**CO₂ solubility in primitive martian basalts similar to Yamato 980459, the effect of composition on CO₂ solubility of basalts, and the evolution of the martian atmosphere**

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**ABSTRACT**

To determine the influence of basalt composition on the CO₂ 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. CO₂ 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 CO₂ 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 Fe²⁺- and Mg²⁺-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 CO₂ solubility to compositional variations among martian and tholeitic basalts means that the experimentally determined solubilities may be applicable to a wide spectrum of martian magmatic products. Using experimentally determined CO₂ solubilities of Y 980459 and Humphrey allows the calibration of the thermodynamic parameters governing dissolution of CO₂ vapor as carbonate in martian basalts. This relation facilitates calculation of the CO₂ dissolved in magmas derived from graphite-saturated martian basalt source regions as a function of P, T, and fO₂. 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 CO₂ 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:** CO₂, solubility, Mars, infrared spectroscopy, martian basalts, atmosphere, experimental petrology

**INTRODUCTION**

Evidence for standing liquid water on the martian surface during the Late Noachian and Hesperian epochs (e.g., Irwin et al. 2005; Fassett and Head 2008; di Achille and Hynek 2010; Grant et al. 2011) strongly suggests a thick greenhouse atmosphere not evident on Mars today (Pollack et al. 1987; Pepin 1994). Yet there remains considerable uncertainty as to how this greenhouse was created and maintained, and how it evolved to a thin, modern atmosphere. Early studies assumed that the current thin, modern atmosphere was formed by a relative dearth of substantial layered carbonate deposits that would be the expected record of a thick CO₂ atmosphere (Schaefer 1993; Bullock and Moore 2007; Chevrier et al. 2007). Furthermore, alternative greenhouse environments involving SO₂ and CH₄ have been proposed (Brown and Kasting 1993; Squyres and Kasting 1994; Fairen et al. 2004; Bullock and Moore 2007; Chevrier et al. 2007; Halevy et al. 2007; Gaillard and Scaillet 2009; Righter et al. 2009).

The volcanogenic supply of volatiles is an important input and key limiting factor to martian atmospheric evolution (Gillmann et al. 2011). Understanding this flux requires constraints on the cumulative magmatic flux to the martian surface and on CO₂ solubilities in primary martian basalts. The time integrated magmatic flux through martian history, although subject to considerable uncertainties, has been estimated from photogeology (Greeley and Schneid 1991; Jakosky and Shock 1998; Craddock and Greeley 2009) and from models of heatflow through time (Carr 1999; Manning et al. 2006; O’Neill et al. 2007), and has been parameterized by Hirschmann and Withers (2008).

A key constraint on the likely CO₂ fluxes accompanying