

Pattern and rhythm of mantle convection modulated by the transition zone

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During the mid-Cretaceous, production rate of the oceanic crust was much higher compared to the present rate, and the large igneous provinces such as the Onton-java plateau and the Kerguelen plateau were formed. In the mid-Cretaceous, from 120 Ma normal geomagnetic polarity duration lasted for about 40 million years. This is known as Cretaceous superchron. The intermittent activity of mantle plumes is one of the plausible substances that produce the rhythm relating to these phenomena. The problem is how we can reproduce mantle plumes activity that has intermittency of hundreds million years with large fluctuation of heat transport. Here we focus on the phase transition of mantle minerals at 660 km depth, which works as a barrier against the vertical flow, and seek the intrinsic intermittency of mantle convection. In order to clarify the origin of the correlation between the variations of the surface volcanism and the core, we performed numerical simulation of mantle convection in a 3-D spherical shell, where systematic parameter studies were made in the space of the Rayleigh number (Ra) and the Clapeyron slope (dP/dT) of the phase transition at 660 km depth. In the studied parameter range, we find three convection regimes. At low Ra and low $|dP/dT|$, the whole-layer convection mode is observed, and at high Ra and high $|dP/dT|$, the convection is in two-layer mode. At transitional values of Ra and $|dP/dT|$, the convection mode vacillates between the whole-layer and the two-layer regimes. In this intermittent convection regime, especially for the conditions close to two-layer mode, there exist horizontally large-scale stagnant structures in the mantle transition zone, and they collapse into the lower mantle periodically. This causes the fluctuations of surface and core-mantle boundary (CMB) heat flows, moreover the surface and CMB heat flows vary coherently. The surface heat flow can be translated into volcanic activity, and high heat flow means high production rate of the crust. The cycle of the heat flow variation at both top and bottom of the mantle is characterized by the rapid increase within several tens of million years, and gradual decrease after the peak. This feature is very similar to the curve of reconstructed crustal production rate that has the maximum in mid-Cretaceous. Lateral heterogeneity of the heat flow is also high around the peak. In the typical case, the period of the fluctuation is around 200 Myr, which is comparable with the geological evidences mentioned above.