American Mineralogist, Volume 97, pages 1841–1848, 2012

CO_2 solubility in primitive martian basalts similar to Yamato 980459, the effect of composition on CO_2 solubility of basalts, and the evolution of the martian atmosphere

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Abstract

To determine the influence of basalt composition on the CO_2 solubility in martian lavas, we investigated experimentally a synthetic melt based on the martian meteorite Yamato 980459 (Y 980459), an olivine-phyric shergottite and a picritic rock (19 wt% MgO) thought to be a near-primary liquid derived from high-temperature (>1540 °C) partial melting of the martian mantle. Experiments were performed in a piston-cylinder apparatus at 1–2 GPa and 1600–1650 °C. CO_2 contents in quenched glasses were determined using Fourier transform infrared spectroscopy (FTIR) and range from 0.45–1.26 wt%. Despite large differences in FeO* and MgO contents, the CO_2 solubilities in Y 980459 are similar to that in a less primitive synthetic martian basalt based on the Humphrey rock and to a Hawaiian tholeiite. The lack of enhanced solubility in Fe^{2+}- and Mg^{2+}-rich melts is likely owing to the complex structural role of these cations in silicate melts, acting partly as network formers, rather than network modifiers. The small sensitivity of CO_2 solubility to compositional variations among martian and tholeiitic basalts means that the experimentally determined solubilities may be applicable to a wide spectrum of martian magmatic products. Using experimentally determined CO_2 solubilities of Y 980459 and Humphrey allows the calibration of the thermodynamic parameters governing dissolution of CO_2 vapor as carbonate in martian basalts. This relation facilitates calculation of the CO_2 dissolved in magmas derived from graphite-saturated martian basalt source regions as a function of P, T, and f_{O_2}. The hot conditions in the source of Y 980459, 1540 ± 10 °C, and 1.2 ± 0.5 GPa, are plausible for plume-related magmas forming the giant Tharsis volcanic complex, which accounts for 50% of martian igneous activity since stabilization of the primordial crust. If oxygen fugacity in the sources of hot Tharsis magmatism were equivalent to that at the iron-wüstite buffer (IW) or 1 log unit above (IW+1), respectively, then the entire Tharsis event would outgas 30–300 mbars of CO_2 to the martian atmosphere, which is far from the 2 bars required to stabilize an equable climate in the late Noachian and early Hesperian epochs. This mismatch could be reconciled if significant martian igneous activity derived from comparatively oxidized mantle sources (i.e., IW+2) similar to those responsible for the nakhlite meteorites.

Keywords: CO_2, solubility, Mars, infrared spectroscopy, martian basalts, atmosphere, experimental petrology