Hydrology of Subsaline Lakes in Southern Mongolia: A Terrestrial Analog Study for Lacustrine Environments and Chloride Depositions on Early Mars.

T. Chida[1], Y. Sekine[1], K. Fukushi[2], H. Matsumiya[2], T. Solongo[2], N. Hasebe[2], and J. Davaadori[3], [1]Dept. Earth and Planetary Sci., Univ. of Tokyo (7-3-1 Hongo, Bunkyo 113-0033 Japan), [2]Inst. Nat. Environ. Tech., Kanazawa Univ., [3]Dept. Geograph., National Univ. of Mongolia

Introduction: Chlorides are found across the southern highlands of Mars through Mars Odyssey's Thermal Emission Imagery System and Mars Global Surveyor's Thermal Emission Spectrometer [e.g., 1–4]. These deposits are found on mid-Noachian to early Hesperian (3.9-3.5 Gyr old) crust, and generally on local topographic lows. Some deposits are found in basins and feeder valleys, suggesting that the deposits were formed in lacustrine environments upon ponding and evaporation [1,2,4]. On the other hand, their formation by evaporation of upwelling groundwater and/or hydrothermal brines has also been proposed [1,3]. Despite the importance of the formation process(es) of the widespread chloride deposits for understanding hydrology and climate on early Mars, the fact that the chloride deposits are often small and degraded leads to their formation process(es) being unclear.

In this regard, terrestrial analogs can provide unique insights into the formation process(es) of chloride deposits on Mars. A number of previous studies have investigated terrestrial analogs for geological and geophysical processes on early Mars, including hematite concretions on desert sites [5], impact crater lake [6], and hydrological system on polar sites [7]. Less studies, however, have focused on formation of chloride deposits in arid environments, especially hydrological cycles and the roles of surface and subsurface water to sustain saline lakes.

In the present study, we performed a geological survey for three subsaline lakes and their surrounding areas in the Gobi Desert-Altai mountains transition zone of Mongolia (the Olgoi, Böön Tsagaan, and Orog lakes: Figs. 1 and 2). This area is a promising terrestrial analog environment that harbors ponding and lake evaporating under arid-to-semi-arid conditions [8,9]. We measured groundwater levels and analyzed chemical compositions of the lakes, rivers, springs, and groundwater in the region. In addition, using the numerical model of the General-purpose 3D Terrestrial fluid-FLOW Simulator (or GETFLOWS), we reproduce the groundwater levels surrounding the lakes and the flux of groundwater upwelling into the lakes. Finally, we discuss the implications of our results for the formation of chloride deposits on Mars.

Geological Survey of Subbrine Lakes in Southern Mongolia and Analytical Methodology: Lakes and rivers in the Gobi Desert create an arid-to-semi-arid hydrological system which serves as an analog of early Mars' surface. Two lakes, the Böön Tsagaan lake and the Orog lake, are the possible remains of a larger lake that previously existed under a more humid condition [9]. The surface area of the Böön Tsagaan lake is on monotonic decrease, meanwhile the Orog lake has been dried up several times in the last decade [8]. While the lakes each have their inflow rivers, they do not, at least currently, possess any outflow rivers (Fig. 2), thus creating a closed-basin system. Water samples were taken from the lakes and the river supplying the Böön Tsagaan lake, as well as from wells and springs in the region (Fig. 2). The dissolved species of the water were measured using an inductively coupled plasma optical emission spectrometer (or ICP-OES) and ion chromatograph, and the results are displayed using stiff diagrams. We then used Visual MINTEQ, a chemical equilibrium model, to calculate the saturation index of minerals. To determine the surface water/groundwater ratio of the inflow into the Böön Tsagaan lake, we used the chemical compositions of the inflow river and/or wells surrounding it, and concentrated the dissolved species by removing water abundance as a simulation of evaporation of lake water.

Results and Discussion. Lake water exhibits a contrasting water chemistry compared to others, such as rivers, springs, and groundwater (Fig. 3). The lake pHs are all basic (pH 9–9.5); meanwhile, those of rivers, springs, and wells are circumneutral (pH = 6.4–8.1) (Fig. 2). Lake water has high concentrations of dissolved species, such as Na^+, SO_4^{2-}, and Cl^-, excluding Ca^{2+} and HCO_3^-. This is most likely a result of surface/groundwater input and subsequent evaporation, leading to precipitation of calcite ($CaCO_3$) within the lakes. Rivers, springs, and well groundwater generally have low ion concentrations; Ca^{2+} and HCO_3^- being relatively high, compared with those of the lakes. Some wells have peculiar ionic compositions, which may be a result of a different groundwater flow route. (e.g., the well located west of the Böön Tsagaan lake may have a flow from the western region of the catchment area) (Fig. 2). Figure 3 shows that even the groundwater adjacent to the Böön Tsagaan lake, with only a few meters below the surface, has a distinctive chemical composition than that of the lake water. This fact suggests that the lakes have no effective groundwater outflow, despite high salinity and, thus, high density of the lake water.

Although our results of chemical analysis and numerical simulations using GETFLOWS indicate supply of groundwater and river water into the Böön Tsagaan lake, our results of chemical equilibrium calculations show that evaporation of river water, groundwater, or a mixture of them cannot reproduce the current pH and chemical composition of the lake water. A possible explanation for this is that the current chemical composition of the lake water is also affected by evaporation of a large paleolake [9]. In fact, the Böön Tsagaan lake may be a remain of a large paleolake upon aridification [9]. The large lake captures surface/subsurface water from both catchment areas of the Böön Tsagaan and Orog lakes; whereas, each lake currently has an individual catchment area. Accordingly, the large paleolake should have a different composition from those of the Böön Tsagaan or Orog lake. We suggest that the lake composition would be determined not only by current hydrology but also by a long-term change of hydrology and climate of the area.

Implications for Chloride Deposition and Hydrology on Early Mars: It is likely that paleolakes on early Mars underwent similar evaporation processes as the lakes in this study. The paleolakes with chloride deposits on Mars may have had active groundwater supply, as well as possible supply from the surface water. Our results of the contrasting water chemistry between the subsaline lake water and its neighboring groundwater suggests that a similar chemical contrast between the surface and subsurface water may have occurred on early Mars. This implies that, near chloride deposition areas on Mars, steep pH and chemical gradients might have existed from the surface to subsurface in the past, which may be essential for an emergence and early evolution of life [10].

Our results of the effect of the previously existing large lake on the chemical composition of the present-day lakes on the Gobi Desert also suggests a need to consider a long-term evolution of climate for evaluation of hydrology responsible for chloride formation on early Mars.

Fig.1 Map of Mongolia. The black square is the area of this study and the map area of Fig. 2.

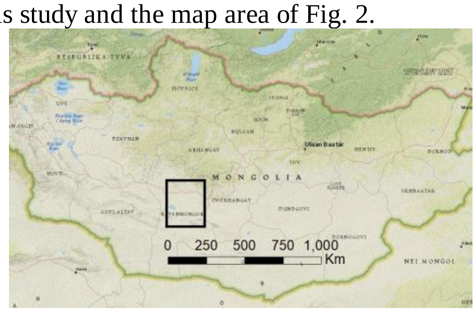


Fig.2 Location of the sampling points and their pH

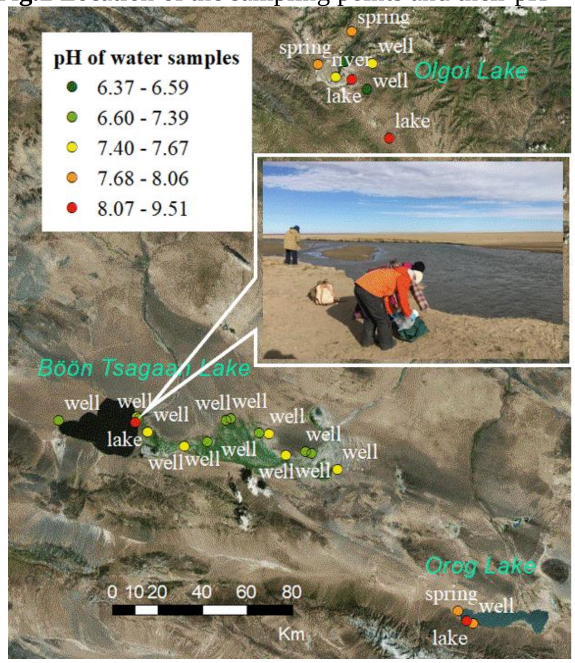
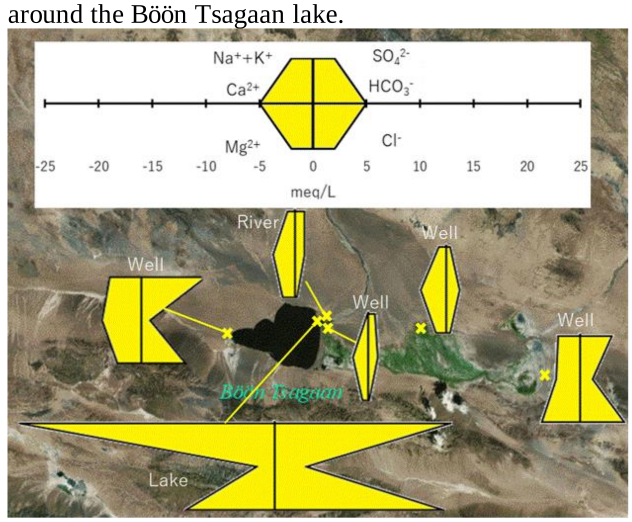


Fig.3 Stiff diagrams of surface water and groundwater around the Böön Tsagaan lake.



References: [1] Osterloo et al. (2008) *Science 319*, 1651–1654. [2] Hynek et al. (2015) *Geology, 43, 9*, 787–790. [3] Glotch et al. (2010) *Geophysical Research Letters, 37,* L16202. [4] Daswani et al. (2017) *J. Geophs. Res. Planets*, *122*, 1802–1823. [5] Chan et al. (2017) *Nature 429*, 731–734. [6] Komatsu et al. (2014) *Planetary Space Sci. 95*, 45–55. [7] Head and Marchant (2014) *Antarct. Sci. 26,* 774–800. [8] Szuminska (2016) *Sedimentary Geol. 340*, 62–73. [9] Komatsu et al. (2001*) Geomorphology 39*, 83–98. [10] Martin and Russell (2003) *Phil. Trans. R. Soc. Lond. B.*, *358*, 59–85.