

MASS LOADING AND THE EARLY MARS GREENHOUSE: WHEN A POLLUTANT BECOMES THE ENVIRONMENT

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Attempts to model a greenhouse condition on early Mars are fostered by the need to explain clearly fluid dissection of the most ancient terrain despite the presumption that the sun's luminosity was probably significantly lower than today. Such attempts have typically relied on a greenhouse effect produced by a massive (2-4 bar) carbon dioxide atmosphere ¹. A possible fatal flaw in these scenarios is the expectation that such a situation would produce lower temperatures than otherwise owing to carbon dioxide clouds ². Alternatively trace constituents such as SO₂ and NH₃ (which are intrinsically much better greenhouse gases than) have been suggested to augment such a greenhouse effect. Perhaps the most prominent model is that suggested by Postawko and Kuhn ³ who pointed out that SO₂ in a mixing ratio of 10⁻³ could augment a CO₂ greenhouse in a major way. This approach also encounters a serious problem in that the mean residence time of an SO₂ molecule in the atmospheres of both the present Earth and Mars is extremely short - perhaps a year or less. Thus mixing ratios even as low as 10⁻³ for SO₂ could never be approached. Such an evaluation assumes that the mean residence time (M.R.T.) of SO₂ on early Mars would have been comparably short. That assumption is incorrect.

The SO₂ M.R.T. on the Earth and Mars is controlled by the OH⁻ concentration. If an eruption should supply SO₂ to either atmosphere the SO₂ would be quickly destroyed. If two identical such eruptions occurred the SO₂ would be just as quickly destroyed. In the second case the absolute rate of destruction of SO₂ molecules would be twice as high as in the first case and the M.R.T. would be the same in both cases. On early Mars the situation may have been qualitatively different; the M.R.T. of SO₂ with respect to destruction by OH⁻ may have been, for pragmatic purposes, infinite ⁴. This comes about because of the dot product of two factors: First, maximum published estimates of Hesperian eruption epochs imply SO₂ supply rates orders of magnitude greater than any current Earth eruption. Although deduced from studies of Mars morphology, these high rates are clearly related to the fact that Mars' heat flow at that time was probably 6-8 times the present ¹. Second, although the Earth can renew OH⁻ inventory quickly, the rate of renewal of OH⁻ on Mars would be orders of magnitude slower owing to cold trapping of H₂O.

Specifically, if the atmospheric H₂O inventory suddenly removed it would be replaced from the poles on the time scale of about a year. The maximum reasonable global SO₂ supply rate associated with the most intense Hesperian epochal eruption rate is about $1.0 \times 10^{-8} \text{ g sec}^{-1} \text{ cm}^{-2}$. The current Mars atmospheric (only) H₂O inventory is about $10^{-3} \text{ g cm}^{-2}$. therefore if a Hesperian eruption epoch occurred today enough SO₂ to destroy the current H₂O inventory would be emitted every 105 seconds or 30 hours! Since H₂O replacement would take about 1 year. SO₂ concentration would increase at the same rate as if there were no H₂O and the atmosphere would remain completely dry. On this basis we suggested a series of models in which the 'rules' are very different from those governing previous models ⁴. In our models the governing factors are: 1.) Conservation of mass must be obeyed (the mass loading principle), 2.) the M.R.T. of SO₂ a variable which depends on the ratio of the SO₂ supply rate to that of the H₂O resupply rate, with the latter equaling the SO₂ destruction rate. 3.) All species must be present at pressures equal to or below saturation value at the saturation value at a single polar temperature 4.) Since obliquity and eccentricity variation (which affect polar and equatorial conditions) are caused by factors totally unrelated to the factors that control eruption rates, we may arbitrarily juxtapose the two sets of conditions in time in any manner. 5.) The final set of conditions must allow for the relationship between polar and equatorial conditions to be consistent with the resulting putative atmosphere. 6.) Radiative transfer calculations are performed as in Postawko and Kuhn ³.

We have only begun to search for optimum conditions which, for examples, yield maximum temperature with minimum cloud effects. However in table 1 we show the results of two arbitrary chosen cases. In both these cases we simply assumed that the SO₂ and the CO₂ are buffered (when enough is available) at the same polar temperature. The table shows the behavior of the system during an intense Hesperian eruptive phase.

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Steady state can be achieved in the system prior to saturation, but this obviously requires the H₂O flux to equal the SO₂ flux or otherwise the SO₂ will continue to increase. Such an H₂O flux cannot be supplied via the poles or regolith. The eruption itself will supply H₂O molecules at a more than sufficient rate, but they will be cold trapped. Steady state TH₂O=TSO₂ could be achieved if there existed an open water lake near 0°C with a diameter of about 200 km or , assuming an ablation rate of 30 cm yr⁻¹, and ice covered lake with D=900 km ⁴.

Many more models are being run in an attempt to understand the operation of this system. Current issues include: 1.) In the effective absence of H₂O, what processes (e.g. photodissociation and chemical reaction) destroy the SO₂ and how fast do these operate? 2.) Here we have ignored any role for internal heat ² but still argue that the atmospheric greenhouse effect and a major role for internal heat are quantitatively and inextricably linked ⁵. 3.) What is the most favorable juxtaposition of total CO₂ inventory and timing of an eruptive phase relative to the obliquity and eccentricity? 4.) Could a point eruption source quickly create and maintain steady state local or regional conditions with SO₂ mixing ratios than the global value?

In any event, we conclude that a major Hesperian eruptive phase would dry the atmosphere quickly so that the SO₂ lifetime can be greatly extended and SO₂:CO₂ mixing ratios at least an order of magnitude higher than those postulated by Postawko and Kuhn ³ can be achieved. The resulting SO₂ augmentation to the greenhouse effect can be greater than the diminution of the greenhouse effect brought about by CO₂ clouds.

⁴Fanale, F.P. and Postawko, S.E. (1994) Bull. Am. Astron. Soc., 26.

²Kasting, J.F. (1991) Icarus 94, pp. 1-13.

¹Pollach, J.B. et al. (1987) Icarus 71, pp. 203-224.

³Postawko, S.E., and Kuhn, W.R. (1986) JGR 91, D431-D438.

⁵Postawko, S.E., and Fanale, F.P. (1993) JGR 98, pp. 11017-11024.

Table 1

	Polar Temp. (K)	P _{CO2} (bars)	P _{SO2} (mb)	Time to eat H ₂ O	Time to reach SO ₂ equil.	SO ₂ abundance (g/g)	ΔT from SO ₂ alone
Case A	213	4.1	53	20 days	265 years	10 ⁻²	25°C
Case B	195	1.1	12	33 hours	60 years	10 ⁻²	15°C

This table shows the results of two preliminary runs. Arbitrarily chosen polar temperatures are matched with maximum Hesperian eruption rates CO₂ and SO₂ pressures are limited by polar cold trapping. The time to rid the atmosphere of OH⁻ for the course of the eruption phase is given as is the time to fully saturate the atmosphere with SO₂. The final mixing ratios are given and the last column shows the resulting augmentation of the greenhouse effect the SO₂ over and above that which result from the CO₂ alone.