

A POSSIBLE SCENARIO FOR ATMOSPHERIC EVOLUTION: STEAM ATMOSPHERE TO PRESENT ONE. Takafumi Matsui, Masaki Ishiwatari, and Yutaka Abe, Geophysical Institute, Faculty of Science, Univ. of Tokyo, Tokyo 113, Japan.

Recently Matsui and Abe (1) proposed formation of a steam atmosphere during accretion of Earth and Venus. A steam atmosphere becomes unstable with decrease in impact energy flux and thus H_2O in the atmosphere condenses into ocean at the final stage of accretion of Earth but not for Venus (2, 3). After the formation of ocean CO_2 becomes a main constituent of the atmosphere and its abundance is controlled by dissolution equilibrium of CO_2 between atmosphere and ocean (4). In this paper we study atmospheric evolution after the formation of ocean by modelling CO_2 cycle between three reservoirs: (i) atmosphere-ocean, (ii) oceanic plate and (iii) continent.

In Fig. 1 we show a model of CO_2 cycle. We consider the atmosphere-ocean system as one reservoir because dissolution equilibrium of CO_2 is probably achieved within very short time compared to other characteristic time scale such as residence time of carbonate rock in oceanic plate. CO_2 ion dissolved into ocean reacts with Ca^{++} produced by hydrothermal reaction at ridge and weathering of continental rocks and forms calcium carbonate. Then calcium carbonate precipitated on oceanic plate. We simply assume plate tectonics similar to the present one but residence time t_r of carbonate rock in oceanic plate is assumed to vary with change in heat flow. Some amount F of carbonate rock is added to continent accompanying with subduction and the rest finally degasses into atmosphere. We assume no regassing into mantle for simplicity.

The mass balance equations for the three reservoirs are given as follows:

$$dM_{AO}/dt = -G + (1-F)M_P/t_r + W_C,$$

$$dM_P/dt = G - M_P/t_r,$$

$$dM_C/dt = F M_P/t_r - W_C,$$

where M_{AO} , M_P , M_C are the masses of carbon in the three reservoirs, G is the mass of carbon in calcium carbonate precipitated on oceanic plate, and W_C is the mass of carbon produced by weathering of continental rocks.

In Fig. 2 is shown the temporal variation of carbon content in each reservoir. In this model we assume $pH=6.5$ for no continent stage (0 to t_1 b.y.), $pH=7$ and $F=0.9$ for the continental growth stage 1 (t_1 to t_2 b.y.), and $pH=8$ and $F=0.86$ for the continental growth stage 2 (t_2 to 4.6 b.y.), respectively.

As shown by Walker (4), partial pressure of CO_2 becomes almost steady before continental growth. We can see two abrupt variation points in each growth curve, which correspond to changes in growth model of continent. We used the continental growth rate similar to Reymer and Schubert (5).

Although increase and decrease rate of carbon content is dependent on pH of ocean, the final carbon balance in three reservoirs is mostly controlled by accretion rate F of carbon into continent. If we adopt $F=0.9$ after t_2 , most of carbon concentrate into continent (Fig. 3). This is obviously not the case for the present Earth.

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In conclusion, $\text{CO}_2\text{-N}_2$ atmosphere evolves into N_2 dominant atmosphere only when the continental growth occurs. Formation of continent is a necessary condition for decreasing CO_2 in the proto-atmosphere.

References

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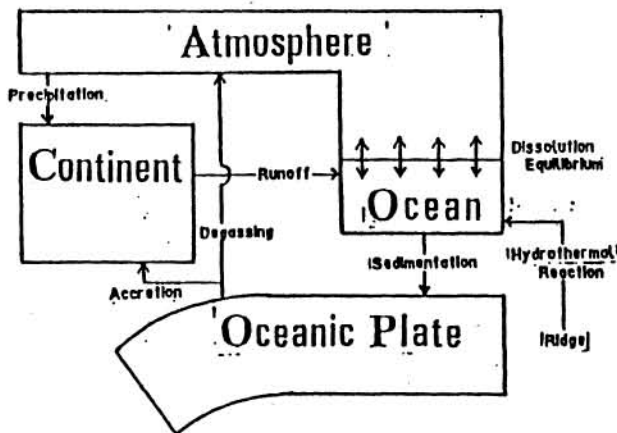


Figure 1. A model of CO_2 cycle.

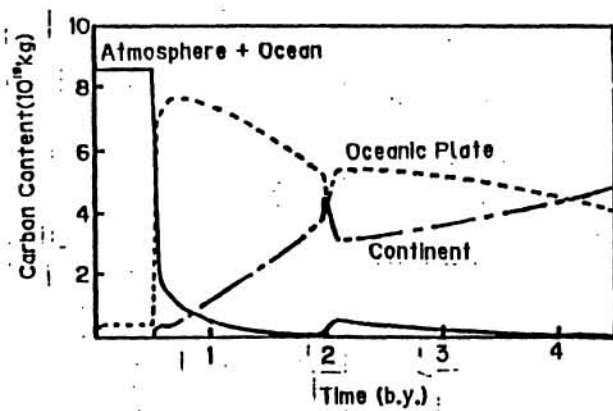


Figure 2. Evolution of carbon budget in three reservoirs (see the text more in detail about model).

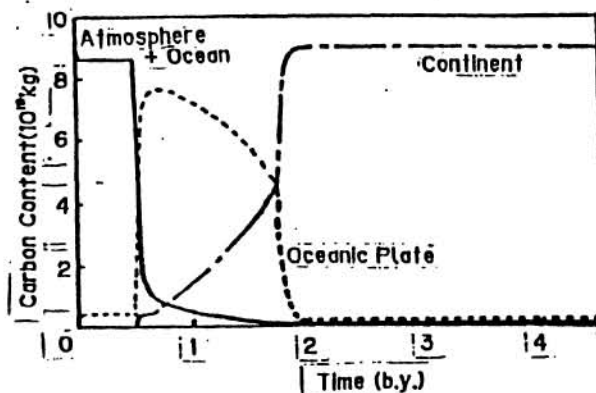


Figure 3. Evolution of carbon budget in three reservoirs ($F=0.9$ at the growth stage 2).