12th International Workshop on Modeling of Mantle Convection
and Lithospheric Dynamics

August 20th to 25th 2011, Döllnsee Germany

The Influence of rotation on an early magma ocean

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During its evolution, the Earth most likely experienced a 'Giant Impact' in which a Mars size body hit the early planet. Today it seems widely accepted that the origin of the Moon is a result of this Giant Impact. Another consequence of such an impact would be the formation of a 'Deep Magma Ocean', i.e. a layer of molten material, extending to a depth of about 1000 km. Transport of heat and matter in a vigorously convecting Magma Ocean plays a key-role for the further evolution and differentiation of the Earth. The sinking of iron droplets in the convecting Magma Ocean probably provides an effective mechanism leading to the separation of metallic and silicate material. The metal will form small droplets in the size of a few centimeters. Being much denser than the silicate around it is thought that the iron droplets will start to fall through the magma ocean, which is therefor called the 'metal rain'. The dense material would finally pond at the bottom of the magma ocean. An instability of this dense material (Rayleigh-Taylor Instability) could lead to a rapid formation of the Earth's Core.

We employed a 3D cartesian numerical model with finite Prandtl number, in order to study the sinking of heavy particles in a vigorously convecting environment. Differently from most approaches we have included the effect of rotation on the flow dynamics. While a significant role of rotation can be ruled out for the today's Earth's mantle, due to the high viscosity of the mantle material, this is not the case for a magma ocean. Our numerical fluid model is based on a Finite Volume discretization, while the numerical model for the iron droplets based on a discrete element model for the simulation of granular Material. The particles influence the fluid flow through the chemical component of the fluid model, which is the volumetric ratio of the particle in each fluid cell. The particles themselves experience the force of the fluid through the fluids drag. Also gravitational and Coriolis forces act on the particles. In our simulations unlike to other approaches the particles are much smaller than the numerical fluid cells, thus saving computational effort.

In our present work we study the influence of strong rotation on the iron droplets with a rotation axes parallel to the gravitational acceleration like on the earth pole and with a rotation axes perpendicular to gravity like on the equator. To quantify the influence of rotation on the dynamic of the fluid we use the Rossby number. Rossby numbers higher than one mean only marginal influence of rotation whereas Rossby numbers lower than one implicate a strong rotation dominated fluid dynamic. Depending on the Rossby number of the system we find different behaviors of the particles. For the poles the particles fall nearly with Stokes' velocity to the bottom. There forming the expected dense metal pond. Whereas for the equatorial case the particles can stay suspended depending on the strength of the Coriolis force acting against gravity. We find three regimes depending on the strength of rotation. At low rotation rates the particles fall to the bottom like at the poles. At higher rotation rates the particles stay suspended in the bottom 1/3 of the box and have an insulating effect on the hot thermal boundary layer. This leads to a layering of the temperature field. At high rotation rates the particles stay completely suspended and form a small ribbon in the middle of the box. The temperature field in this case shows no layering due to the missing insulation of the particles at the bottom thermal boundary.

If on of these scenarios was true for the earth it leads to an interesting setup for the following core formation processes.

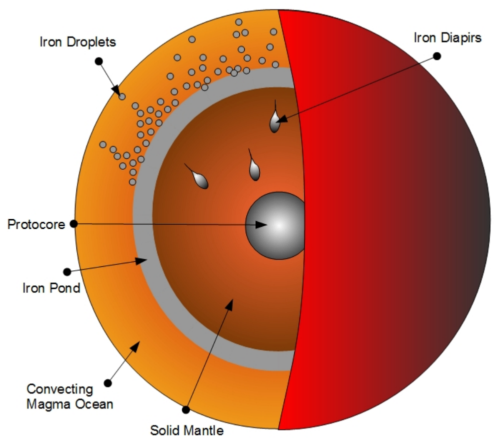

Figure 1: Schematic view of the earth 4.5 billion years ago during the metal rain.