

## MAXIMUM CO<sub>2</sub> AMOUNT ON VENUS: PRESENT AND PAST

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**Carbonate as storage of CO<sub>2</sub>:** Venusian atmospheric CO<sub>2</sub> amount is suggested to be controlled or buffered by carbonate on the surface (*Carbonate Buffer*). That is, atmospheric CO<sub>2</sub> increase would be suppressed by carbonate formation and CO<sub>2</sub> decrease would be thwarted by carbonate decomposition. Carbonate-silicate equilibria, such as



are suggested by some authors [1,2]. In fact, observed Venusian CO<sub>2</sub> atmosphere that mean temperature is 740K and pressure is 92bar at the bottom, agree well with the equilibrium CO<sub>2</sub> pressure for reaction (1), which is  $P_{\text{CO}_2} = 89\text{bar}$  at 740K [2]. However, Hashimoto et al. [3,4] showed that the state buffered by large amount of carbonate is unstable for small perturbations. We constrained the maximum CO<sub>2</sub> amount on present Venus by this stability condition, and that on past Venus by the stability of carbonate on the surface.

**Present Venus:** Considering the stability field of the carbonates, there is an altitude of phase boundary  $z_B$ , below which carbonate is unstable and above which carbonate is stable (Fig. 1). At equilibrium, the altitude of phase boundary  $z_B^*$  is expressed by the atmospheric CO<sub>2</sub> amount, because atmospheric pressure  $P_B$  at  $z = z_B^*$  is identical to the equilibrium CO<sub>2</sub> pressure for reaction (1) [3]:

$$z_B^* = T_0 \frac{\gamma}{\gamma - 1} \frac{k_B}{\mu m_H g} \left[ \left( \frac{P_S}{P_0} \right)^{\frac{\gamma-1}{\gamma}} - \left( \frac{P_B}{P_0} \right)^{\frac{\gamma-1}{\gamma}} \right] \quad (2)$$

where  $\gamma$  is polytropic exponent,  $k_B$  is Boltzmann constant,  $g$  is gravitational acceleration,  $\mu$  is mean molecular weight,  $m_H$  is mass of hydrogen atom,  $P_0$  and  $T_0$  are the pressure and temperature at reference state, and  $P_S$  is the pressure at  $z = 0$ . We approximate that Venusian atmosphere is expressed by a polytrope atmosphere. Polytropic exponent  $\gamma = 1.21$  is chosen to represent the temperature lapse rate of the Venusian lower atmosphere ( $dT/dz = 8.0 \text{ K/km}$  [5]).

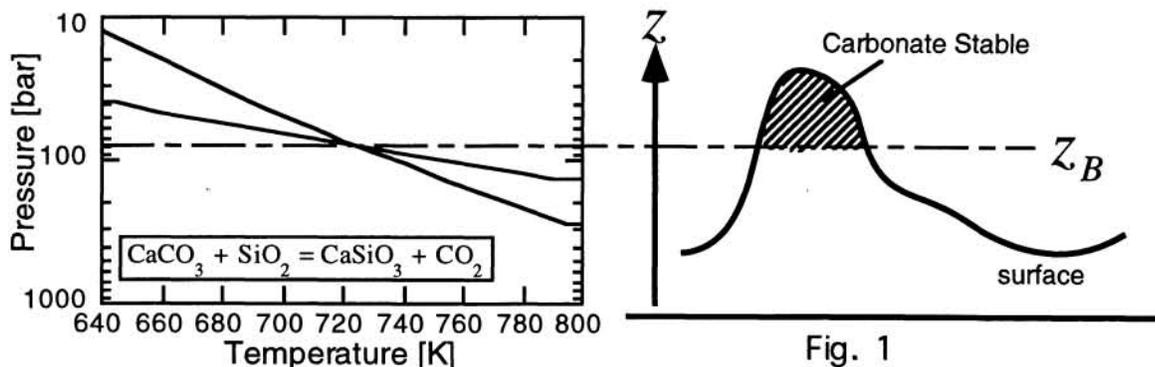


Fig. 1

As shown in equation (2),  $z_B$  is a function of the atmospheric CO<sub>2</sub> and it increases with the atmospheric CO<sub>2</sub>. Runaway CO<sub>2</sub> fixation and runaway carbonate decomposition would take place by small increase in the atmospheric CO<sub>2</sub> should raise  $z_B$  and promote CO<sub>2</sub> release from carbonate consumption, and decrease in atmospheric CO<sub>2</sub> would lower  $z_B$  and deprive the

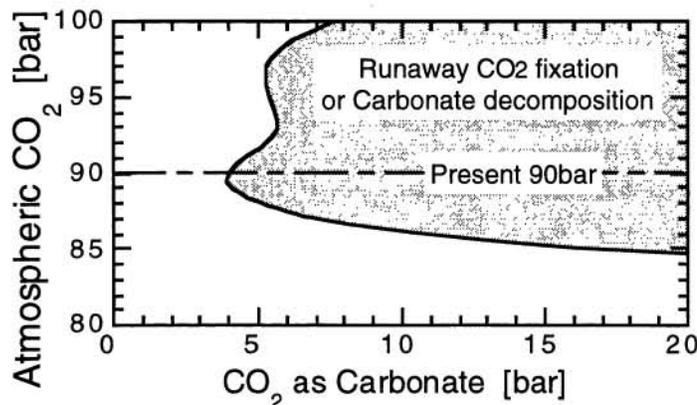
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Fig. 2

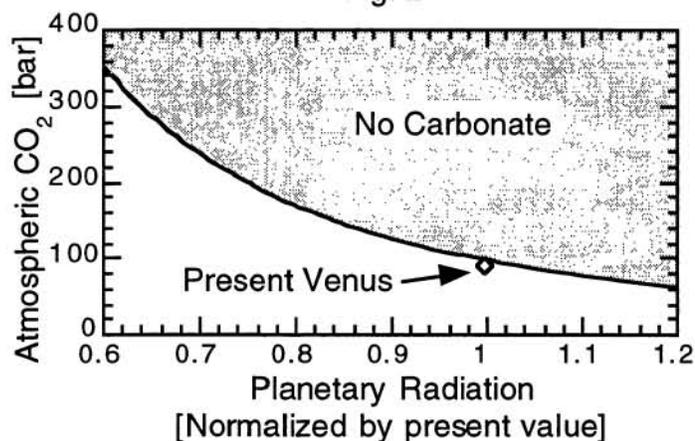


Fig. 3

**Past Venus:** From equation (2), increase of atmospheric CO<sub>2</sub> makes carbonate unstable at low altitude. When CO<sub>2</sub> amount in the atmosphere is too large, carbonate becomes unstable all over the surface, and carbonate formation can no longer deprive the atmospheric CO<sub>2</sub>. Since there is no mechanism except carbonate formation to reduce the considerable atmospheric CO<sub>2</sub>, maximum atmospheric CO<sub>2</sub> amount on past Venus is constrained by the stability of carbonate. Fig. 3 shows the condition that carbonate is stable at the altitude 3km. Even if the past value of planetary radiation is as small as 0.7 times the present, maximum atmospheric CO<sub>2</sub> amount is ~240bar.

**Conclusion:** At present, the total CO<sub>2</sub> amount on the Venusian surface is ~95bar, and most of CO<sub>2</sub> exists in the atmosphere. On past Venus, atmospheric CO<sub>2</sub> amount cannot exceed three times the present.

**Reference**

- [1]H.C. Urey (1952) *The Planets* (Yale Univ. Press) [2]B. Fegley Jr. & A.H. Treiman (1992) in *Venus and Mars: Atmospheres, Ionospheres, and Solar Wind Interactions*, *Geophys. Monogra.*, **66** (AGU), 7-71. [3]G.L. Hashimoto et al. (1995) *Proc. 28th ISAS Lunar Planet. Symp.* (Institute of Space and Astronautical Science), *in press*. [4]G.L. Hashimoto et al. (1995) *Bull. Amer. Astron. Soc.*, **27**, 1079. [5]A. Seiff (1983) in *Venus* (Univ. of Arizona Press), 215-279. [6]J.S. Lewis (1970) *Earth Planet. Sci. Lett.* **10**, 73-80.

atmospheric CO<sub>2</sub> through carbonate formation. When  $z_B$  is assumed to approach asymptotically  $z_B^*$  with time, the condition of stability is written as follows [3]:

$$T_0 \frac{k_B}{\mu m_{H_2}} \left( \frac{P_S}{P_0} \right)^{\gamma-1} \frac{P_C}{P_S} \frac{dH}{dz_B} + 1 > 0 \quad (3)$$

where  $P_C$  is the amount of CO<sub>2</sub> fixed as carbonate when carbonate is stable all over the surface, and  $H(z_B)$  is the fraction of the area where the altitude above  $z = z_B$  to the whole surface. This condition is not satisfied in hatched region of Fig. 2. Hence, assuming that the Venusian atmosphere is stable at present, upper limit of condensed CO<sub>2</sub> for reaction (1) is only ~4bar, and this amount is very small compared with the atmospheric CO<sub>2</sub> amount. As shown by Lewis [6], all carbonates except CaCO<sub>3</sub> may be stable on the Venusian surface only in elevated regions of limited extent area. Hence, even if carbonate should exist on the Venusian surface, the amount of carbonate would be small and most of the total CO<sub>2</sub> on the Venusian surface should exist in the atmosphere.