The Frankenstein Gabbro (Odenwald, Germany): A New Analogue for Martian Hydrothermal Systems

Conference or Workshop Item

THE FRANKENSTEIN GABBRO (ODENWALD, GERMANY): A NEW ANALOGUE FOR MARTIAN HYDROTHERMAL SYSTEMS. R. G. W. Seidel[1], J. C. Bridges[2], T. Kirnbauer[3], S. C. Sherlock[1] and S. P. Schwenzer[1], [1]The Open University, Milton Keynes, UK (robert.seidel@open.ac.uk), [2]University of Leicester, UK, [3]Technische Hochschule Georg Agricola, Bochum, Germany.

Introduction: Analogues can provide important information about hydrothermal processes on Mars beyond the data gathered by rovers on the Martian surface, or from Martian meteorites. For the latter, detailed histories of fluid properties and habitability may be reconstructed [1, 2, 3]. However, only the nakhlite group of Martian meteorites shows unambiguous hydrothermal alteration [4]. These igneous clinopyroxene-rich cumulate rocks [5] formed ~1.3 Ga ago [6], and were altered sometime after 670 Ma [7]. Models suggest the hydrothermal fluid affecting the nakhlites would have been suitable for life at least intermittently [3]. The nakhlites however do not represent average, basaltic, Martian crust [8]. The alteration behaviour of Martian basalts, and the habitability of associated hydrothermal systems, remain uncertain. Model studies, either of rocks measured *in situ* on Mars, Martian meteorites [e.g., 9] or terrestrial analogues [e.g., 10], for now provide the only way of addressing that question.

The aim of this ongoing study is to predict hydrothermal alteration in basaltic host rocks on Mars, and to identify proxy minerals indicative of hydrothermal fluids that could have sustained potential Martian life in the past. Such information may be crucial in selecting target and sampling sites for future Mars missions.

The Frankenstein Gabbro – a Martian analogue rock. We use a gabbro from the Frankenstein Massif in the Odenwald Mountains, Germany. The site was chosen due to its in-land location at the time of alteration, resulting in seawater-free fluids similar to fluids present on Mars [9]. The Odenwald is part of the Mid-German Crystalline Rise, a former magmatic arc [11, 12]. The gabbro intrusions of the Frankenstein Massif formed ~360 Ma ago [e.g., 13], and were hydrothermally altered 138 ± 8 Ma ago [14]. Samples were collected from an active quarry in the municipality of Nieder-Beerbach, and analysed using optical microscopy, a FEI Quanta 200 SEM-EDX and a CAMECA SX100 EMP (Open University). T-H_2O phase diagrams were calculated using the thermochemical modelling software TheriakDomino [15], and a comparison made for Martian basaltic soil (Portage Soil) as measured by NASA's Curiosity rover at Gale Crater [16].

Results: Gabbro samples consist of ~60–70 vol. % plagioclase ($An_{0\text{-}80}$; Fig. 1), ~10–15 vol. % clinopyroxene ($En_{55\text{-}65}He_{22\text{-}36}Di_{4\text{-}19}$), ~5 vol. % amphibole (actinolite-pargasite), ~5–10 vol. % chlorite and a combined ~5 vol. % of apatite, epidote, magnetite, and phyllosilicates (Fig. 2).

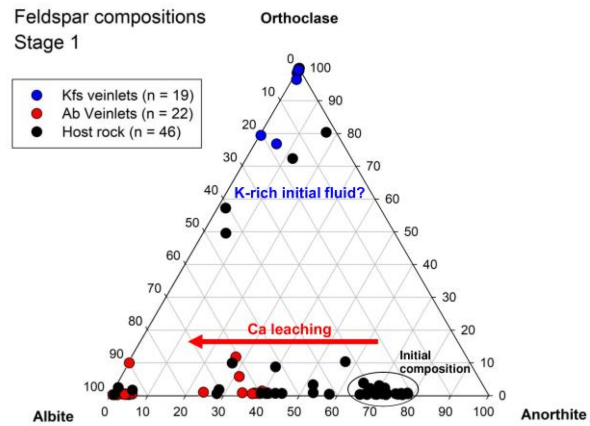

Fig. 1. EMP analyses of feldspar, showing Ca-leaching from host rock plagioclase during alteration stage 1.

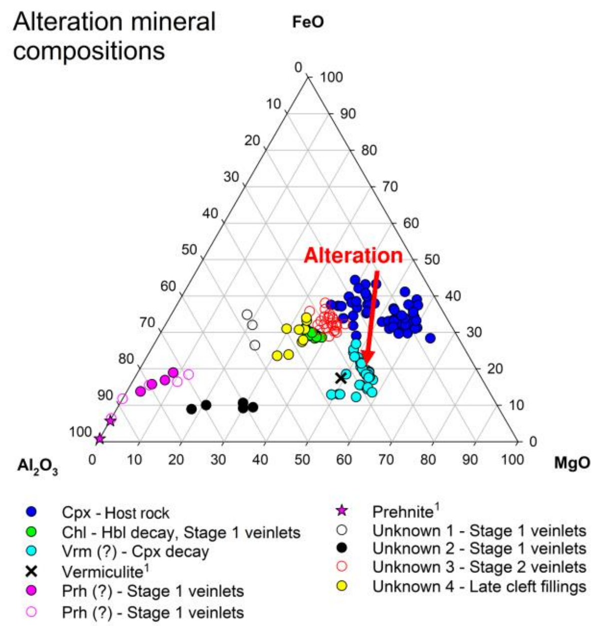

Fig. 2. EMP (solid circles) and EDS (open circles) analyses of minerals formed during alteration stages 1 and 2. A common alteration trend, host rock clinopyroxene to vermiculite, is shown as example. 1) reference data from [17].

Discussion: The gabbro from the Nieder-Beerbach quarry shows two stages of tectonically-related alteration. The first stage is moderate and widespread, associated with N-S to NNW-SSE striking hairline faults. The second stage is extensive and restricted to more rarely occurring W-E oriented, steeply inclined faults 10 cm to 1 m in size with offsets of up to several meters. The unaltered gabbro is massive-homogeneous with a fairly uniform grain size of 0.5–2 mm. Primary magmatic minerals are plagioclase, clinopyroxene, pargasite, magnetite, and accessory apatite. In an early post-magmatic phase [13, 18] clinopyroxene and pargasite were partially replaced by actinolite.

Stage 1 alteration. During the first stage of the ~138 Ma hydrothermal event, fluids entered along the hairline faults, healing some of them, and leading to the formation of numerous ~25–250 µm thin veinlets that either cut the primary minerals, or follow grain boundaries. Major alteration effects on primary minerals are 1) albitisation [19], involving a likely influx of Na and Si from the fluid, leaching of Ca from An-rich plagioclase and recrystallisation to form albite (Fig. 1), dissolved Al and Ca being accommodated by chlorite, epidote, and calcite; 2) replacement of clinopyroxene with actinolite and a phyllosilicate (vermiculite?), the former chemically similar, the latter relatively enriched in Al and depleted in Fe (Fig. 2); 3) replacement of pargasite with either actinolite (relatively depleted in Al, K, Ti) or chlorite, plus titanite. The healed faults, ~100–250 µm in width, are dominated by chlorite with lesser albite, epidote, actinolite, and possibly prehnite. Larger veinlets have a similar assemblage of albite-epidote ± chlorite ± actinolite. In veinlets smaller than ~100 µm, a strong dependence on host rock mineralogy is seen: Parts of veinlets hosted by plagioclase consist of albite ± chlorite ± calcite or, at the smallest widths, kalifeldspar ± chlorite, possibly reflecting a potassium-rich initial fluid (Fig. 1). Parts of veinlets hosted by clinopyroxene consist of actinolite and as yet unidentified phyllosilicates (Fig. 2).

Stage 2 alteration. During the second stage, the host rock is disrupted by calcite veins reaching several centimeters in thickness. The calcium probably derives from the first-stage leaching of plagioclase. The primary magmatic minerals are wholly replaced by recrystallised albite, chlorite, vermiculite(?), and another as yet unidentified phyllosilicate (Fig. 2).

P-T-H_2O conditions. The thermochemical models suggest that the major alteration reactions of stage 1 – albite, actinolite, chlorite and epidote forming alongside plagioclase, clinopyroxene and pargasite – took place at a bulk water content of ~5 wt. % and temperatures above ~250 °C, in agreement with previous temperature estimates [20]. In order to maintain liquid water at that temperature, a fluid pressure of at least 80 bar is required [21].

Implications for Mars. At the same T-H_2O conditions, projected alteration minerals of Portage Soil-type basalt are quartz, chlorite, and amphibole (Fig. 3). The latter is found in melt inclusions in Martian meteorites [e.g., 22] but has not yet been described as a secondary mineral on the Martian surface [23].

Future Work: We will investigate the phyllosilicate phases, and explore other modelling approaches that simulate localised action by non-neutral fluids [24]. In this, we will particularly focus on the observed drastic changes in veinlet mineralogy over short distances (tens of µm). Small-scale variability of hydrothermal veinlets has also been observed in the nakhlites [1, 2]. This suggests that fluid properties, in terrestrial or Martian rocks, may differ significantly even within the same vein, and that any prediction about the habitability of Martian hydrothermal systems has to be made on the scale of individual mineral grains.

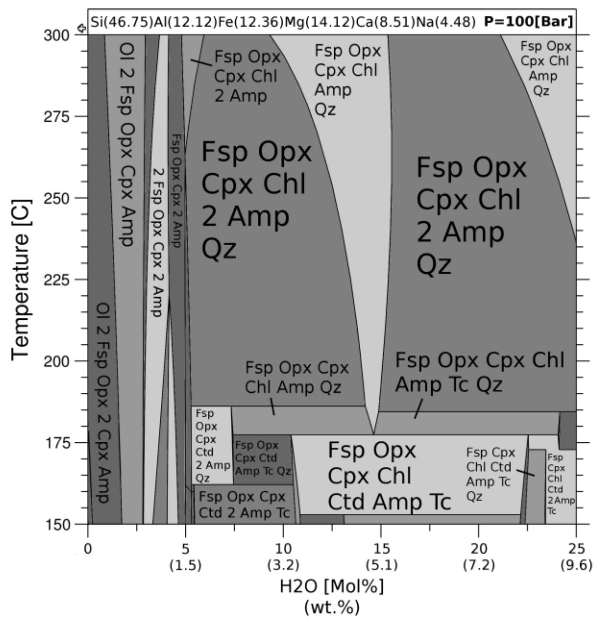

Fig 3. T-H_2O phase diagram for Martian basalt (Portage Soil). Bulk chemistry data (K, Ti excluded) from [16].

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