CO_2 Solubility in Primitive Martian Basalts Similar to Yamato 980459 and the Evolution of the Martian Atmosphere

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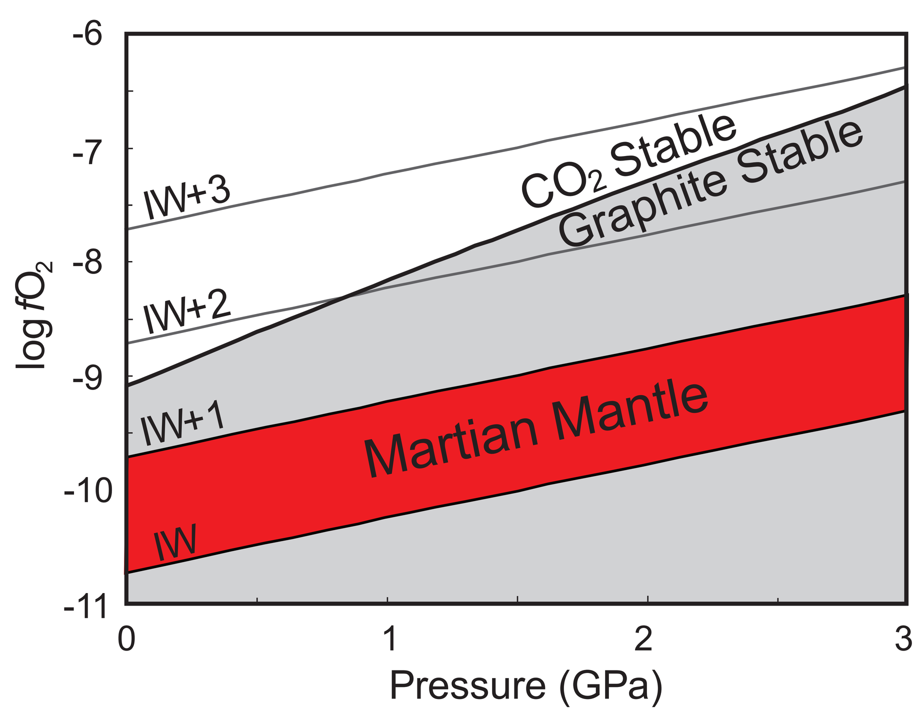
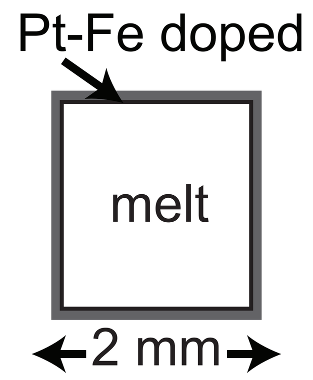
Introduction

There is considerable evidence that liquid water was stable on the ancient Martian surface during at least some parts of the late Noachian and early Hesperian epochs. Yet there remains considerable uncertainty as to how this greenhouse was created and maintained and how it evolved to the current thin, modern atmosphere.



Oxybarometry of SNC meteorites suggests that the oxygen fugacity of much of the Martian mantle is reducing (iron-wustite, IW, ±1) and so carbon is likely stored as graphite in a reduced Martian mantle (After [1]).

Experiments



Experiments were performed using a 0.5" piston-cylinder apparatus.

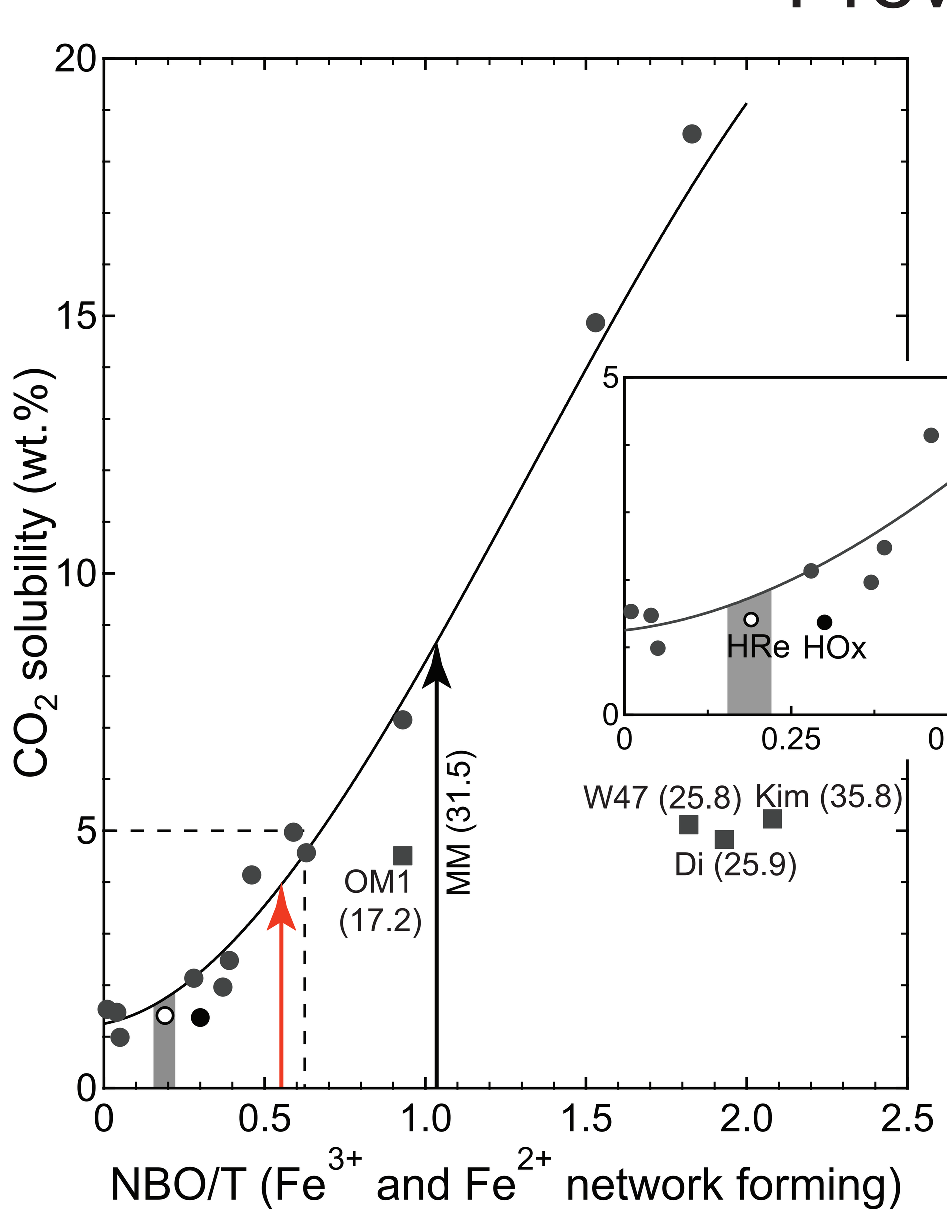
The 2 mm Pt capsules were iron-presaturated to prevent Fe-loss.

Conditions: 1600-1650 °C, 1.0-2.0 GPa, and a duration of 30 min.

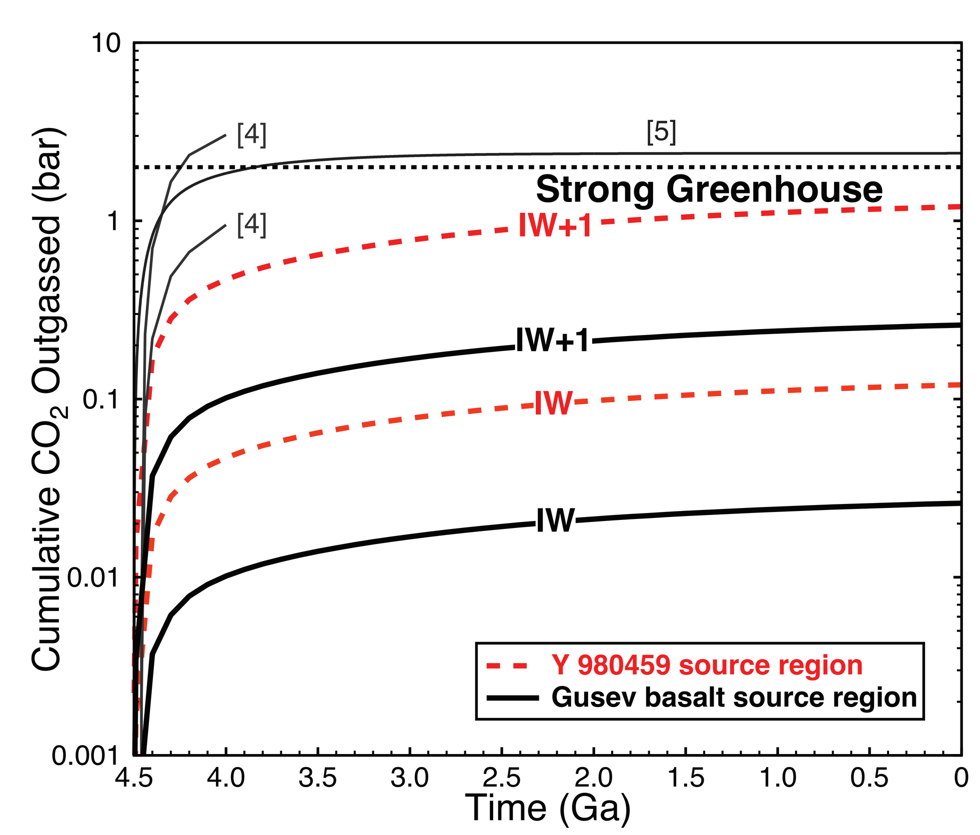
Oxide	Humphrey	Experimental Humphrey	Y 980459	Experimental Y 980459
SiO_2	46.96	46.91	49.61	51.59
TiO_2	0.56	0.53	0.51	0.49
Al_2O_3	10.93	10.52	5.70	6.12
FeO_T	19.23	19.87	16.75	14.31
MnO	0.42	0.38	0.03	0.45
MgO	10.65	10.79	19.08	18.80
CaO	8.02	7.99	6.86	7.23
Na_2O	2.56	2.40	0.65	0.65
K_2O	0.10	0.11	0.02	0.02
P_2O_5	0.57	0.52	0.30	0.34
Total	100.00	100.00	100.00	100.00

Compositions are calculated Cr and FeS-free and normalized. Humphrey - [6]; Y 980459 - [7]; Experimental Humphrey and Y 980459 - electron microprobe analysis of experimental glass

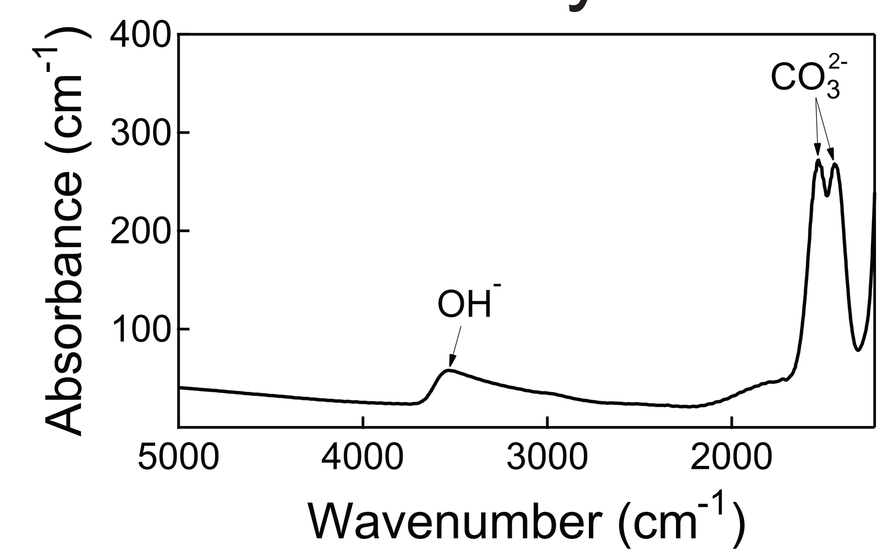
Previous Work



The CO_2 solubility of synthetic Martian basalts based on the Humphrey Adirondack-class basalt showed that degassing of CO_2 may not be sufficient to create greenhouse conditions [2]. However, solubilities are predicted to be greater for depolymerized melts similar to Y 980459 [3], possibly allowing degassing of increased amounts of dissolved CO_2 and a significant contribution of volcanogenic CO_2 to an early Martian greenhouse.

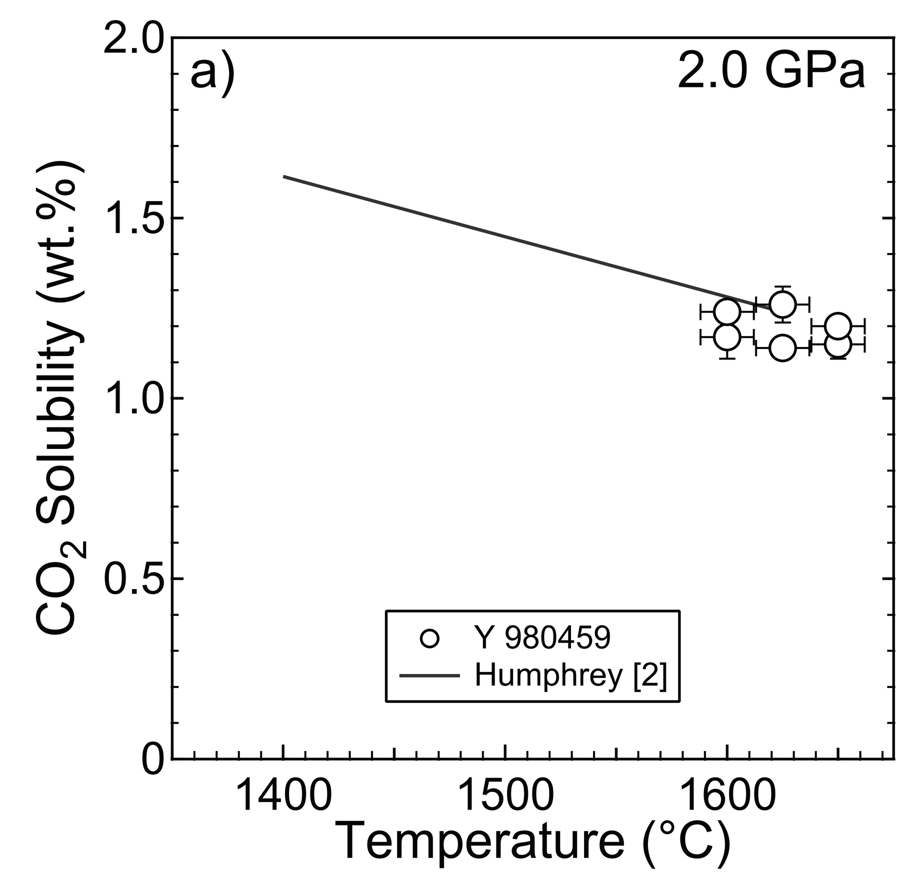


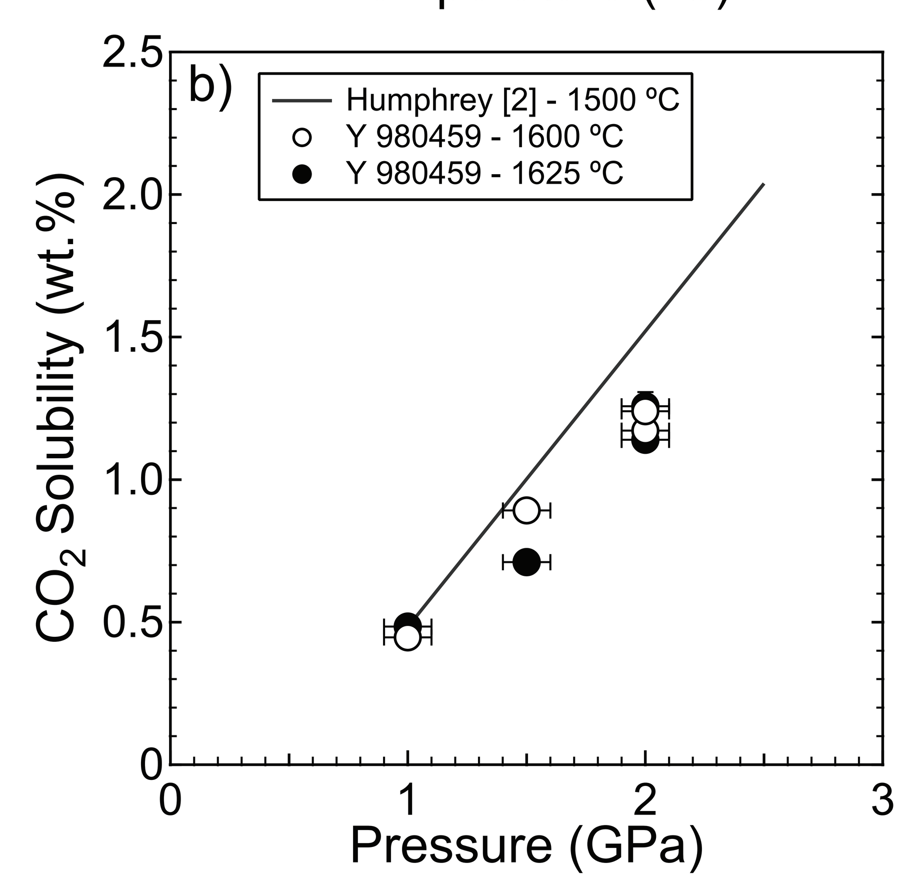
FTIR Analysis



$$CO_2 \text{ concentration} = \frac{44.01 \cdot I}{d\,\rho\,\epsilon^*}$$

Data





Calculations

Holloway et al. [8] showed that the solubility of CO_2 in graphite saturated melts is only related to fO_2.

$$\underset{\text{graphite}}{C} + \underset{\text{gas}}{O_2} \leftrightarrow \underset{\text{gas}}{CO_2} \Rightarrow K_I = \frac{fCO_2}{fO_2}$$

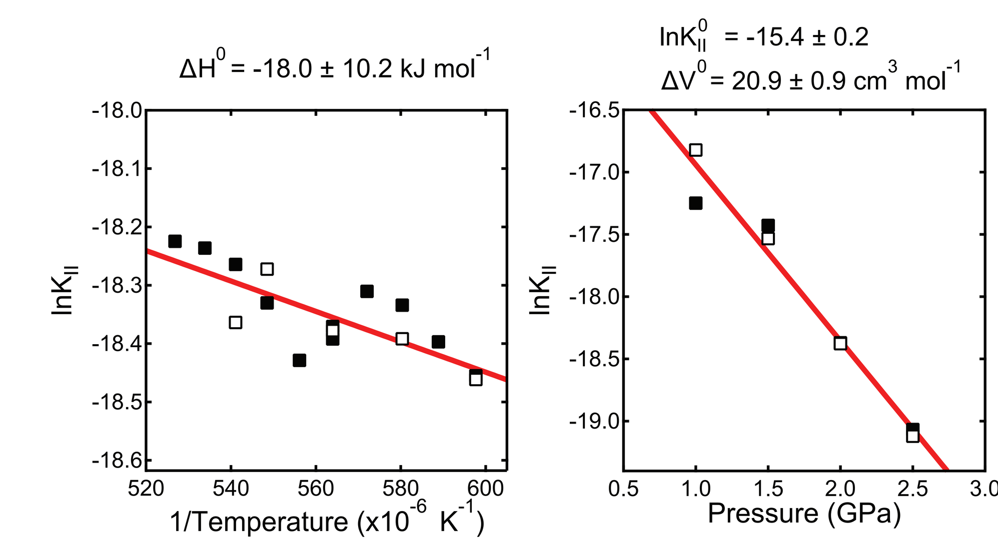
$$\underset{\text{gas}}{CO_2} + \underset{\text{melt}}{O^{2-}} \leftrightarrow \underset{\text{melt}}{CO_3^{2-}} \Rightarrow K_{II} = \frac{X^{melt}_{CO_3^{2-}}}{X^{melt}_{O^{2-}} fCO_2}$$

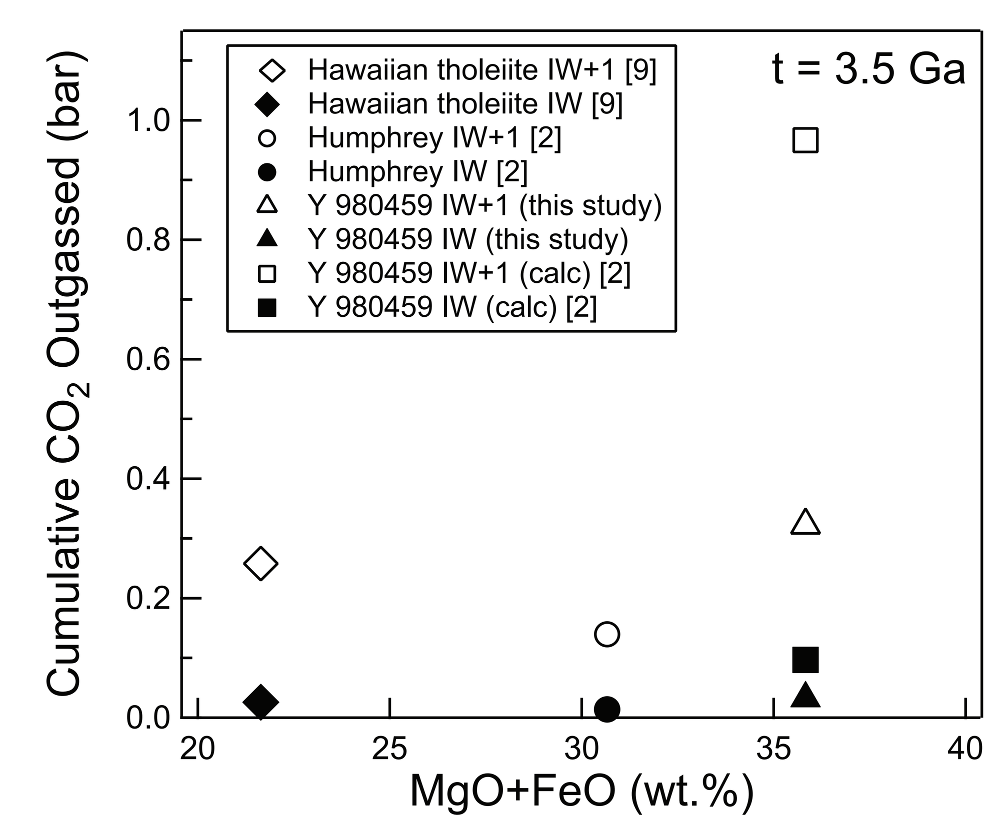
where $X^{melt}_{O^{2-}} = 1 - X^{melt}_{CO_3^{2-}}$

$$X^{melt}_{CO_3^{2-}} = \frac{K_I K_{II} fO_2}{1 + K_I K_{II} fO_2} \text{ at constant T and P}$$

Experimental CO_2 solubilities from [2] were used to fit $\ln K_{II}$ allowing calculation of at $X^{melt}_{CO_3^{2-}}$ any P-T-fO_2 conditions.

$$\ln K_{II} = \ln K^0_{II} - \left(\frac{\Delta V^0}{RT}\right)(P - P^0) - \left(\frac{\Delta H^0}{R}\right)\left(\frac{1}{T} - \frac{1}{T^0}\right)$$





Conclusions

- Experimentally-determined solubility of synthetic shergottite basalts confirm that the Martian mantle is incapable of degassing sufficient CO_2 to sustain a thick greenhouse atmosphere in the Late Noachian.
- Models of Martian atmospheric evolution using only CO_2 should be reexamined and additional volatiles such as SO_2 and CH_4 should be considered.
- There is little effect of composition on CO_2 solubility in Martian basalts.
- NBO/T is an imperfect predictor of CO_2 solubility in MgO-rich silicate melts.

References

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In memory of the Spirit Rover
01/04/04-03/22/10

Thanks for the rock analyses!