Paper Number: 5494

The life cycles of mantle plumes and superplumes: observations, modelling, and geodynamic implications

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Mantle plumes and superplumes (large lower shear velocity provinces – LLSVPs, that can drive "secondary" mantle plumes above them) are widely believed to be features caused by thermal anomalies or thermal instabilities around the core-mantle boundary, and are independent of the plate tectonic system. It is also believed by some that the antipodal superplumes in the present-day lower mantle could have been a stable feature since the Earth's early history.

However, the intensity of plume activity during the Earth's history appears to suggest a coupling in time and space with the supercontinent cycle. The positions of the present-day antipodal Pacific and African superplumes align with the position of the supercontinent Pangea before it broke up, and global large igneous province (LIP) record indicates that global plume activity intensified soon after Pangea assembly and peaked during its breakup. A similar supercontinent-supercontinent coupling has been argued for the time of the Late Precambrian supercontinent Rodinia, and the sub-Rodinia superplume appears to have travelled together with the supercontinent from higher latitude to the paleoequator through true polar wander event(s). It has thus been proposed that circum-supercontinent subduction of cold slabs to the lower mantle could be the driver for the formation of large antipodal domes of hot and dense lower mantle (LLSVPs), or superplumes, that are aligned with the position of the respective supercontinent, and a complete disassemble of the supercontinent may lead to the disappearance of such a global circular subduction system, therefore the weakening or possibly even disappearance of such an antipodal superplume system [1]. In addition, the centrifugal force of the Earth's spinning would bring such an antipodal superplume system (along with the coupled plate system) to equatorial positions through true polar wander events.

Geodynamic modelling suggests that such a coupled plate-plume system is viable. In addition, similar yet much smaller circular subduction systems could lead to the formation of so-called "lone plumes" that are not related to LLSVPs or superplumes, such as the late Cenozoic Hainan plume that formed within the circum-Pacific mantle downwelling zone [2].

References:

[1] Li ZX and Zhong S (2009) Physics of the Earth and Planetary Interiors 176: 143-156