EARLY EVOLUTION OF THE EARTH. Yutaka Abe and Takafumi Matsui, Geophysical Institute, Faculty of Science, University of Tokyo, Bunkyo-ku, Tokyo 113

If the earth was formed by accretion of planetesimals in the gas-free environment, the surface of a planet would melt due to the blanketing effect of an impact-induced atmosphere, as suggested by previous studies (1,2). Once melting occurs, the mass and composition of the proto-atmosphere will be significantly affected, because volatile materials such as H_2O and CO_2 are redistributed between the atmosphere and magma ocean. The evolution of an impact generated H_2O atmosphere will be controlled by the solubility of water into silicate melt.

Generation of the proto-atmosphere depends on the surface temperature. (We assume the proto-atmosphere composed of only H_2O.) We need to consider three different source and sink mechanisms, depending on the temperature. i) When the surface temperature is lower than 900K, generation of H_2O atmosphere is mostly due to impact dehydration. (We can use an impact dehydration model and energy balance equation to calculate the surface temperature (2).) Once the peak impact pressure exceeds a critical value, P_{cr}, then some fraction, f, of H_2O retained in the planetesimals is added to the atmosphere, and so the mass of the atmosphere, M_a, is given by $\dot{M}_a = fX_p\dot{M}$, where X_p and $\dot{M}$ are the H_2O content of planetesimals and mass accretion rate. ii) When the surface temperature exceeds 900K, serpentine becomes unstable and a dehydration reaction occurs without impact. Then the mass of the atmosphere M_a is given by $\dot{M}_a=X_p\dot{M}$. iii) When the surface temperature exceeds the melting temperature, M_a is controlled by the degree of partial melting, α, at the surface and by the solubility of water into molten rock, X_{sol}. M_a is given by $\dot{M}_a=(X_p-\alpha X_{sol})\dot{M}$. Based on the experimental data compiled by Fricker and Reynolds (3), X_{sol} is given by $X_{sol}(wt\%)=2.08\times10^{-3} P^{0.54}$, where P is the atmospheric pressure at the surface (in Pa). If there exists enough metallic iron to be able to react with H_2O, the H_2O in the atmosphere will decompose into H_2 and FeO. Since the H_2/H_2O ratio of the atmosphere is a function of temperature, the evolution of an impact-induced H_2O atmosphere becomes very complicated. In the following, we follow the heterogeneous accretion model proposed by Matsui and Mizutani (4,5); that is, iron accretes first and silicate second.

Figure 1 shows the trace of the surface temperature for the standard model($f=0.2$, $P_{cr}=228$kbar, $X_p=0.1\%$ by weight and accretion time=50m.y.). When the surface of the earth is molten, the surface temperature is nearly constant, due to the buffering function of the magma ocean. (When the degree of partial melting increases, the amount of water which dissolves into molten rock increases.) This leads to the decrease in the mass of the atmosphere, and decreases the surface temperature. Such an stable process keeps the surface temperature nearly constant. Figure 2 shows the growth curve of the H_2O atmosphere for the standard model. Generation of the atmosphere begins when the radius exceeds $0.2R_0$. Inflection of the growth curve at $R=0.4R_0$ is due to the generation of magma ocean. It was shown that mass of the atmosphere is not determined by f and P_{cr} but determined by the accretion time and X_p. This is because of the buffering function of the magma ocean. The final mass of the resulting atmosphere varies from $3x10^{20}$kg to $3x10^{21}$kg by changing the accretion time from $5x10^6$ to $5x10^7$y and X_p from 0.1 to 1%. This value is very close to the mass of the present ocean ($1.4x10^{21}$kg), and may imply that the mass of the present ocean was determined by the nature of magma ocean during earth's accretion.

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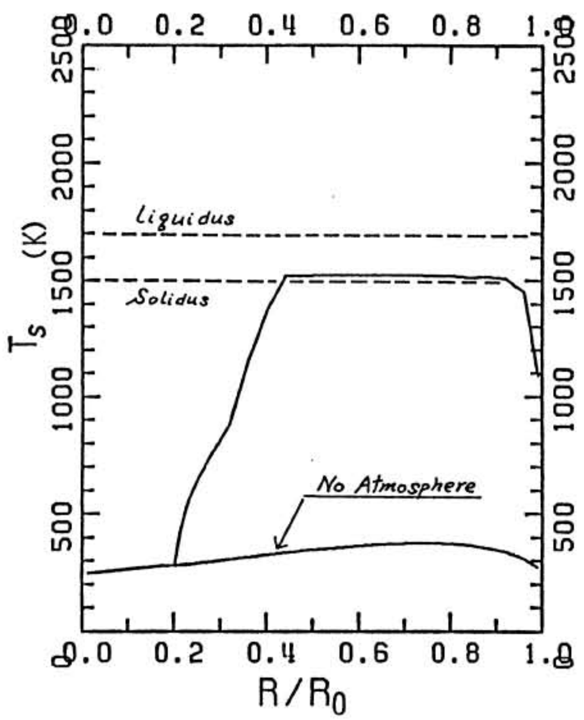

Figure 1
The surface temperature of the earth during accretion for the standard model. R_0 is the radius of the present earth.

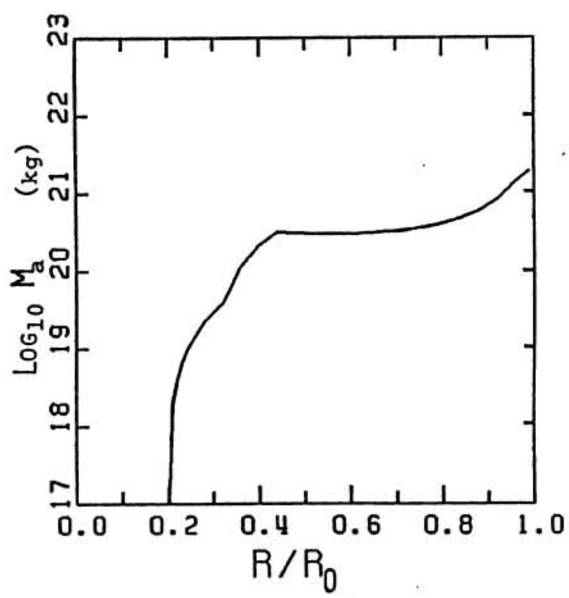

Figure 2
Growth curve of the H_2O atmosphere for the standard model.