IMPACT-GENERATED HYDROTHERMAL ALTERATION ON MARS: CLAY MINERALS, OXIDES, ZEOLITES, AND MORE. Susanne P. Schwenzer[1] 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.

Introduction: In the Noachian, Mars' crust was deeply affected by impact crater gardening [1], and subsequent hydrothermal alteration. While water was present in the Martian crust [2,3], frequent impacts [4,5] provided prominent heat sources that drove hydrothermal systems. Those systems were scattered randomly over the planet's surface and variable in size, but generally spanned the diameter of any ≥10 km complex crater (based on analyses by [6]). These systems were also deep reaching and long-lived [7] with central crater uplifts and crater modification zones affected by the most intense water flow [8]. Because circulating water driven by a temperature gradient changes the thermochemical status of a system, mineralogical reactions inevitably took place. Similar mineralogical consequences have been documented in terrestrial impact-generated hydothermal systems. Approximately half of all known impact structures on Earth show hydrous alteration phases produced by the interaction of water with a melt sheet and/or hydrothermal systems that penetrated the crust beneath the crater floor [9]. Immense systems have been documented in drill cores from Earth's largest impact structures, such as the Chicxulub crater (Yucatán, Mexico) and the Sudbury structure (Ontario, Canada) [10,11].

As we have shown earlier for the basaltic crust of Mars [12–14], thermochemical changes caused by circulation of heated formation brines mainly result in the crystallization of sheet silicates (serpentine, chlorite, nontronite, and kaolinite), amphiboles, oxides and hydroxides (magnetite, hematite, diaspore), and additional minor phases. Our results compare favorably with those from sattelite-based spectroscopic measurements of the Martian surface by OMEGA and CRISM (aboard the European Mars Express and U.S. Mars Reconnaissance Orbiter, respectively). They report many of the same minerals, amongst them several smectites and micas – such as kaolinite, Fe/Mg-smectite, saponite, illite/muscovite, and chlorite – but also hydrous silica, zeolite, and carbonate [15–17]. Potential testimony of impact-generated hydrothermal systems has been found in three Martian craters so far: hydrous phases are located in central peaks and inner crater walls in a ~ 100 km diameter crater in Mawrth Vallis [18], a crater of similar size in Terra Meridiani [19], and an ~20 km diameter crater in the Western Isidis region [15].

In addition to producing mineral assemblages similar to those being observed on Mars, our calculations constrain formation conditions. Our results suggest that alteration assemblages are largely controlled by the water to rock ratio (W/R) and temperature, while the pH is bufferd by the precipitating and dissolved species. Our previous studies showed that three sheet silicates, which also have been found on Mars (chlorite, nontronite, kaolinite), point to specific formation conditions: Chlorite is indicative of intermediate to low W/R and occurs over the whole temperature range [12]. The clay minerals nontronite and kaolinite indicate intermediate and high W/R, respectively. Moreover, nontronite forms below 250 °C only. While our previous studies focussed on the parameters pressure, temperature, and W/R, in this study we explore the influence of host rock variability on the resulting alteration assemblages.

Method and host rock chemistry: To understand the thermochemical conditions of impact-generated hydrothermal systems, we performed a series of ΔG-minimization calculations using the computer code CHILLER [23]. For details of assumptions, the chemical input data of earlier calculations, as well as the water composition used in all of our studies, see [12]. The chemical proxy for these calculations was the plutonic shergottite LEW 88516. We chose this rock composition, because impact-generated hydrothermal systems are deep reaching [7] with the largest part of the affected volume being at depths where plutonic rocks are found. However, rock variability is to

Table 1. Rock compositions used as input data for the CHILLER calculations.

	Dhofar 378[1]	Humphrey[2]	Chassigny[3]
SiO_2	49.75	45.9	38.16
TiO_2	0.98	0.55	0.1
Al_2O_3	10.94	10.7	0.69
Cr_2O_3*	0.04	0.6	0.628
Fe_2O_3	1.92	3.55	0.52
FeO**	17.54	15.6	26.53
MnO	0.46	0.41	0.526
MgO	5.48	10.4	31.6
CaO	10.34	7.84	0.6
Na_2O	2.08	2.54	0.128
K_2O	0.17	0.1	0.041
P_2O_5	0.77	0.56	0.058
SO_2***	0.22	1.02	0.012
sum	100.62	99.72	99.593

[1]Data from [20]. S is inferred from the amount of pyrrhotite (0.6 %; [20]) in the sample. Fe_2O_3 is calculated with the program MELTS taking the oxygen fugacity given by [20]. [2]Data from [21]. [3]Data from [22]. Fe_2O_3 is calculated with MELTS.
**Cr is not included in the calculations. **Dhofar calculated using melts at QFM,Chassigny calculated for 0.02% Fe_2O_3/(FeO+Fe_2O_3). ***Sulfur is given as S for the meteorites and SO_3 for Humphrey and recalculated as SO_2 here.*

be expected on a planet. We therefore explore the effect of host rock variability on the alteration products in those systems. For this study two Martian meteorites, a basaltic shergottite and a cumulate dunite were chosen (Dhofar 378 and Chassigny). Dhofar 378 reflects the most feldspathic and Chassigny the ultramafic end of the petrologic spectrum. In addition, the composition of Humphrey, a rock found on Mars by the MER Spirit, was examined (Table 1).

Results: Calculated assemblages for 1 km depth and 150 °C are displayed in Figure 1. At W/R=1 the most obvious difference between Chassigny and LEW 88516 on the one hand and Dhofar 378 and Humphrey on the other is that the first two are altered to serpentine and magnetite, while the latter are not, but form feldspar (and zeolite for Humphrey). At W/R=1000 only an altered version of Chassigny still contains some serpentine, with hematite being the main phase present. The shergottites and Humphrey are altered to nontronite plus hematite assemblages at this intermediate W/R. At very high W/R all protoliths are converted to assemblages dominated by hematite.

Conclusions: With impact cratering being a dominant process in the the early, Noachian history of Mars [4,5], deep-reaching impact-generated hydrothermal systems [6,7] are expected to be widespread – but not necessarily uniformly distributed – on early Mars. Moreover, host rock chemistry can be diverse [24], leading to variable alteration assemblages. Therefore, the alteration process will affect the rocks inhomogeneously depending on local host rock chemistry, rock permeability, and fracturing.

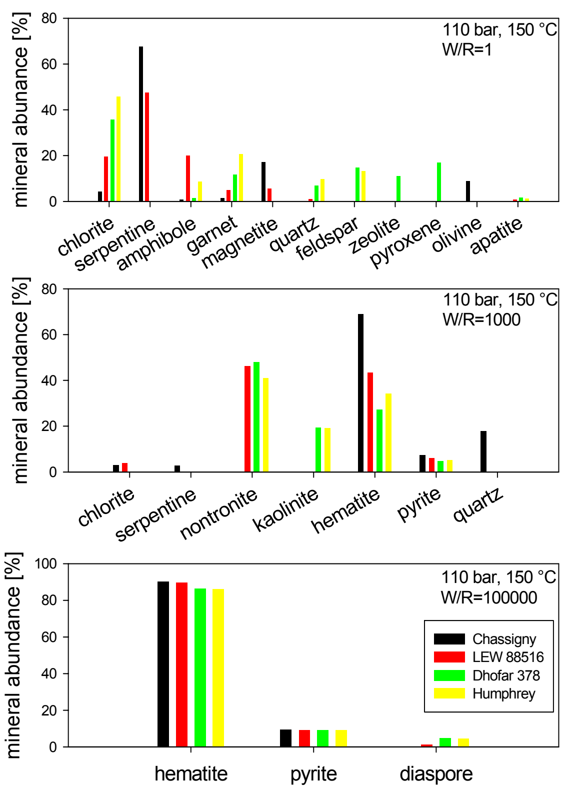

Figure 1. Minerals that form upon alteration of four different Martian rock compositions.

Chlorite, smectite (including notronite), and hematite occur under the greatest variety of conditions. Nontronite [25] and chlorite [26] were, indeed, the first hydrous phases reported by the OMEGA instrument. From our calculations, other minerals (e.g., serpentine, zeolite) are more restricted to certain prerequisites. A more detailed comparison of spacecraft data with our calculations, including the geologic intricacies of impact-generated alteration, should be possible once the relative abundances of altertion minerals are extracted from spectra [27] and additional high-spatial-resolution spectra are collected. This will add to our understanding of the Martian formation conditions for clay minerals, which have been suggested as a catalyst for the formation of biopolymers on Earth [28]. Moreover, it will further enhance our assessment of physical conditions during alteration that may have favored reactions transitional from abiotic chemistry to biota on Mars [6,7], similar to those that may have affected the emergence of life on Earth [29,30].

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