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The mechanics and kinematics of mantle exhumation at rifted margins, slow and ultra-slow spreading ridges

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Traditionally crust is considered as either granodioritic and continental or basaltic and oceanic, both underlain by the mantle. However, within the continent-ocean transition of magma-poor rifted margins and at slow- and ultraslow-spreading ridges, large expanses of mantle rocks have been exhumed by slip on large-offset normal faults to form the seafloor and hydrated to have similar physical properties to basalt and gabbro, producing a third type of "crust": serpentinized mantle. We consider the mechanics and kinematics of the process of mantle exhumation, from crustal embrittlement and faults cutting into the mantle to allow mantle hydration and serpentinization, exemplified by the Porcupine basin, the first mantle exhumation exemplified by the peridotite ridges at the west Iberia rifted margin, to long-lived mantle exhumation at ultraslow-spreading ridges, and more temporally and spatially localized mantle exhumation at slow spreading ridges forming oceanic core complexes (OCCs). We develop a kinematic model based on symmetric divergence about a rift axis at depth, with a repeating cycle in which a fault propagates up from the rift axis, develops into a detachment fault accommodating the plate divergence, migrates beyond the rift/spreading axis and is abandoned when a new fault propagates up through the footwall from below, and explore the controls on the depth, dip and timing of fault initiation and abandonment. The model explains the unroofing of mantle in the COT, the evolution of oceanic core complexes and the long-live exhumation of mantle at the Southwest Indian Ridge (SWIR), through the development of successive detachments of flipping polarity, each forming as steeply dipping faults cutting through the footwall of the preceding structure, causing the abandonment of the existing detachment root as a structure dipping steeply away from the rift axis. Such abandoned root zones form the landward-dipping reflections observed beneath exhumed mantle at some magma-poor margins. At the SWIR, the faults root along a narrow and fixed rift axis at the base of the seismically defined brittle lithosphere at 80°, the dip of seismically defined OCC detachments. Such a steep dip is not expected for normal faults but is consistent with dikes: we speculate that the faults may have initiated along epidositized dikes, consistent with the epidote and chlorite rich mineralogy of detachments at some OCCs. We consider that the lateral transition from amagmatic to dominantly magmatic spreading is analogous to the temporal transition within the continent-oceanic transition of rifted margins: at ultraslow spreading ridges, exhumation detachments (exhuming mantle in their footwall) transition laterally into rafting detachments (rafting blocks of volcanics up and out of the ride axis) before eventually dying out to be replaced by dominantly magmatic spreading towards the more volcanic portions of the spreading axis. All told, detachment tectonics dominate the process of ultraslow seafloor spreading as well as much of slow seafloor spreading, totalling about one third of the global ridge system.