Reconstructing groundwater hydrology and water-rock reactions around Gale Crater on early Mars

*Natsumi Noda[1,2], Yasuhito Sekine[1], Shuya Tan[1,2], Takazo Shibuya[3], Hidenori Genda[1]

1. Earth-Life Science Institute, Tokyo Institute of Technology, 2. Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, 3. Department of Subsurface Geobiological Analysis and Research, Japan Agency for Marine-Earth Science and Technology

NASA’ s Mars Science Laboratory Rover, Curiosity, has provided key information on geochemistry and mineralogy of the lacustrine sediments deposited within Gale Crater on early Mars(e.g. Grotzinger et al. 2015, Rampe et al. 2017). Gale’ s lacustrine mudstones of Murray Formation are characterized by authigenic depositions of high levels of silica (e.g., opal CT and amorphous silica) together with iron oxides (e.g., magnetite and hematite), suggesting inputs of dissolved SiO_2 and Fe^{2+} into the early Gale lake (Hurowitz et al. 2017). One possible source of dissolved SiO_2 and Fe^{2+} is upwelling groundwater. However, little is known about the conditions of both climate and water table capable of upwelling groundwater into Gale Crater. Additionally, the chemical compositions of groundwater on early Mars, particularly the determining factors of concentrations of dissolved SiO_2 and Fe^{2+}, have been poorly constrained.

Here, we perform both hydrological modeling and hydrothermal experiments to interpret the observations. Based on the simulation and experimental results, we discuss the climate, groundwater hydrology, and input fluxes of dissolved SiO_2 and Fe^{2+} of Gale lakes.

In the hydrological modeling, we perform three-dimensional hydrological simulations for the area surrounding Gale Crater using GETFLOWS, which deals with fully-coupled surface and subsurface flows based on the hydro-geophysical equations. We find two modes of the lake distribution and groundwater flow around Gale. One is the high-evaporation mode where multiple shallow lakes can appear at local topographic lows owing to vigorous upwelling of groundwater under (semi-)arid climate conditions. The other is the low-evaporation mode where lake(s) exists only at the lowest place(s) under relatively humid climate conditions. To explain both a closed-basin lake within Gale Crater and some lakes around Gale, the high-evaporation mode is most likely to have occurred on early Mars. Our results suggest (semi-)arid climate conditions around Gale with a shallow water table. Under the arid climate conditions, evaporation of lake water would have caused effective upwelling of groundwater. Given thermal gradient within the crust, such upwelled groundwater would have experienced hydrothermal reactions with the crustal rocks.

In the hydrothermal experiments, we simulate high-temperature water-rock reactions between groundwater and Martian crustal rocks. Hydrothermal reactions at 200ºC between a synthesized Martian rock analog and fluids are performed using a Dickson-type apparatus. Various secondary minerals, such as analcime, quartz, albite, Fe(Mg-)saponite, Fe(Mg-)serpentine, and trace carbonates are also formed via the hydrothermal reactions. We find that dissolved SiO_2 concentration (1–10 mM) is buffered by dissolution of quartz; whereas, that of Fe^{2+} (˜10^{-3} mM) is likely controlled by dissolution of Fe-carbonate (siderite).

Combining these simulation and experimental results, we estimate the input fluxes of dissolved SiO_2 and Fe^{2+} contained in upwelled groundwater into Gale lakes. The flux of dissolved SiO_2 corresponds to ˜0.02–0.2 mm/year of the deposition rate of silica, implying that the parallel laminae of the lacustrine mudstone(Grotzinger et al. 2015) may be varve. This further suggests ~10^5 years of warming periods to explain the thickness of Murray Formation. Upwelling groundwater might have also provided Fe^{2+} into the lake, leading to formations of Fe oxides and H_2. Our results suggest that low-latitude deep craters, including Gale, would have played key roles in upwelling deep groundwater at arid climates in the global hydrological cycles, providing reductants and greenhouse effect gas to the surface of early Mars.

Keywords: Mars, Hydrothermal experiment, hydrologic model

