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Evolution and stability of oceanic lithosphere: small-scale convection and the rheology of the sub-lithospheric mantle

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It is generally believed that sub-lithospheric small-scale convection (SSC) beneath oceans is the main responsible for the flattening of the sea floor and surface heat flow at ages $>$ 70 Ma. However, the necessary physical conditions (e.g. mantle rheology, internal heat production, melting) to generate SCC, the geophysical observables it produces, and its connection with plate models, are still a matter of debate. Here we use 2D thermo-mechanical numerical simulations to 1) obtain possible ranges of all relevant parameters for which SSC is generated, and 2) to study the connection between SSC, plate models, and geophysical observables.

Our results show that both diffusion and dislocation creep mechanisms can generate SSC when using rheological parameters within the ranges of laboratory experiments. However, the most favorable condition seems to be when dislocation creep is dominant over diffusion only in the uppermost $\sim$ 200 km. We find that vigorous SSC occurs only if the upper mantle viscosity is of the order of 10^{19} Pa s; higher values suppress SSC, while lower values generates unrealistic high velocities. Although shear heating is negligible, significant re-heating ($\sim$ 100 °C) of the base of the lithosphere by SCC is only achieved if radiogenic internal heating is included. The sub-lithospheric mantle is cooled in average by about 30 °C in the depth range of 150 - 350 km. All isotherms greater than $\sim$ 1300 °C are significantly affected by SSC, while colder isotherms are practically undisturbed and follow conductive profiles. Importantly, unless internal heating is set to values well above those typically accepted for the upper mantle,

the development of SSC does not result in an effective flattening of the lithospheric thickness, sea floor bathymetry, or surface heat flow. Lithospheric thickness (depth to the 1300 °C isotherm) increases continuously with values between those predicted by half space cooling models and those from plate models. However, our syntectic seismic tomographies resemble closely those recently obtained in the Pacific. Reconciling the discrepancy between seismic information and other geophysical observables will require further investigations on the seismic, thermal, and compositional structure of the oceanic lithosphere and sub-lithospheric upper mantle.