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Constraining mantle convection models with palaeomagnetic reversals record and numerical dynamos

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Abstract

We present numerical models of mantle dynamics forced by plate velocities history in the last 450 Ma. The lower-mantle rheology and the thickness of a dense basal layer are systematically varied and several initial procedures are considered for each case. For some cases, the dependence on the mantle convection vigor is also examined. The resulting evolution of the CMB heat flux is analyzed in terms of criteria known to promote or inhibit reversals inferred from numerical dynamos: (1) mean value of CMB heat flux q^0, (2) amplitude of heat flux heterogeneities q^*, (3) polar vs. equatorial cooling (measured by harmonic coefficient q_2^0), (4) equatorial symmetry of the heat flux pattern.

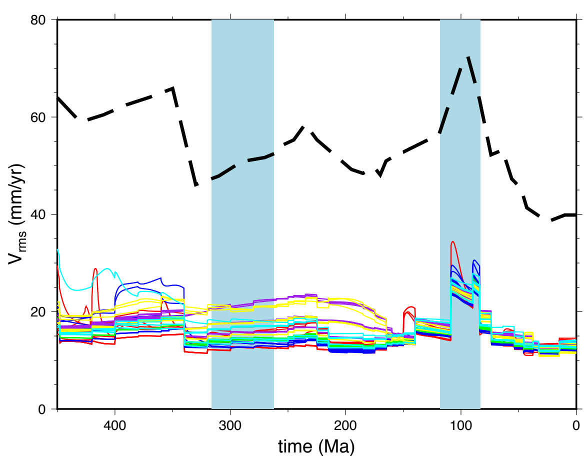

Figure 1: Time evolution of the surface average prescribed plate velocity model (thick dashed line) as well as the volume average velocity for 54 numerical mantle convection models (colored lines). The two light blue rectangles indicate the Kiaman Reverse Superchron (KRS) and the Cretaceous Normal Superchron (CNS).

Most models present a rather dynamic lower mantle with the emergence of two thermochemical piles towards present-day. Only a small minority of models present two stationary piles over the last 450 Myr. At present-day, the composition field obtained in our models is found to correlate better with tomography than the temperature field. In addition, the temperature field immediately at the CMB (and thus the heat flux pattern) slightly differs from the average temperature field over the 100-km thick mantle layer above it.

The evolution of the mean CMB heat flux or of the amplitude of heterogeneities seldom presents the expected correlation with the evolution of the palaeomagnetic reversal frequency suggesting these effects cannot explain the observations. In contrast, our analysis favors either inertial control on the geodynamo associated with polar cooling and in some cases break of Taylor columns in the outer core as sources of increased reversal frequency. Overall, the most likely candidates among our mantle dynamics models involve a viscosity increase in the mantle equal or smaller than 30: models with a discontinuous viscosity increase at the transition zone tend to agree better at present-day with observations of seismic tomography, but models with a gradual viscosity increase agree better with some of the criteria proposed to affect reversal frequency.

References

[1] Choblet G., Amit H., Husson L., Geophys. J. Int. 207 (2016).

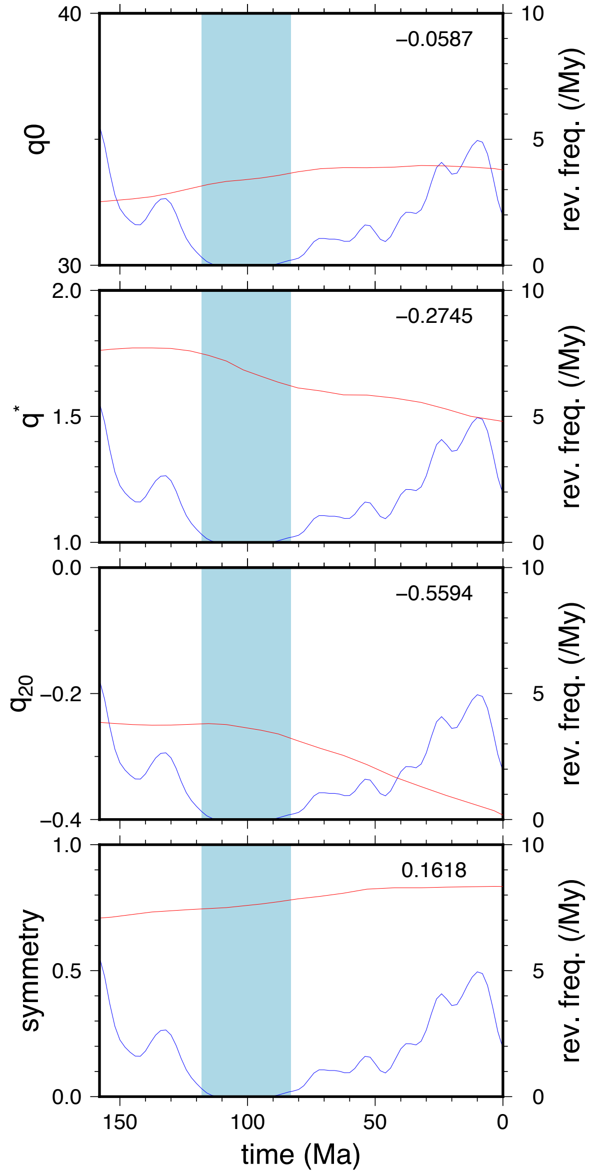

Figure 2: Time evolution of the values associated with the four criteria on CMB heat flux for one model (red) vs. reversal frequency (blue). The CNS is highlighted in light blue.

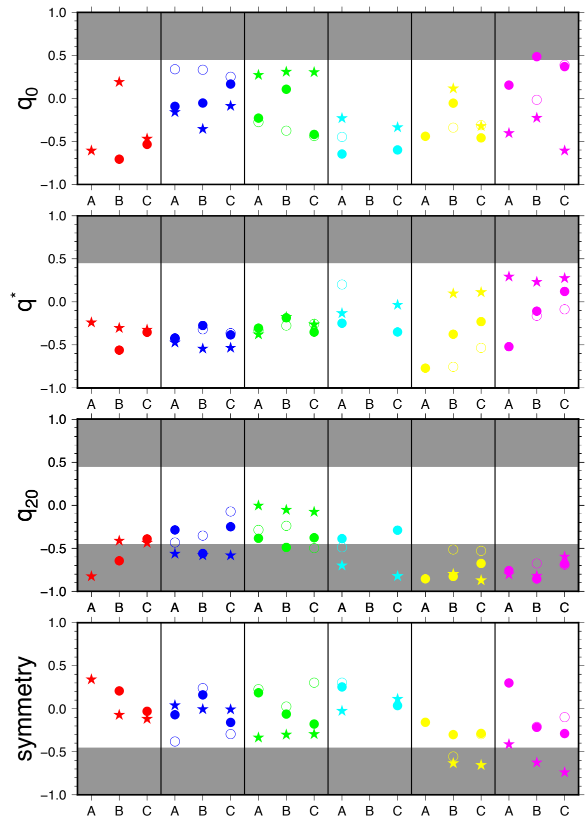

Figure 3: Linear correlation coefficient between the time evolution of reversal frequency and the time evolution of criteria for the CMB heat flux. The various colors, symbols and letter (A,B,C) denote various rheological models, initial procedure and thickness of the dense layer at the base of the mantle, respectively. Only models whose present day composition field correlates sufficiently well with tomography (with at least a 90 % confidence), are presented here. Shaded rectangles denote statistically significant correlation/anticorrelation (a 95 % confidence for the number of degrees of freedom considered, approx. 20). For example, a minimal heat power q^0 or a pattern presenting larger equatorial symmetry is expected during the CNS, thus a positive correlation is expected for q^0 and a negative one for symmetry.