

**AFTER THE DUST HAS SETTLED: HYDROTHERMALLY-DRIVEN CHEMICAL AND MINERALOGICAL CHANGES IN PLANETARY CRUST FOLLOWING IMPACT EVENTS.** Susanne P. Schwenzer and David A. Kring, Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX, 77058, USA; schwenzer@lpi.usra.edu.

**Introduction:** On Earth, evidence for impact-generated hydrothermal systems has been found in more than 60 impact structures [1]. These systems were driven by heat in central melt sheets, impact melt breccias, and uplifted basement material. The amounts of heating and, thus, volumes of the systems scale with crater size and are particularly prevalent in large (>100 km diameter) craters like Chicxulub [2], but can occur in much smaller craters [1]. While crater formation itself happens in seconds to minutes, impact-generated hydrothermal activity can persist for  $10^3$  to  $>10^6$  years [3–5]. Such systems are capable of maintaining temperatures in the range of 100 to 300 °C [3–5], of altering the mineralogy of the target rock [1 and references therein, 6], and of producing hydrothermal brines that can transport ions. We have also argued [7] that these systems may have been important in the origin and early evolution of life.

Impact craters produced during the early evolution of Earth, however, have not survived. The examples cited above are temporal proxies that suggest impact-generated activity was intense during early solar system bombardment, but we do not have a direct measure of that activity on Earth. In addition, the proxies that we have are largely in granitic and/or sediment-rich terrains and do not provide a direct measure of the alteration one might find in more primitive mafic planetary crust.

Ancient cratered terrains on Mars, however, have survived and can provide additional insights about hydrothermal alteration of mafic planetary crust. Thermal models [3,4,8] suggest that impact-generated hydrothermal activity was long-lived and geographically broad. In this paper, we extend those thermal models to investigate the chemical and mineralogical changes induced by those systems and compare them to observations of ancient cratered (Noachian) terrains on Mars.

**Hydrothermal modeling and results:** Using CHILLER we calculated minerals that precipitate at a variety of P and T, if a rock with the composition of the Iherzolitic Martian meteorite LEW 88516 is in contact with an Fe, Mg, Ca bearing fluid [6]. Modeling results can either be read as an evolution with increasing/decreasing water to rock ratio (W/R) or each step can be taken as a reaction of a given fluid with the starting rock plus the precipitates in the system. Here we illustrate the solid and fluid products of hydrother-

mal reactions with three examples at  $T=150$  °C and  $P=550$  bar: (1)  $W/R=10000$ ,  $pH=3.8$ ,  $fO_2=-42.3$  (2)  $W/R=1000$ ,  $pH=4.3$ ,  $fO_2=-43.0$  (3)  $W/R=1$ ,  $pH=6.2$ ,  $fO_2=-47.9$ . The pH and  $fO_2$  are controlled by the mineralogy.

**Precipitates.** The nature of precipitates changes with fluid composition (especially  $SiO_2(aq)$ , Ca, and Mg). A rock dominated system ( $W/R = 1$ ) precipitates an assemblage that chemically resembles the magmatic composition of LEW 88516 (comp. Fig. 1 panel a and b). However, there is one major difference: water is introduced into the assemblage, which dramatically affects the mineralogy. While the magmatic precursor assemblage is made of 95% ortho-, chain- and framework silicates, the alteration assemblage contains 64% sheet silicates. At  $W/R = 1000$ , most of the precipitation mass is clay and, specifically, notronite. At higher  $W/R$  values ( $W/R= 1000$  to 100000) the system precipitates an assemblage that contains mostly iron: 43% and 90% hematite are precipitated at  $W/R = 1000$  and 100000, respectively (Fig. 1 panel c, d).

**Fluids.** The amount of dissolved ions varies with the precipitating assemblage controlling it. The elements Na and K largely accumulate in solution. Furthermore, a significant amount of Ca is present. Also, some elements can form molecular complexes (e.g.,  $Ti(OH)_4$  in one example) and stay in solution.

Collectively, the calculations suggest impact-generated alteration of early Martian mafic to ultramafic crust produced clay-rich assemblages that included smectites (like notronite) and kaolinite. The fluids associated with those alteration assemblages are dominated by those ions that are not preferred by the precipitating assemblage, thus forming an Na, K-rich brine that contains Ca and  $SiO_2(aq)$  plus some elements that form molecular complexes.

**Discussion.** Our model results can be compared and contrasted with two sources of information: spacecraft observations of Mars surface and meteoritic samples of Mars crust.

One Martian meteorite (ALHA 84001) is a crustal sample that crystallized 4.5 Ga and has experienced a complex geologic history, including a thermal metamorphic overprint at  $\sim 4.0$  Ga and the formation of carbonates about 400000 years thereafter [9]. Several mechanisms for the formation of carbonates [see 10 and references therein] have been proposed, amongst which are carbonic fluids forming carbonates at the

expense of maskelynite [11, 12] or by precipitation from solution [10]. Hydrothermal modeling [13] and the incorporation of fractionated Martian atmosphere [14 and references therein] support the reasoning of a carbonic (atmosphere derived) fluid interacting with a host rock at elevated temperatures.

Spacecraft observations of the Martian crust also indicate water was available for many geologic processes in the Noachian, including the formation of valley networks [15], rampart craters [16] and clay minerals [17,18]. Recent and ongoing orbiter missions reveal several indications of impact-generated hydrothermal systems, amongst which the strongest are hydrous signatures in crater rims and central peaks [19,20].

The number of craters on Noachian surfaces of Mars approach the saturation limit [21] and the old

highlands “should have been gardened to a depth of a kilometer or so” [21]. Given the fact that hydrothermal systems reach even deeper [3,4], Mars crust can be deeply affected by gardening, fracturing and subsequent hydrothermal alteration. The latter thereby will change the rock properties from a solid magmatic rock that does not contain water to a hydrothermally altered rock (comp. Fig. 1) that

- contains structurally bound water in sheet silicates,
- contains exchangeable water in interlayer positions,
- contains exchangeable ions in some of the clay mineral assemblages,
- has a different chemistry, thus liberating ions that are available for transport and deposition elsewhere,
- has different physical properties such as density and strength.

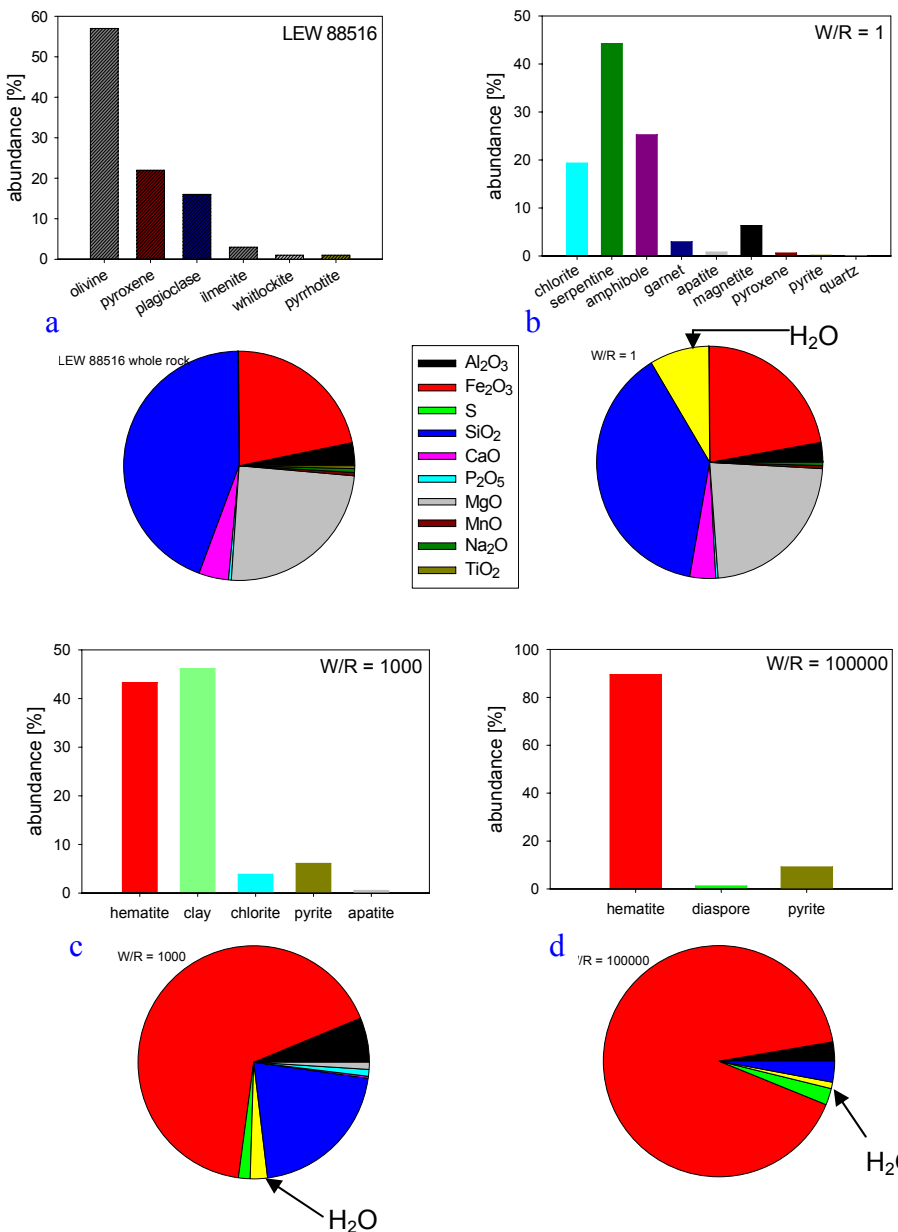


Fig. 1. Results of model calculations of LEW 88516 chemistry with an ion containing fluid: starting rock mineralogy and composition(a), W/R = 1 (b), W/R = 1000 (c), and W/R = 100000 (d). Details on the modeling see [6].

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