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A new numerical simulation model of mantle convection with spontaneous continental drift within 3D spherical geometry

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The continental lithosphere exhibits a general behavior that is almost uncorrelated with the behavior of the oceanic lithosphere and/or mantle because its material is less dense than that of the oceanic lithosphere and mantle and is more rigid than that of the mantle. It thus acts as an assemblage of fairly rigid bodies `floating' on top of the mantle, which explains the modeling of continents as nondeformable, highly viscous blocks or rigid lids in two-dimensional (e.g., Gurnis, 1 988; Lowman and Jarvis, 1993; 1995; 1996; Zhong and Gurnis, 1993) and three-dimensional (3D) Cartesian/spherical-shell (Yoshida et al., 1999; Lowman and Gable, 1999; Honda et al., 2000; Zhong et al., 2007; Trubitsyn et al., 2008; Zhang et al., 2009; Yoshida, 2010a) spaces. Meanwhile, characteristic tectonic structures such as young orogenic belts and suture zones in a continent are expected to be mechanically weaker than the stable part of the continental lithosphere with the cratonic root (i.e., cratonic lithosphere) and yield lateral viscosity variations in the continental lithosphere. However, the dynamic role of a weak (low-viscosity) continental margin (WCM) in the stability of a continent has not been understood in terms of geophysics.

Here, I present a new numerical simulation model of mantle convection with a compositionally and rheologically heterogeneous, deformable, mobile continental lithosphere by using 3-D regional spherical-shell geometry (Yoshida, 2010b). A compositionally buoyant and highly viscous continental assemblage with pre-existing WCMs, analogous to the past supercontinent, is modeled and imposed on well-developed mantle convection whose vigor of convection, internal heating rate, and rheological parameters are appropriate for the Earth's mantle. The visco-plastic oceanic lithosphere and the associated subduction of oceanic plates are incorporated. The time integration of the advection of continental materials with zero chemical diffusion is performed by a tracer particle method. The time evolution of mantle convection after setting the model supercontinent is followed over the geological timescale.

Earth-like continental drift is reproduced, and the characteristic thermal interaction between the mantle and a continent/the supercontinent is observed in my new numerical model. Results reveal that a WCM protects the cratonic lithosphere from being stretched by the convecting mantle and may play a significant role in the stability of the cratonic lithosphere during the geological timescale because it act as a `cushion' that prevents the cratonic lithosphere from undergoing large deformation. From geological evidence that a cratonic root survives at the surface for billions of years, a WCM may have existed in the past supercontinent throughout the Earth's geologic history. The preliminary model presented here should represent an important step toward realizing a more realistic model that could be used to address many outstanding geodynamic problems about the thermal and mechanical feedbacks between the mantle and continents and the temporal evolution of the Earth's mantle structure.

References:
Yoshida, M., Temporal evolution of stress state in a supercontinent during mantle reorganization.

Geophys. J. Int., 180(1), 1-22, 10.1111/j.1365-246X.2009.04399.x, 2010a.
Yoshida, M., A new preliminary three-dimensional spherical-shell model of mantle convection with compositionally and rheologically heterogeneous, deformable, mobile continental lithosphere: Dynamic role of continental weak margins in Earth-like continental drift and the stability of cratonic lithosphere, Earth Planet. Sci. Lett., 2010b, submitted.

Keywords: mantle convection, numerical simulation, continent, continental drift, continental margin, craton