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Modelling Fluids Associated with Sulfate Veining in Yellowknife Bay, Gale Crater

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1. Introduction

The sedimentary outcrops in Yellowknife Bay, Gale Crater show sulfate veining (Fig. 1). Understanding the fluid chemistry, temperature and pH of the associated fluids is an important part of the aims of Mars Science Laboratory – establishing where conditions were habitable for microbial life. The veins are particularly abundant in the Sheepbed area which contains fine-grained lithified sediments in the lowest part of the exposed Yellowknife stratigraphy.

The sulfate identity has been determined from Laser Induced Breakdown Spectroscopy analyses, the latter suggesting Ca sulfate [1]. Visually, the MastCam and Remote Micro-Imager photographs suggest that the veins are near pure sulfate.

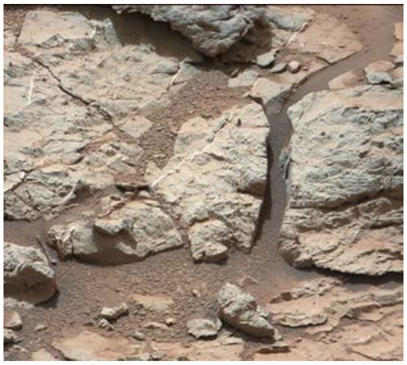

Figure 1: Mastcam image from sol 126 showing white sulfate veining in the Sheepbed outcrop of Yellowknife Bay. Field of view 40 cm.

1.1 Modelling Approach

Our work is based on CHIM-XPT [2] and CHESS [3] thermochemical modeling. For this we build on our experience with previous models of shergottite [4] and nakhlite [5] Martian meteorites, and derive the input parameters from the composition of the country rocks based on data from the APXS and ChemCam instruments [6, 7]. The models consider a range of alteration scenarios through a variation of pressures and temperatures, ranging from ambient temperature weathering to mid-ocean ridge-like hydrothermal conditions. We start with a dilute brine and assume that it reacts with the country rock, in which 10% of the iron is ferric. We then compare the Curiosity observations at Yellowknife Bay to the mineral assemblages and compositional parameters within our models.

2. Results

Reaction of the country rock compositions with a brine of up to 0.5 mole SO_4^{2-} concentration at a range of temperatures 25–150 $^\circ$C and water/rock ratios between 10000 and 1 fails to create the sulfate enrichment necessary for the veining. Instead abundant iron oxide and phyllosilicates are produced. As a result of this the fluids in our models are depleted in Fe, Si and Al. We model evaporation of this fractionated fluid, and this can produce significant sulfate enrichment (together with silica). For instance, evaporation of this fractionated fluid at 25 $^\circ$C from water/rock ratios of 1000 to 0.1 can create sulfate, as is shown in Figure 2. Progressive evaporation increases the proportion of anhydrite to gypsum. However in order to create the sulfate veins, which appear from the images to be highly pure, a final stage of re-dissolution and purification is necessary.

There is no one definitive solution to our models with the data available at present. For instance, an alternative acid-fog model has been explored by [8,9] at Gale Crater and for the veining in Meridiani Planum. However, the need for fluid purification prior to sulfate precipitation at Yellowknife is evident and most of the assemblages are consistent with a low temperature scenario, located within a few km depth of the surface assuming a geothermal gradient of about 13 °C km^{-1} [10], but at present we cannot exclude a scenario that includes higher temperatures during the different stages. More observations of such veins, especially those yielding more information on the assemblage of the sulfate phase with other minerals, are expected to help narrow the range of formation conditions possible.

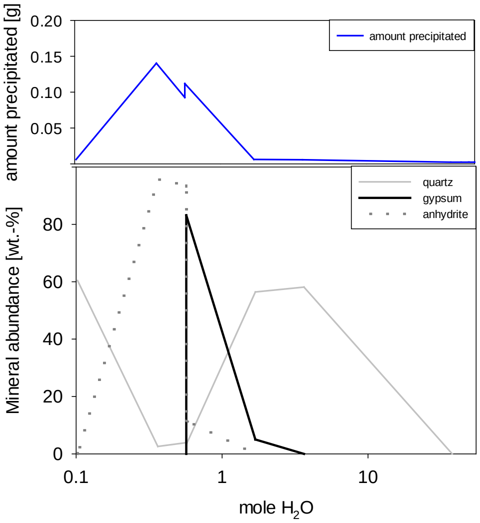

Figure 2: Modelled evaporation of a second stage (intermediate) fluid at 25°C. This is similar for all scenarios containing sufficient amounts of sulfur. Note that with decreasing water activity, SiO_2 precipitates. With further decreasing water activity sulfate precipitates, first as gypsum, then anhydrite. In one model that we considered, the sulfate veins at Yellowknife are produced by re-mobilization of sulfate phases from mixed sulfate and silica bearing precipitates such as these.

6. Summary and Conclusions

Combining the observations available at present with the model results, reveals that the alteration history of the Yellowknife Bay rocks was likely to be a multi-stage process. Our modelling results so far suggest that reaction of a – likely – low temperature, e.g. 25 °C, dilute brine with the Gale Crater country rock would initially lead to iron oxide and phyllosilicate precipitation. However, significant quantities of sulfate are not produced unless fluid associated with the veins has dissolved sulfur from enriched sources in adjacent or deeper strata or the fluid resulting from the first stage alteration undergoes transport and evaporation. We conclude that the observed sulfate enrichment could have resulted from evaporation of a fractionated fluid, which previously reacted with the rocks present in the adjacent and underlying strata.

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