EFFECTS OF BASALT COMPOSITION ON A MARTIAN ANALOGUE MAGMA-SEDIMENT HYDROTHERMAL SYSTEM STUDIED THROUGH THERMOCHEMICAL MODELING

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Introduction: High-temperature hydrothermal systems have been identified on Mars associated with both hypervelocity impacts and magmatic activity on Mars's early history [1, 2]. These processes may have produced habitable environments by providing heat, energy, and volatile species necessary to support microbial life [3, 4]. Hydrothermal systems formed after the intrusion of mafic magmas in sedimentary rocks are of particular interest when investigating the habitability of high-temperature aqueous environments on Mars [5, 6],because during magma-sediment contact metamorphism bond fluids (e.g. in ice, pore spaces, minerals) are mobilized favoring the alteration of the country rocks and the release of bio-essential elements [7, 8]. The chemistry and mineralogy of these systems on Mars are not well constrained and, for this reason, terrestrial analogues need to be investigated. Costello et al. [5] and Crandall et al. [6] have studied a mafic dike intruding the Jurassic Entrada sandstone (Colorado Plateau, UT). The intrusion has produced a hydrothermal system with Cl-CO_2 rich fluids and near-neutral pH, which induced chemical and mineralogical changes in the dike and in the sediments [5, 6]. The system reached temperatures higher than 700 °C around the contact zone [6], but lower temperatures (< 200 °C) were reached as the system cooled down [5] making the environment potentially habitable [6]. However, previous studies do not consider compositional differences between the terrestrial dike and basaltic rocks on Mars [9, 10] making difficult a direct comparison between alteration mineralogy and brine chemistry of terrestrial and martian systems. Here, we use thermochemical modelling to investigate how differences in bulk dike composition will affect secondary mineral assemblages and fluid chemistry.

Modeling approach: Thermochemical modelling was performed using the code CHIM-XPT [11, 12], which has already been used to predict secondary mineral assemblages and variations in fluid chemistries during water-rock interactions in terrestrial and extra-terrestrial basaltic systems, including hydrothermal systems on Mars [13, 14, 15]. We performed stepwise titration simulations using basaltic rocks of four different compositions (Table 1) and a modelled brine (Table 2). As previous studies showed significant Cl-mobility in the system, in our models we added Cl and F in concentrations as observed in terrestrial lamproites [16], which are similar to the calculated halogen contents for some Martian parental magmas [17]. Rock dissolution was modelled from an initial water/rock ratio of 10^6 to a final water/rock ratio of 1 in order to simulate different degrees of interaction between rock and water. For each rock composition the modeling was carried out at 13 °C, 100 °C and 200 °C, at a pressure of 110 bars; the pH was set as a free parameter. These parameters were constrained from the Mars analogue dike system and were used to simulate the different alteration conditions at which the dike undergone.

Table 1. Bulk Composition of terrestrial dike and Martian basalts as modelled.

| Wt. %	Dike	Jake_M	Humphrey	Clast in NWA7034
SiO_2	34.8	51.6	45.9	54.0
TiO_2	5.7	0.7	0.58	1.0
Al_2O_3	14.7	15.7	10.7	11.5
FeO	7.4	10.8	18.6	12.0
MgO	3.8	4.4	10.41	7.0
CaO	11.6	6.7	7.84	6.0
Na_2O	1.0	7.0	2.5	3.1
K_2O	4.4	2.12	0.1	1.2
P2O5	2.6	0.68	0.56	1.2
Cl	0.2	0.2	0.2	0.2
F	0.2	0.2	0.2	0.2

Dike composition modified from: [6, 18]; Mars basalts as summarized in: [10]; Halogens from: [16, 17]

Table 2: fluid composition

Ion	H^+	H_2O	Cl^-	SO_4^-	HCO_3^-	
Moles	$-1.3E^{-3}$	$1.0E^{+0}$	$1.6E^{-3}$	$4.0E^{-3}$	$1.2E^{-4}$	
Ion	Ca^{++}	Mg^{++}	Fe^{++}	K^+	Na^+	
Moles	$1.8E^{-4}$	$3.0E^{-8}$	$3.6E^{-12}$	$1.0E^{-3}$	$9.6E^{-3}$	
Ion	Mn^{++}	HPO_4^{--}	$Ti(OH)_4$	HS^-	H_4SiO_4	Al^{+++}
Moles	$6.9E^{-6}$	$4.3E^{-11}$	$5.0E^{-5}$	$-4.5E^{-13}$	$1.1E^{-3}$	$3.1E^{-10}$

Results: Figure 1 shows the secondary minerals modelled for the four basaltic compositions at 13 °C (temperatures consistent with cooling of the hydrothermal system). All the models show mineral assemblages characterized by zeolites (analcime, stilbite), phyllosilicates (talc, nontronite, chlorite, celadonite, greenalite), carbonates (calcite), tectosilicate (quartz), oxyhydroxides (goethite, diaspore) and silicate hydrate (tobermorite) that precipitate in variable amounts at different water/rock ratios. Traces of phosphate (apatite) are also present in all models, but one (Figure 1A). The first two models have comparable mineral assemblages and mineral abundances with zeolites (40 – 70 wt. %) representing the most abundant precipitates followed by phyllosilicates (10 – 45 wt. %); in the third model phyllosilicates (24 – 75 wt. %) are

more abundant than zeolites (13 – 37 wt. %), while in the fourth model zeolites and phyllosilicates have similar total abundances (20 – 52 wt. %). Humphrey basalt has the most complex mineral assemblage, while the alteration of clast in NWA7034 produces fewer mineral species that precipitate in concentration higher than 5 wt. %.
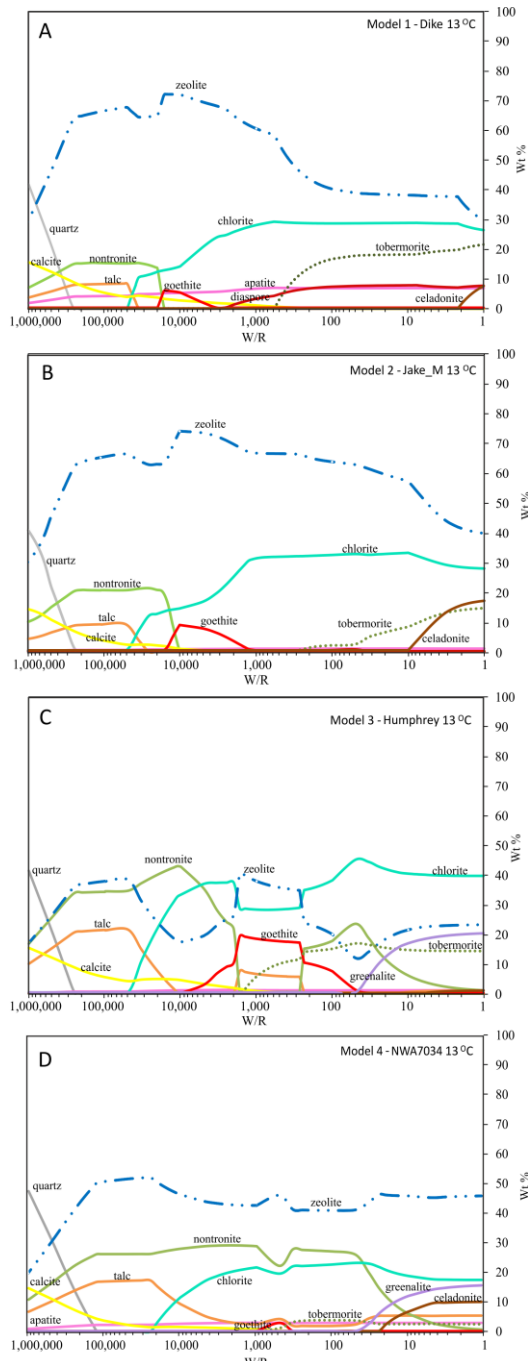
Figure 1: Variations of the secondary minerals that precipitate at 13 C when the modelled fluid interacts with basalt of different compositions. In the models: apatite = apatite-OH + apatite-F; talc = talc + talc-Fe; nontronite = Na-Ca-K-nontronite; chlorite = clinochlore + daphnite + chlorite-Mn; zeolite = analcite (models 1-2) + stilbite (models 1-2-3-4).

Conclusion and future work: The results show that the interaction of basaltic rocks of different composition with a martian-like fluid at low temperature (13 °C) produces different secondary mineral assemblages. The models highlight the differences in the type and abundance of secondary minerals that would form when a water-dike system cools down to ambient temperature. These preliminary results reinforce the necessity to further explore compositional differences in basalts when investigating aqueous systems formed after the intrusion of mafic dikes in sedimentary rocks. This is important to improve our understanding of the relationships between the geochemistry of the magmatic rocks, the water-sediment-magma interactions, and the mobility of elements that can be used for microbial metabolism. This will help to critically assess the potential habitability of hydrothermal environments on Mars. The following step will be to investigate reaction paths at 100 °C and 200°C to understand how temperature variations affect the fluid chemistry and mineral assemblage. Future work will vary the basaltic Cl content to see the effect on brine chemistry and on precipitates. The model results will be compared with the alteration minerals observed in the alteration zone of the terrestrial dike [5, 6] and in similar settings on Mars; Finally, the modeling of Humphrey will be directly compared with previous modeling results [13].

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