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Ultra-slow spreading ridges: a response to the interplay between mantle convection and plate tectonics

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Ultra-slow spreading ridges such as the South West Indian ridge or the Arctic ridge system are oddities amongst oceanic ridges. Conversely to faster oceanic ridges, petrographic and seafloor studies have shown that they are characterized by low melt supply and present low crustal thicknesses and heat flow; these features are interpreted as an evidence for a cooler sublithospheric mantle. In cartoonish sketches of plate tectonics, ridges open above upwellings, subduction zones occur over downwellings, and plates are riding over the mantle convection cells. In this study, we designed a simple yet dynamically consistent thermal convection model to test the impact of far-field forces on spreading ridges and show that this pattern is disrupted by plate tectonics. In particular, continental collisions modulate the spreading rates because resisting forces build up at plate boundaries. As a consequence, this modifies the surface boundary conditions and therefore the underlying mantle flow. We show that the ideal convection cell pattern quickly breaks down when plate motion is impeded by continental collisions in the far field. Not only the decreasing spreading rates are diagnostic, but in the same time, (i) the heat flow is decreasing at the ridge, (ii) the thermal structure of the cooling lithosphere no longer matches the cooling half-space model, and (iii) the mantle temperature beneath the ridge drops by more than 100 degrees. We compare our model predictions to available observables and show that this simple mechanism explains the atypical thermo-mechanical evolution of the South West Indian ridge and Arctic ridge system. Last, the recent S wave seismic tomography model of Debayle and Ricard (2012) reveals that only away from those two ridges does lithospheric thickening departs from the half-space cooling model, in accord with our model predictions.