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Understanding plate-motion changes over the past 100 Myr with quantitative models of the coupled lithosphere/mantle system

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The volume of geophysical datasets has grown substantially over recent decades. Our knowledge of continental evolution has increased due to advances in interpreting the records of orogeny and sedimentation. Ocean-floor observations now allow one to resolve past plate motions (e.g. in the North Atlantic and Indian Ocean over the past 20 Myr) at temporal resolutions of about 1 Myr. Altogether, these ever-growing datasets allow us to reconstruct the past evolution of Earth's lithospheric plates in greater detail. This is key to unravelling the dynamics of geological processes, because plate motions and their temporal changes are powerful probe into the evolving force balance between shallow- and deep-rooted processes. However, such progress is not yet matched by the ability to quantitatively model past plate-motion changes and, therefore, to test hypotheses on the dominant controls. The main technical challenge is simulating the rheological behaviour of the lithosphere/mantle system, which varies significantly from viscous to brittle.

Traditionally computer models for viscous mantle flow on the one hand, and for the motions of the brittle lithosphere on the other hand, have been developed separately. Coupling of these two independent classes of models has been accomplished only for neo-tectonic scenarios, without accounting for the impact of time-evolving mantle-flow (e.g. Iaffaldano and Bunge 2009). However, we have built a coupled model to simulate the lithosphere/mantle system (using SHELLS and TERRA, respectively) through geological time, and to exploit the growing body of geophysical data as a primary constraint on these quantitative models. TERRA is a global spherical finite-element code for mantle convection (e.g. Baumgardner 1985, Bunge et al. 1996, Davies et al. 2013), whilst SHELLS is a thin-sheet finite-element code for lithosphere dynamics (e.g. Bird 1998).

Our efforts are focused, in particular, on achieving the technical ability to: (i) simulate the impact of the mantle time-evolving buoyancy-field on lithospheric plate-motions; and (ii) explore the dynamics of lithosphere/mantle interactions by using the geological record as constraint, focusing on regions featuring cratonic lithosphere, dynamic topography or high topographic features. This progress allows us to self-consistently simulate any tectonic scenario from the late Cretaceous – through the Cenozoic – to the present-day. Our work will aid with better understanding the processes that govern the coupled lithosphere/mantle system.