Carbon dioxide sequestration on Earth and Mars: Potential of carbonates derived from Samail Ophiolite as analogues for Martian atmosphere-hydrosphere interactions

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The difference in climate between Earth and Mars may be due to differences in their atmospheric composition, specifically CO_2 levels (Earth = 0.4 mbar; [1], Mars = 1-3 bar; [2]). CO_2 sequestration via enhanced weathering of ultramafic rocks is regarded as one of the best strategies to mitigate climate change on Earth [3]. It has been extensively studied that the terrestrial atmospheric CO_2 reacts with alkaline H_2O to form carbonates for long-term storage [4]. Similar research on Mars relies on rover observations [5] and Martian meteorite analyses [6].

According to a recent estimate, atmospheric CO_2 accounts for ~80% of the C-budget in Ca-rich carbonates from Oman [4]. Mars has had a thicker atmosphere since the Noachian era (3.9 Ga), due to Tharsis volcanic activity injecting huge amounts of SO_2 [7], with greater CO_2 buildup than the modern Martian atmosphere. As a result of cloud formation followed by acidic rain, sulfate-rich (40%) sediments were abundantly formed [8]. The Noachian atmosphere could have been lost to space as a result of a combination of impact erosion and sputtering [9]. The residual CO_2 began to form carbonates in dust and soil [10], and trace amounts were also found in Martian meteorites [11]. Discovery of phyllosilicates [12] suggest that the H_2O on Mars was not acidic until the Tharsis formation. We attempted to estimate the Martian atmospheric CO_2 input in Ca-rich carbonates (age = 3.9 Ga; [13]) in ALH84001 (4.1 Ga; [14]). Distinct carbonate populations have been found in ALH84001 using sequential acid extraction and microprobe analysis [6].

The Martian atmospheric CO_2 contribution in Ca-rich carbonates in ALH84001 is calculated using a 2-tracer and 3-component mixing model [15]. The end members, such as Noachian CO_2 [16], water [17, 18], Fe-Mg-rich carbonates [6], and weathered carbonates [6], are used in the 3-component mixing model (see Image1). Our calculations show that the Ca-rich carbonates in ALH84001 received half of their C-budget (48 ±16%) from atmospheric CO_2, assuming that they formed after the formation of Fe-Mg-rich carbonates during an aqueous event in early Martian history. Other sources (e.g., DIC) account for the remaining 52 ±14% of the C-budget in ALH84001 Ca-rich carbonates.

Martian meteorites and terrestrial analogues are useful resources for studying Martian surface and subsurface processes until the samples returned to Earth by a mission linked to the Perseverance rover [19]. The carbonates in ALH84001 [6, 17] and Samail Ophiolite [20, 21] are chemically and isotopically distinct, implying that the latter could be a useful Mars analogue [22]. A detailed examination of these carbonate types (particularly listwaenite) will help us understand the evolution of Martian atmosphere-hydrosphere interactions.

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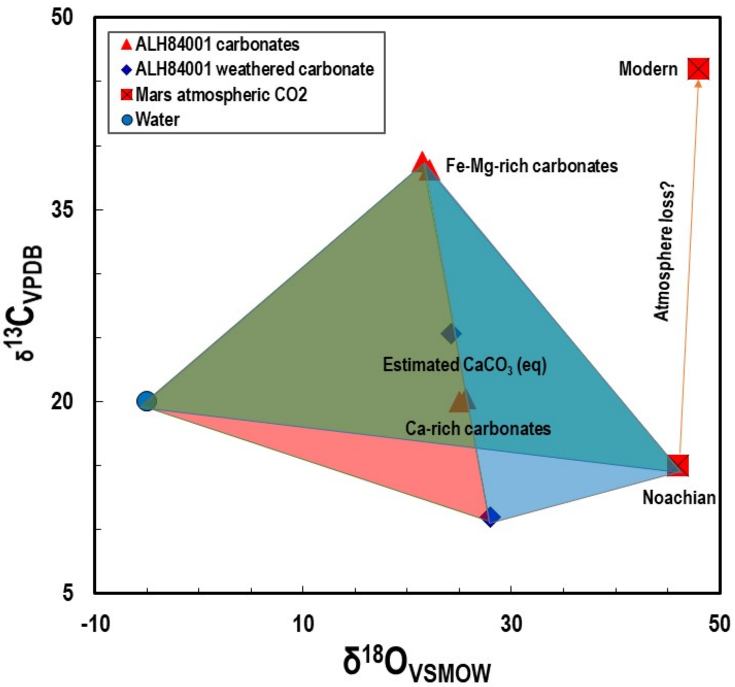

Image 1. $\delta^{18}O_{VSMOW}$ vs. $\delta^{13}C_{VPDB}$ model for estimating the contribution of Martian atmospheric CO_2 in C-budget of Ca-rich carbonates precipitated in ALH84001 meteorite during early Martian history (3.9 Ga). Isotopic compositions of equilibrated $CaCO_{3(eq)}$ were estimated using the equilibrium fractionation factor between $CO_{2(g)}$ and $CaCO_3$ (i.e., $\epsilon^{13}C_{CO2\text{-}CaCO3} = -10.3$ ‰ at 20°C; [23]. Data sources: [6, 16-18, 24].