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Mantle plumes: influence of partial melting on the lithosphere erosion

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Mantle plumes are traditionally proposed to play an important role in erosion of the base of the lithosphere [1]. However, previous models show that unless the plate is almost motionless in a hotspot reference frame the thermo-mechanical erosion does not exceed 30 km. We propose to further investigate this process, focusing on the role of partial melting on the plume-lithosphere interaction, by using a 2D petrological-thermo-mechanical numerical model based on a finite-difference method on a staggered grid and marker in cell method [2].
An homogeneous peridotite composition is used to represent the plate and the underlying mantle. The lithosphere-asthenosphere boundary initially follows the half-space cooling model and we impose a constant velocity of 5 and 10 cm/y at top of the plate. We modeled plumes with a diameter of 50 km and thermal anomalies between $200 - 400$ K in a mantle deforming by diffusion creep; the viscosity at the base of the upper mantle ranges between 10^{20} and 10^{21} $Pa \cdot s$. Partial melting is estimated using the melting curves for anhydrous melting as a function of pressure, temperature [3], which have been modified to account for the progressive depletion of peridotites by solely considering difference between the instantaneous melt fraction and the cumulated one for a given marker; this modified model predicts reasonable melt fractions at the base of the lithosphere (<1 %). The effect of partial melting on the viscosity of the sub-lithospheric mantle has then been studied using an experimentally-determined flow law for partially molten peridotite, in which the viscosity depends exponentially on melt fraction, pressure, and temperature [4].
The impact of a plume beneath the lithosphere leads to thermal rejuvenation of the lithosphere by favoring a small-scale convection in the plume-fed low-viscosity layer at the base of the lithosphere. The plumes induce up to 30 km of uplift of the 1200 °C isotherm. The viscosity of the mantle and the plume buoyancy flux, depending on temperature anomaly and plume diameter, play an important role in controlling the behavior of the plume and, consequently, its erosional potential and amount of melting. Using a melt-dependent rheology the viscosity at the lithosphere base reaches very low values, facilitating the small scale convection, and then the lithosphere erosion, compared to the results obtained without considering the influence of melting. Differently results are obtained when the progressive depletion is taken in account, very low melting fraction (< 1%) values are too much low to reduce the viscosity at the lithosphere base.
The model will be expand to consider more sophisticated melting law and melt migration (two-phase flow).

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