Hydrothermal Alteration in the Frankenstein Gabbro Martian Analogue

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We present results of an ongoing petrologic and modelling study of a new Martian analogue rock: The Frankenstein Gabbro (Odenwald, Germany). Our aim is to predict mineral reaction paths and fluid properties during hydrothermal alteration of basaltic host rocks on Mars – thought to be a common by-product of impact cratering – in order to assess the habitability of the fluids for the potential of Martian life, and establish a link between habitable fluid conditions and secondary mineral assemblages.

Primary minerals of the analogue are mostly plagioclase (~70 vol.%) and clinopyroxene (~20 vol.%) with lesser percentages of amphiboles and Fe-oxides. We focus on a chloritic-propylitic alteration event associated with hairline fault planes and mineral veinlets. The secondary mineralisation shows strong small-scale variability, depending on host mineral and type of fluid pathway: For plagioclase hosts, fault planes are dominated by chlorite with additional epidote and prehnite, while mineral veinlets consist of albite ± calcite ± chloride ± epidote ± K-feldspar ± mica. For clinopyroxene hosts, fault planes consist of actinolite with additional chloride or vermiculite, while mineral veinlets consist of prehnite and vermiculite.

We use the software CHIM-XPT to model mineral reaction paths, with published XRF bulk rock data, EMP analyses of single minerals, and a starting fluid enriched in Na, K, Mg and Si for input, the latter based on calculated element budgets of mineral replacement reactions. Our models reproduce secondary assemblages related to plagioclase-hosted fault planes (chlorite–epidote–prehnite) and veinlets (albite–chlorite–epidote–K-feldspar–mica), as well as alteration rims around clinopyroxene related to fault planes (actinolite–chlorite). Corresponding fluid conditions are ~200–250 °C, pH ~6.5–8.0, at water/rock ratios >3000, in agreement with pre-model constraints by mineralogy. The breakdown of clinopyroxene and plagioclase releases large amounts of Ca, with calcite inferred to be a late-stage product of cooling. Fluid redox state is shown to be largely controlled by host minerals, and in turn exerts strong influence on secondary mineral formation: clinopyroxene releases Fe²⁺ during alteration, which is taken up by chlorite; in contrast, plagioclase contains up to 0.5 wt.% Fe³⁺ substituting for Al, which is taken up by epidote. Prehnite, of the same elemental composition except for Fe, is inversely correlated with epidote.
Thus, the relative percentages of chlorite, epidote and prehnite can serve as indicators of redox state in similar types of rock.

Our models match key petrological observations and provide information about the alteration process beyond what may be directly observed. They illustrate the need to account for small-scale variability, and to adjust models on a case-by-case basis. This has important implications for models of Martian habitability, where similar features may be expected. Next, we will apply these reaction pathways to Martian rocks (shergottitic basalts), focusing especially on small-scale distribution of dissolved iron species, a suggested energy source for hypothetical microbial Martian life.