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Tilting of plates driven by lateral flow of asthenospheric mantle

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Continents can experience anomalous dynamic uplift or subsidence often attributed to the induced flow driven by mass anomalies in the mantle (e.g. rising plume or sinking slab) or small-scale convection at the edge of continents. Using 2-D numerical models, we show that long-wavelength components of dynamic topography may be induced by relative horizontal motions of the lithosphere with respect to the asthenosphere. In our models, a velocity boundary condition imposes a linear increase in horizontal velocity from 150 km to 700 km depth, at both sides of the model. This boundary condition leads to a quasi-horizontal laminar flow underneath the lithosphere, which is fixed on both sides. In nature, this flow could be related to the displacement of the asthenosphere associated to far-field slab subduction, or to the influx into the asthenosphere from the deep mantle. In our models, the lithosphere involves two continents (135 km thick) separated by an oceanic domain.

To balance the forces induced by the horizontal motion, the entire lithosphere tilts with uplift of the leading continental edge (i.e. continent facing the incoming asthenospheric flow), and subsidence of the trailing continental edge. The magnitude of the tilt (+/– 1.4 km) is independent of the length of the model. This dynamic response is induced by the horizontal motion of the asthenosphere underneath the lithosphere. The imposed asthenospheric shear applies a torque on the overlying plate and this is balanced by the tilt of the lithosphere. The magnitude of the tilt is a function of the ratio between viscous stresses and buoyancy forces; hence it varies with the viscosity of the asthenospheric mantle and the magnitude of the imposed velocity. We propose that the torque imposed by a flowing asthenosphere could explain some anomalous episodes of uplift/subsidence observed along some continental margins. Our numerical experiments particularly provide insights on the Cenozoic evolution of the Australian margins. Around the mid-Eocene, the N-NW margins of the Australian plate are anomalously uplifted (e.g., the Canning, Bonaparte, Browse and Arafura Basins) whereas at the same time the S-SE margins experience accelerated subsidence (e.g., the Bass Strait and Great Australian Bight Basin), which implies tilting of the plate. This is coeval with the initiation of an increased sea-floor spreading rate between Australia and East Antarctica and acceleration of the Australian plate to speeds between 4.0 cm/yr – 6.0 cm/yr, which indicates a likely increase in the asthenospheric shear beneath the plate. We propose that the tilting of the Australian plate in the mid-Eocene might have been driven by the relative motion between the plate and the underlying asthenospheric mantle.