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The CO2 Inventory of the terrestrial Planets

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Abstract

By adopting a few assumptions, the CO_2 contents in the proto-atmosphere of the Earth was calculated to be 5.9 x 10^{23} g, which is equivalent to a partial pressure of 114 bar on the surface of the early Earth. The assumptions adopted are either intuitive (but reasonable) or substantiated by shock experiments and theoretical calculations. The total CO_2 contents are estimated to be 5.1 x 10^{23} g for Venus, 6.3 x 10^{23} g for Earth, and 3.6 x 10^{22} g for Mars.

Introduction

It is generally assumed that Venus, Earth and Mars were formed from similar infalling materials via a similar accretion process. This assumption appears to be reasonable if the average densities and the semimajor axes (distances to the Sun) of these terrestrial planets are taken into account. On the other hand, the fact that the present atmospheres of both Venus and Mars are composed of more than 95% CO_2, whereas the Earth's atmosphere contains no appreciable amount of CO_2, appears to challenge this assumption. The apparent discrepancy might be rationalized by a hypothesis that the Earth's early atmosphere contained at least as much CO_2 as in the present Cytherean atmosphere, but the Earth's CO_2-enriched atmosphere was removed by the formation of the oceans in its early history [Liu, 1988; 2004].

It has been estimated that the CO_2 locked in carbonate rocks on the Earth is about 2/3 that of the CO_2 contents in the present Cytherean atmosphere [Ronov and Yaroshevsky, 1976; Holland, 1984]. Thus, it is expected that the remaining 1/3 or more CO_2 on the Earth may have been retained in the deep interior. Indeed, petrological and geochemical evidence indicate that there is a substantial amount of CO_2 present in the mantle [e.g., Irving and Wyllie, 1973; Kushiro et al., 1975; Wang et al., 1996].

The existence of magnesite ($MgCO_3$) at depths greater than 200 km has been favored by many recent studies [e.g., Redfern et al., 1993; Liu and Lin, 1995] and diamonds derived from the Earth's lower mantle are also proposed [Scott-Smith et al., 1984; Harte et al., 1999; Liu, 2002].

Model and Calculations

Based on shock experiments on calcite ($CaCO_3$) and other carbonate rocks, Boslough et al. [1982], Kotra et al. [1983], and Lange and Ahrens [1986] suggested that decarbonation begins at about 100 kbar and is complete near 700 kbar during planetesimal impacts. Thus, when the Earth's radius grew to more than 1000 km, CO_2 should have escaped from Earth's gravitational field and be lost to outer-space. On the other hand, Donahue [1986] calculated that loss of any gas, except hydrogen, should occur very slowly from a growing planet exceeding $\sim 10^{26}$ g, and hence, the composition becomes practically frozen.

The exact impacting pressures or the exact radius and/or mass of the growing planets estimated by these authors are not so important here, but the concepts postulated are adopted in the present study. It is first assumed that the CO_2 of infalling planetesimals is all in the form of carbonate (some may exist as graphite), and that complete decarbonation due to impacting processes occurred both in infalling planetesimals and at the surface of the growing planets when they grew to a certain mass. Then, the composition of the growing planets became practically frozen (except for the escape of hydrogen) after the planets grew to a mass $> \sim 10^{26}$ g. It is further assumed that the present atmospheres of Venus and Mars retained nearly all of their CO_2 as in their proto-atmospheres. By these assumptions, the mass at which the composition became frozen was calculated to be 6.415 x 10^{26} g and the partial pressure of CO_2 in the proto-atmosphere of the Earth is calculated to be 114 bar.

Discussion and Conclusion

In the present model, there must be some appreciable amount of CO_2 retained inside the planets during and after accretion. These deeply buried CO_2-containing materials (or carbonates) could be the sources of carbon that form magnesite and the lower mantle diamonds inside the Earth (as addressed earlier). The total amount of deeply buried CO_2 can be estimated to be 3.6 x 10^{22} g. This value is more than one order of magnitude less than that in the present Cytherean atmosphere and in the Earth's proto-atmosphere. These amounts of CO_2 should not be too significant to the nature and evolution of both Venus and Earth. However, it should be rather significant to Mars. Thus, the total inventory of CO_2 is estimated to be 5.1 x 10^{23} g for Venus, 6.3 x 10^{23} g for Earth, and 3.6 x 10^{22} g for Mars.

References

Boslough, M. B., T. J. Ahrens, J. Vizgirda, R. H. Becker and S. Epstein, *Earth Planet. Sci. Lett.*, 61, 166-170, 1982.

Donahue, T. M., *Icarus*. 66, 195-210, 1986.

Harte, B., J. W. Harris, M. T. Hutchison, G. R. Watt and M. C. Wilding, M.C., In: Y. Fei, C. M. Bertka and B. O. Mysen (Eds.), Mantle Petrology: Field Observations and High Pressure Experimentation, *Geochem. Soc. Spe. Publ. 6*, pp. 125-153, 1999.

Holland, H. D., *The Chemical Evolution of the Atmosphere and Oceans*. Princeton Univ. Press, Princeton, N. J., 1984.

Irving, A. J. and P. J. Wyllie, P.J., *Earth Planet. Sci. Lett*., 20, 220-225, 1973.

Kotra, R. K., T. H. See, E. K. Gibson, F. Horz, M. J. Cintala and R. S. Schmidt, *Lunar Planet. Sci*., 14, 401-402, 1983.

Kushiro, I., H. Stake and S. Akimoto, S., *Earth Planet. Sci. Lett*., 28, 116-120, 1975.

Lange, M. A. and T. J. Ahrens, *Earth Planet. Sci. Lett*., 77, 409-418, 1986.

Liu, L., *Icarus*, 74, 98-107, 1988.

Liu, L., *Contri. Mineral. Petrol*., 144, 16-21, 2002.

Liu, L., *Earth Planet. Sci. Lett*., 227, 179-184, 2004.

Liu, L. and C.-C. Lin, *Earth Planet. Sci. Lett*., 134, 297-305, 1995.

Redfern, S. A. T., B. J. Wood and C. M. B. Henderson, *Geophys. Res. Lett*., 20, 2099-2120, 1993.

Ronov, A. B. and A. A. Yaroshevsky, *Geochem. Int.*, 13, 89-121, 1976.

Scott-Smith, B. H., R. V. Danchin, J. W. Harris and K. J. Stracke, K.J., In: J. Kornprobst (Ed.), *Kimberlites I: Kimberlites and Related Rocks*. Elsevier, Amsterdam, pp. 121-142, 1984.

Wang, A., J. D. Pasteris, H. O. A. Meyer and M. L. Dele-Duboi, *Earth Planet. Sci. Lett*., 141, 293-306, 1996.