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Impact of the Rayleigh number and endothermic phase transition on the mantle dynamics

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A leading tool for understanding thermal convection in the Earth's mantle is numerical modelling. 2D and 3D numerical models have been applied using the anelastic-liquid approximation of the governing equations [1]. In the rectangular box domain only one endothermic phase-transition zone has been modelled at 660 km depth.

The exact value of Rayleigh number (Ra) in the mantle is not known, consequently our scientific target was to analyse the influence of Rayleigh number on the structure of flow regime by different Clapeyron slopes. Therefore a systematic series of simulations have been investigated, the Ra varied in the range of 1e4 to 2e7 and the Clapeyron slope 0 to -9 Mpa/K. Due to the phase transition the flow system is mainly layered especially at higher Clapeyron slopes (-6, -9 Mpa/K), when the transition zone is not permeable. The surface heat flow decreases with increasing Clapeyron slopes and increases with Ra. The temperature of the upper layer decreases while the lower increases. This effect intensifies going to higher Ra. It means that the upper and lower mantle have their own local Ra (the upper mantle has approx. two magnitudes lower Ra). By the strongest Clapeyron slope (-9 Mpa/K) and lower Ra (1e4-1e5) the upper layer is not convecting any more only the conduction can carry the heat.

Three models have shown mantle avalanches. Avalanches have been found in the case of Ra: 1e7, 2e7, Clapeyron slope: -3 Mpa/K and 1e6, -6 Mpa/K. The avalanche phenomena are stronger at higher Ra. The most interesting case is at Clapeyron slope -3Mpa/K (probably the case of Earth) the structure of the flow is mixed. Depending on the Ra the transition zone is totally permeable (at lower Ra, 1e4-5e5), and a global mantle flow exists. But at higher Ra (5e5-2e7) the mantle is partially layered and sometimes rapid avalanche-like events occur (Ra: 1e7-2e7).

References

[1] Jarvis, G.T., McKenzie, D.P., 1980. Convection in a compressible fluid with infinite Prandtl number. J. Fluid Mech. 96, 515–583.