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Ultraslow, slow, or fast spreading ridges: Arm wrestling between mantle convection and far-field tectonics

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Oceanic spreading rates are highly variable, and these variations are known to correlate to a variety of surface observables, like magmatic production, heat flow or bathymetry. This correlation lead to classify ridges into fast and slow spreading ridges, but also into the more peculiar ultraslow spreading regime. Here we explore the dynamic relationships between spreading ridges, plate tectonics and mantle flow. We first focus on the thermal signature of the mantle, that we infer from the global S-wave seismic tomography model of Debayle and Ricard (2012). We show that the thermal structure of ridges gradually departs from the half-space cooling model for slow, and above all ultraslow spreading ridges. We also infer that the sublithospheric mantle temperature decreases by more than 150 degrees C from fast to ultraslow spreading regimes. Both observations overall indicate that the mantle convection pattern is increasingly chaotic underneath slow and ultraslow spreading ridges. We suggest that this is due to far-field tectonics at the other ends of lithospheric plates: not only it modulates the spreading rates but it also alters the convection regime by obstructing the circulation of plates, which in turn modifies the surface kinematic conditions for the convecting mantle. We test this hypothesis using a thermo-mechanical model that represents a convection cell carrying a continental lithosphere atop. The continent gradually drifts away from the spreading ridge, from which the oceanic lithosphere grows and cools while the continent eventually collides at the opposite side. In turn, this event drastically modifies the upper kinematic condition for the convecting mantle that evolves from a mobile lid regime to an almost stagnant lid regime. Implications on spreading ridges are prominent: heat advection decreases with respect to thermal conduction, which causes the oceanic lithosphere to thicken faster; the oceanic plates get compressed and destabilized by a growing number of small scale transient plumes, which disrupt the structure of the oceanic lithospheres, lower the heat flow and may even starve ultraslow ridges from partial melting. It follows that the spreading rate of a modern ridge mirrors its status in the global plate tectonics framework within a unique breakup, drift, collision scenario, within the transition from mobile to stagnant lid, and that it is the same mechanism that build mountains at converging boundaries and control spreading rates. Oceanic ridges thus can be regarded as a sensor of the resisting rather than driving forces. Both the model and the seismic structure of the mantle underneath ridges reveal that the temperature variations are largest at shallow depths in the upper mantle, i.e. at the critical depth where the melt supply to the above ridges can be modulated, thereby also explaining why slow and ultraslow ridges are almost exclusively associated to cold mantle. It follows that the chemistry of oceanic ridge basalts may not strictly reveal the mantle potential temperature, but the variations in the sublithospheric temperature field.