IMPACT-GENERATED HYDROTHERMAL SYSTEMS ON NOACHIAN MARS: THE PATH OF WATER. Susanne P. Schwenzer[1], Oleg Abramov[2] and David A. Kring[1], [1]Lunar and Planetary Institute, USRA, 3600 Bay Area Blvd., Houston, TX 77058, USA; schwenzer@lpi.usra.edu; kring@lpi.usra.edu, [2]University of Colorado, Department of Geological Sciences, Center for Astrobiology, Boulder, CO 80309, USA; oleg.abramov@colorado.edu.

Introduction: Impact-generated hydrothermal systems on the Noachian surface of Mars are implicated by morphological [1–3] and chemical [4–6] evidence for (hot) water activity. The mechanics of their emplacement and evolution are well understood [1,7,8–10] and thermochemical models (see our accompanying abstract [11]) help constrain the formation conditions of sheet silicates and other alteration minerals. In this report we explore the paths of water through those systems over the periods (10^3 to $>10^6$ yrs [7]) they were actively driving fluid flow through Mars' crust.

Prerequisites: These systems were particularly important during the Noachian when the cratering rate was at its highest [12]. Moreover, the bombardment occurred over a short timespan lasting between 10 and 150 My [13,14], dubbed the Late Heavy Bombardment, which obliterated any earlier surface features. Chemical [15] and geological [14] evidence points to asteroids being the impactors. While numerous impacts close in space and time provide frequent heat sources and added water/volatiles to Mars' atmosphere [16], they are not a major contribution to the individual hydrothermal system's water budget: Assuming the impactors to be asteroids with chondritic compositions [14,15], their water content ranges between 0.2 and 22 wt-% [17,18]. Therefore, a 10 km asteroid would bring between 5 and 350 km³ water. Comparing that value to the total discharge associated with 100 and 180 km diameter craters (Table 1), the water from an impactor is a minor or even negligible contribution to the water budget of the impact-generated hydrothermal system. Therefore, the target must have been water saturated [1,7,9,10]. That said, it is generally agreed that water was available to geologic processes on Noachian Mars. Morphological evidence for this comes from a variety of sources [e.g., 4,19–22] and includes channel networks [23] and rampart craters [24]. Mineralogical evidence also suggests phyllosilicate formation occurred exclusively in the Noachian [4,6]. Hydrous salts are found on younger terrains [e.g., 25], but are perceived as products of sporadic water activity in a cold and acidic environment [e.g., 26]. Thus, there is a coincidence in time when impacts were occurring and there was abundant water affecting Mars crust and surface.

T*able 1. Total discharge [km³] and rock volumes [km³] assumed to be affected for three Martian craters of 30, 100, and 180 km diameter.*

	30 km	100 km	180 km
discharge*	1.1 x 10^2	2.9 x 10^3	9.9 x 10^4
cone [km³] **	2.4 x 10^3	3.9 x 10^4	1.2 x 10^5
$W_{vol}/rock_{vol}$	0.05	0.07	0.8
cone section [km³] ***	1.2 x 10^3	1.4 x 10^4	4.4 x 10^4
$W_{vol}/rock_{vol}$	0.09	0.2	2.3

*obtained form the water flux in the HYDROTHERM model
**From the flow patterns we simplify the affected volume to a cone with r being the crater radius and h the model depth (10, 15, and 14.5 for the 30, 100 and 180 km diameter craters, respectively).
*** Caused by permeability decrease, the main flow occurs in the upper 2 km of the crust; given here is the volume of the cone section for the first 2 km cone height measured from the bottom of the cone.

Mechanics of impact-generated hydrothermal systems: Assuming the Martian crust was saturated with liquid water/ice and may have contained water bound in minerals, impact-generated heat can liberate the water and drive flow [1,7,8]. While it is sufficient to draw all water from underground sources, a crater lake, thus (transient) surface water, enhances the lifetime of the system [1,7]. A comparison of the water discharge of these systems with the affected rock volume results in very low water volume to rock volume ratios (Table 1). But a simple comparison of those volumes does not consider the nature of hydrothermal circulation. Terrestrial examples show a large variety of flow regimes in hydrothermal systems that are patchy and inhomogeneous in nature (e.g., Chicxulub, [27,28]). Consequentially, it is estimated that 1–2 % of the host rock is altered upon hydrothermal activity in the subsurface of impact craters [29]. Taken at face value, this increases the water to rock volume ratios of Table 1 by factor 50–100. It also implies large scale variations of local W/R ratios. Overall, four types of flow regimes are observed (Fig. 1): 1) vigorous flow in fractures, 2) permeable zones that allow for still high, but less vigorous flow, 3) zones of low permeability, and 4) impermeable rock.

Time and completeness of the alteration are further factors controlling the mineral assemblages that are produced in impact-generated hydrothermal systems. Shortly after the onset of the alteration process, the W/R ratio in the entire system will be low. A "metamorphic" assemblage containing serpentine, chlorite, garnet, and amphiboles [11] will be formed, but be restricted to small reaction rims along the water pathways. As time elapses, the affective W/R ratio may never increase in zones of low permeability, because the reaction progresses deeper into the rock fragments while more water is added. If permeability is high enough for water to be added beyond that consumed by existing reactions, the affective W/R will increase. Therefore, in permeable zones W/R is expected to reach the stability field of clay minerals such as nontronite [11]. However, unaltered rock will most likely survive on microscopic as well as macroscopic scale, because it remains impermeable over the lifetime of the system. The process is different in open fractures. Due to a vigorous flow regime W/R becomes very high, thereby dissolving most of the rock and sweeping ions away in solution. Only few species, e.g., hematite and diaspore [11], will reach their saturation limit and precipitate.

Water in alteration assemblages: Thermochemical changes caused by this water flow result in alteration assemblages [11], which – in contrast to the primary magmatic phases [30] – contain structurally bound water. The water content varies with the composition of the host rock and the alteration conditions. Our calculations [11] produced a variety of OH-bearing phases. Together with anhydrous alteration minerals, those phases form assemblages that contain between 0.04 and 9.02 % structurally bound water (Table 2). Additional water may be found in interlayer positions of smectites [31]. Interlayer water cannot be calculated as a reaction product, but is dependent on the history of the clay minerals. It has to be measured *in situ*. Therefore, our water abundances are minimum abundances as long as the environment is wet. On the dry surface of Mars, however, interlayer water may get lost.

The Noachian in a nutshell: In summary, frequent impact-generated hydrothermal systems are likely to have altered the Martian crust during the Noachian. The localized heat sources drove deep-reaching, convecting, hot-water systems, thereby melting any ground ice and/or releasing structurally bound water from pre-existing hydrous minerals, if present. Some fraction of the water vented at the surface as liquid and steam, while another fraction was locked up

Table 2. Water content (wt-%) of alteration assemblages formed at 1 km depth (110 bar) and 150 °C. For the mineral assemblages see [11].

	W/R=1	W/R=1000	W/R=100000
Chassigny	9.02	0.99	0.04
LEW 88516	8.35	2.38	0.19
Dhofar 378	5.97	7.42	0.72
Humphrey	5.53	1.76	0.69

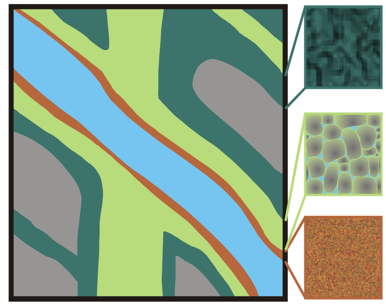

Figure 1. Schematic illustration of different W/R regimes (see text). Blue is water, grey is unaltered rock, dark green box is "metamorphic" assemblages, e.g serpentine–chlorite–garnet, light green box is chlorite–smectite–hematite assemblage, and red box is hematite–diaspore–pyrite assemblage.

in hydrous minerals. As the systems ceased, alteration zones were preserved most prominently in the highly fractured central uplifts and modification zones. Remaining water either froze, evaporated, or stayed liquid depending on the surface/subsurface temperature. With lifetimes up to several Ma for basin-sized events, impact-generated hydrothermal systems provided long lasting, zoned, steadily cooling, hot-water environments that were largely independent of surface conditions.

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