DIFFERENTIATION, MIXING AND COOLING IN A MAGMA OCEAN – PRELIMINARY CONSIDERATIONS;

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Release of gravitational energy possibly caused global melting and formation of a magma ocean during accretion of the Earth [1]. In particular, a giant impact would result in complete melting of the early earth.

It is believed that formation of the magma ocean results in gravitational differentiation of melt and solid. Recent high pressure experiments[2], however, showed that melt-solid differentiation at lower mantle pressure should affect Sm/Hf and Sc/Sm ratios, which are nearly chondritic in the upper mantle. This indicates that no significant melt-solid differentiation should have occurred in the deep mantle.

Even if a deep magma ocean was formed, the melt-solid differentiation in the magma ocean might be disturbed by mixing processes or prevented by rapid cooling. The purpose of this study is to make an order of magnitude estimation on the mixing processes and cooling rate of the magma ocean.

MIXING

We made an order of magnitude estimation on the gravitational differentiation, convective mixing and impact stirring by using one-dimensional two-phase model[3]. As a standard case we considered the case when viscosity of the liquid phase is 10^2 Pas, the grain size is 1mm, solid-liquid density contrast is 5%, and the accretion time is 10^8y. Then following results are obtained: (1) Convective mixing disturbs the differentiation and prevents development of chemical layering, only when melt fraction is kept less than about 10%. (2) Impact stirring process is less efficient than the convective mixing. (3) If planetesimal impacts result in more than 10% melting, planetesimal impacts contribute to differentiation rather than stirring.

The results indicate that, even if we take into account convective mixing and impact stirring, gravitational differentiation is inevitable, if melt fraction is kept larger than about 10%. Hence, in order to make a chemically "homogeneous" mantle from a completely molten magma ocean, the melt fraction in the deep mantle must have decreased to 10% level in a time scale shorter than that of gravitational differentiation.

COOLING

We estimated the cooling rate of a completely molten deep magma ocean by using one dimensional model. We took into account convective heat transfer by using mixing length theory[4]. We also took into account drastic increase of viscosity with decreasing melt fraction. Viscosity of solid and melt are assumed to be 10^{21} Pas and 10^2 Pas, respectively. We did not take into account the blanketing effect of a proto-atmosphere, heating of magma ocean by core formation, planetesimal impacts and radiogenic heating.

As shown in Figure 1, cooling of the deeper part is quite rapid. Solidification rate is about 600km/Ma, which is comparable to the differentiation rate at 20 ~ 30% melting. On the other hand, melt fraction in the shallower mantle is kept at 30 ~ 40% (at the value where drastic change of viscosity occurs) for a period more than 10Ma.

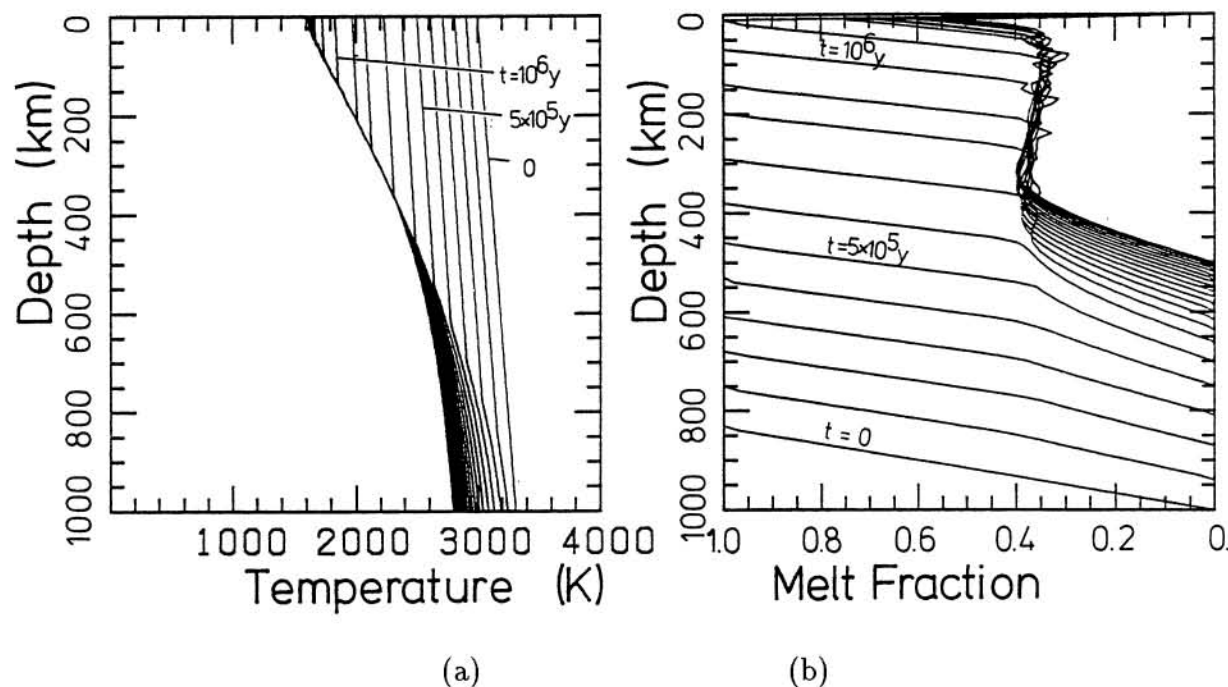DIFFERENTIATION, MIXING AND COOLING IN A MAGMA OCEAN: Abe, Y.

Figure 1.

Cooling and solidification of deep magma ocean. Time evolution of the temperature profile (a) and melt fraction (b) are shown with an interval of 10^5y. Melt fraction decreases rapidly in the deeper part. Solidification rate is about 600km/Ma. In the shallower part, on the other hand, melt fraction is kept at $30 \sim 40\%$.

Since we have neglected number of processes which may affect the cooling rate, the result should be taken as a preliminary. However, the results suggest a possibility that cooling processes competes with differentiation processes in the deeper part. On the other hand, the shallower part should have differentiated, because the degree of melting is kept higher than about 10%.

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