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100 Ma: the new frontier for quantitative global models of the coupled brittle-plates/viscous-mantle system.

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Over recent decades the body of geophysical datasets has grown substantially and rapidly. Ocean-floor observations now allow one to unravel past plate motions (for instance, in the North Atlantic and Indian Ocean over the past 20 Myr) at the unprecedented temporal resolution of about 1 Myr; and more data is anticipated in the near future. Similarly, our knowledge of continental evolution has grown due to advances in interpreting the records of orogeny and sedimentation. Altogether, these ever-growing datasets allow us to reconstruct the past evolution of Earth's lithospheric plates in greater detail than previously achieved. This is key to unravel the dynamics of geological processes, because reconstructed plate motions and their temporal changes are a powerful probe into the evolving balance of shallow- and deep-rooted forces. Such progress, however, is not yet matched by the ability to quantitatively model past plate-motion changes and, therefore to test hypotheses on the dominant geological controls. The main technical challenge is simulating the rheological behaviour of the plates/mantle system, which varies significantly from viscous to brittle. Classically, computer models for viscous mantle flow and for the piecewise motions of the brittle lithosphere have been developed separately. In recent years, coupling of these two independent classes of models has been pioneered, but only for neo-tectonic scenarios (i.e. past few Myr), and with some limitations as to accounting for the impact of evolving mantle-flow on plate motions. It is now timely to further advance the technical ability to simulate the coupled plates/mantle system through geological time (for instance throughout the Cenozoic and possibly the Cretaceous), and to use the growing body of geophysical data as a primary constraint on these quantitative models. In this project, we take steps in this direction. We build on previous work aimed at coupling two advanced codes for mantle flow and lithosphere dynamics: TERRA and SHELLS. TERRA is a global spherical finite-element code for mantle convection. It has been developed by Baumgardner (1985) and Bunge et al. (1996), and further advanced by Yang (1997; 2000) and Davies et al. (2013), among others. SHELLS is a thin-sheet finite-element code for lithosphere dynamics, developed by Bird (1998). In further advancing the coupling between TERRA and SHELLS, our efforts are dedicated, in particular, to achieving the technical ability to: (1) simulate the impact of the time-evolving mantle buoyancy-field on lithospheric plate-motions; (2) explore, by using the geological record as constraint, the dynamics of plates/mantle interactions, for instance in regions featuring cratonic lithosphere or dynamic topography. This will allow us to self-consistently simulate any tectonic scenario, from the Jurassic, through the Cenozoic and to the present-day. As an example, the South Atlantic ocean-floor has recorded rapid changes in spreading rate since the Cretaceous, the reasons for which remain poorly understood. Our modelling advance provides the ability to quantitatively test hypotheses to explain this record.