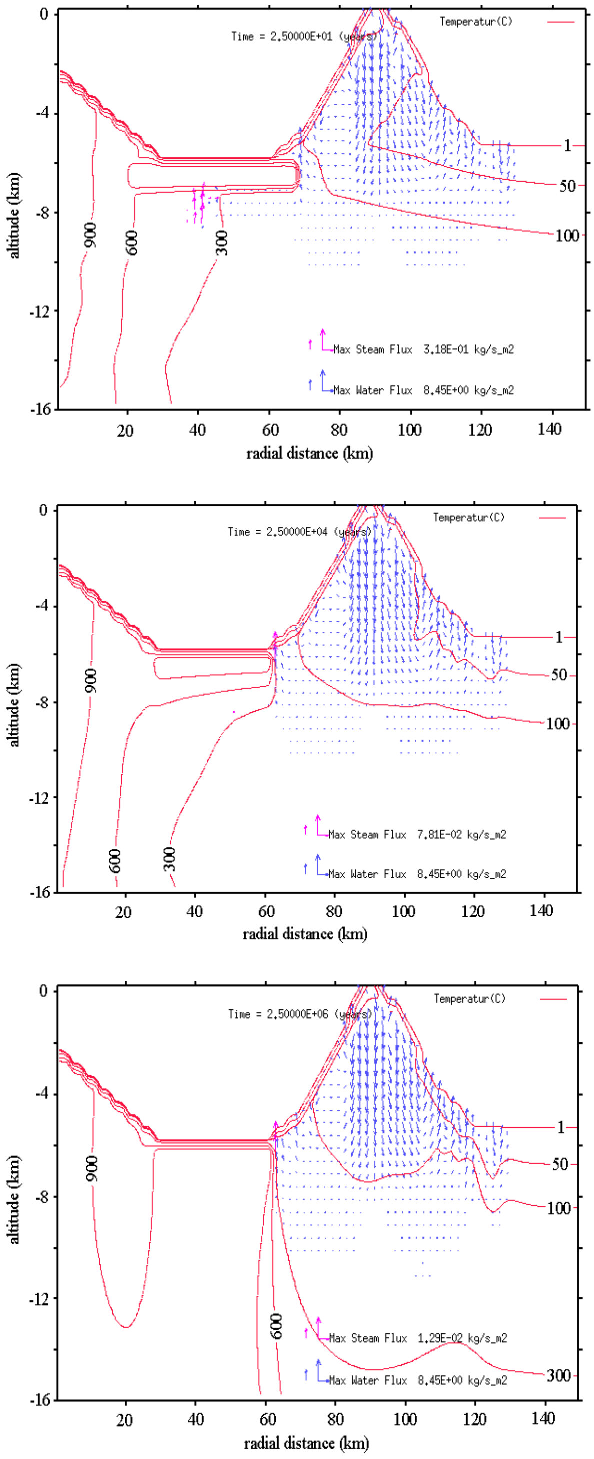

Fig. 1 Results of the simulation of hydrothermal system at Sudbury Crater. The system is shown at 25 years (top panel), 2.5 x 10^4 years (middle panel), and 2.5 x 10^6 years (bottom panel). Red lines are isotherms in degrees Celsius, red arrows indicate steam flux vectors, and blue arrows indicate water flux vectors.

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