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Crustal Eclogitization and Lithosphere Removal in Orogens Drips and Delamination

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In collisional and Cordilleran orogens, shortening produces thickened (>50 km) crust and high elevations. The behaviour of the deep lithosphere is less well-constrained. Crustal shortening should be accompanied by thickening of the underlying mantle lithosphere. However, for the Tibetan plateau and central Andes, geophysical and geological data (e.g., seismic tomography, gravity, paleoelevation, magmatism) suggest thin mantle lithosphere, requiring that part of the lithosphere has been removed. In this study, we use 2D thermal-mechanical numerical models to examine lithosphere removal associated with lower crustal eclogitization during orogenesis. The models include a 100 km thick continental plate (consisting of crust and mantle lithosphere) and an upper mantle that extends to 660 km depth. Shortening is induced at 1 cm/yr through prescribed boundary velocities, resulting in crustal thickening. Metamorphic phase changes are imposed in the lower crust once it reaches pressure-temperature conditions within the eclogite stability field. The models show that

even a small density increase (7% or more) associated with eclogitization causes shortening to localize above the eclogitic crustal root. Gravitational instability of this root can then trigger complete removal of the orogen mantle lithosphere through delamination, as the mantle lithosphere “unzips” from the crust. In our models, delamination requires that the eclogitized lower crust is weak enough to allow the mantle lithosphere to separate from the crust. Lithosphere removal in this manner may be determined by the hydration state of the lower crust, as the presence of water significantly reduces rock strength and promotes eclogitization, which increases the lower crustal density. If the lower crust is relatively strong or it does not undergo eclogitization, delamination is suppressed. Minor Rayleigh-Taylor-type drips occur that remove the lower ~30% of the mantle lithosphere at the orogen edges, but thick lithosphere remains below much of the orogen.

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