Groundwater upwelling and silica deposition within Gale in (semi-)arid climate on early Mars

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Introduction

NASA's Curiosity rover has provided information on geochemistry and mineralogy of lacustrine sediments within Gale Crater [1]. Gale's mudstones of Murray Formation are characterized by authigenic depositions of silica with iron oxides, suggesting inputs of dissolved SiO_2 and Fe^{2+} into the early Gale lake possibly by upwelling groundwater [2]. Here, we perform hydrological modeling and hydrothermal experiments to constrain paleoclimate, compositions of groundwater, and warming duration that can explain the observed geochemistry of Murray mudstone.

Hydrological Modeling

A three-dimensional hydrological model was applied for the area surrounding Gale Crater. Our results show that climate largely controls groundwater flows and surface water volume. We find that multiple lakes can appear owing to groundwater upwelling in (semi-)arid climate, which can explain the observations of paleolakes around Gale. Given paleothermal gradient [3], groundwater would experience hydrothermal reactions at 100–200ºC with the crustal rocks.

Hydrothermal Experiments

To simulate water-rock reactions within Martian crust, hydrothermal experiments were performed at 200ºC using a synthesized Martian rock. Various secondary minerals, analcime, quartz, albite, Fe(Mg-)saponite, Fe(Mg-)serpentine, and trace carbonates, are formed. We find that dissolved SiO_2 concentration (1–10 mM) is buffered by quartz; whereas, that of Fe^{2+} ($\sim10^{-3}$ mM) is likely controlled by Fe-carbonate (siderite).

Implication for Gale's lacustrine environments

Combining the results of upwelling groundwater flux and dissolved SiO_2, a flux of SiO_2 into early Gale lake is estimated. This corresponds to 0.02–0.2 mm/year of deposition rate of silica, implying that laminae of Murray mudstone [1] may be varve. This suggests $\sim10^5$ years of warming and (semi-)arid periods at Gale to explain the thickness of Murray mudstone.

[1] Grotzinger *et al.* (2015) *Science* **350**, aac7575. [2] Hurowitz *et al.* (2017) *Science* **356**, eaah6849 [3] Michalski *et al.* (2013) *Nat. Geosci.* **6**, 133–138.