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Segmented mantle melting yields a segmented lithospheric rheology and the ridge-transform structure of ocean basins

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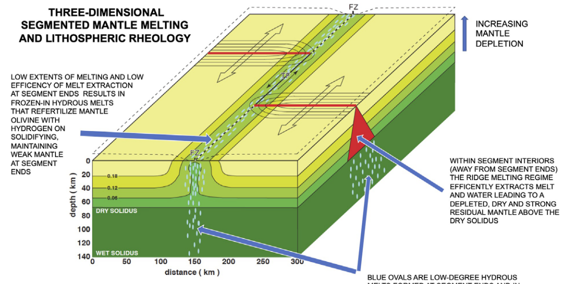
The ridge-transform structure of ocean basins is one of the most prominent expressions of plate tectonics. Yet why this configuration is favored over a simpler continuous divergent plate boundary has remained poorly understood. We propose that the segmented nature of mantle melting at mid-ocean ridges leads to a segmented lithospheric rheology that favors an orthogonal ridge-transform structure. Within ridge segment interiors, mantle melting and melt extraction are efficient, leading to a depleted, dehydrated, and strong residual mantle. Near ridge segment ends, mantle upwelling rates decrease, melt production rates slow, and melt extraction becomes inefficient, leading to formation of low-degree hydrous melts that are inefficiently extracted from the mantle, resulting in hydrous and weak mantle. This rheological banding, with strong segment interiors and weak segment ends, mechanically favors a rectilinear plate boundary oriented orthogonally to the plate opening direction. This model explains the configuration of mid-ocean ridges over the full range of spreading rates. At ultra-slow rates, melting and/or melt extraction are limited and a segmented crustal structure is not developed. Correspondingly, the underlying residual mantle is also not rheologically banded, and these ridges typically lack transform faults, instead forming continuous curvilinear divergent boundaries. As spreading rates increase to slow, spaced buoyant upwelling centers develop and a pronounced crustal segmentation and corresponding mantle rheological banding forms, favoring ridge axes offset by transform and non-transform discontinuities at frequent intervals. At intermediate and fast rates, three-dimensional buoyant upwelling gives way to longer two-dimensional plate-driven upwelling where limited melting, weak mantle rheology, and transform faults only form at more widely spaced ridge offsets. At ultra-fast spreading rates, mantle melting is robust and melt extraction is efficient along the entire plate boundary, leading to a uniformly strong mantle rheology, not favoring transform faults. This model implies that the pattern of mantle melting, controlled by spreading rate, shapes the rheological structure of oceanic lithosphere and the geometry of plate tectonics.

Reference: Martinez, F., and R. Hey (2022), Mantle melting, lithospheric strength and transform fault stability: Insights from the North Atlantic, *Earth and Planetary Science Letters*, *579*, https://doi.org/10.1016/j.epsl.2021.117351



Depletion contours after *Shen and Forsyth*, 1992, JGR