Behavior of carbon dioxide and water during the Martian history

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It is well known that the current Mars has an extremely cold climate. However, valley networks and the ocean hypothesis of Mars imply a warm and wet climate in the past. In this study, we discuss the possible scenario of the evolution of Mars and potential behaviors of CO2 during the history of Mars based on our numerical climate model and reviews of previous studies on the evolution of volatiles on Mars. If the Martian climate was really warm and wet owing to the greenhouse effect of CO2 in the past, thick CO2 atmosphere and no permanent CO2 ice caps must have existed. This means that the total amount of CO2 contained in the atmosphere-ice-regolith CO2 exchange system (AIR system) must have been much more than that at present. The total CO2 is considered to have decreased by removal processes such as impact erosion and sputtering of the atmosphere. On the other hand, the present state is in the permanent-ice regime. According to the behaviors of the AIR system, the climate jump with runaway condensation of CO2 must have occurred during the transition from the non-permanent-ice regime to the permanent-ice regime. If the H2O ice caps might have formed before the formation of the CO2 ice caps, it might have triggered the climate jump due to the high albedo.

Large CO2 ice caps might have formed at the climate jump, which contain a much larger amount of CO2 than that in the AIR system estimated at present. We, however, found a possible solution of this problem. The temperature at the bottom of the CO2 ice cap would exceed the melting point of CO2 because of the thickness of CO2 ice cap and the geothermal heat flux. On the other hand, it is generally considered that the Martian crust would be quite similar to that of Moon; it has been modified by impact processes and is abundant in pores and fractures. If there is no H2O ice below the CO2 ice, liquid CO2 produced by basal melting could permeate and diffuse directly into the subsurface through the pore. If there is H2O ice below the CO2 ice caps, the H2O ice would melt and disappear by basal melting followed by permeation, because the temperature of the H2O ice increased by a blanketing effect of the CO2 ice and CO2 clathrate hydrate. Liquid CO2 generated by the basal melting of the CO2 ice could have diffused in the CO2 clathrate layer and finally reach the ground, resulting in permeation into the subsurface.

The thickness of the cryosphere (the portion of the crust of which temperature remains continuously below the freezing point of water) would have been as much as several kilometers under the cold climatic condition in the permanent-ice regime, even when we assume the high geothermal heat flux in the past. In such a case, a ground ice layer would have formed in the cryosphere. Clifford [1993] suggested that the global ground ice layer would have grown by the thermal vapor diffusion from the underlying groundwater followed by condensation. Therefore, the CO2 molecules which entered the subsurface could not come back to the atmosphere because pore space in near-surface crust might have been sealed up by the ground ice layer. Total capacity of these subsurface reservoirs for the fixation of CO2 could be several bars [Fanale et al., 1992; Carr and Head, 2003]. Therefore, if the large part of CO2 contained in the ancient ice caps were efficiently transported to the subsurface of Mars through the processes proposed above, the problem of the large CO2 ice caps could be resolved. In that case, a large amount of CO2 could be stored in the subsurface of Mars as clathrate, carbonate, and gaseous/liquid phase today.