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Lithosphere thinning by small-scale convection in a plume-fed low viscosity layer beneath a moving plate

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Mantle plumes are traditionally proposed to play an important role in lithosphere erosion. Numerical models show that time-dependent small-scale convective (SSC) instabilities in the low-viscosity layer formed by spreading of hot plume material at the base of the lithosphere may indeed be an effective mechanism to erode the base of the lithosphere. 2D numerical simulations using a petrological-thermo-mechanical numerical model based on a finite-difference method on a staggered grid and marker in cell method were performed to study the plume-lithosphere interaction beneath a moving plate. A homogeneous peridotite composition with a Newtonian temperature- and pressure-dependent viscosity is used to simulate the plate and the underlying mantle. A constant velocity, ranging from 5 to 12.5 cm/yr, is imposed at top of the plate. Plumes were created by imposing a thermal anomaly of 150 to 350 K on a domain 70km wide at the base of the model (700 km depth); the plate age atop this domain is 40 m.y. old. As observed in previous studies, small-scale convection (SSC) in the plume-fed low-viscosity layer at the base of the lithosphere results in thermal rejuvenation of the lithosphere. The onset time and the vigor of this SCC and, hence, the new equilibrium thermal state of the lithosphere atop the plume wake depends on the local Rayleigh number (Ra) in the unstable layer at the base of the lithosphere, which is controlled by the temperature anomaly in the plume-fed layer and by the mantle rheology, and on the plate velocity. Higher plate velocities and lower Ra (which are associated with weak plume dynamics) result in longer onset times and less erosion. In contrast, the rising plume dynamics depends on the mantle viscosity and on the temperature anomaly that characterizes the plume, but not on the plate velocity. Finally, in models that explicitly account for the effect of partial melting on the mantle viscosity and density the lithosphere erosion is enhanced; the upwelling of the 1200°C isotherm may reach 25-30 km.
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