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Counter-intuitive features of the dynamic topography unveiled by tectonically realistic 3D numerical models of mantle-lithosphere interactions

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It has been long assumed that the dynamic topography associated with mantle-lithosphere interactions should be characterized by long-wavelength features (> 1000 km) correlating with morphology of mantle flow and expanding beyond the scale of tectonic processes. For example, debates on the existence of mantle plumes largely originate from interpretations of expected signatures of plume-induced topography that are compared to the predictions of analytical and numerical models of plume- or mantle-lithosphere interactions (MLI). Yet, most of the large-scale models treat the lithosphere as a homogeneous stagnant layer. We show that in continents, the dynamic topography is strongly affected by rheological properties and layered structure of the lithosphere. For that we reconcile mantle- and tectonic-scale models by introducing a tectonically realistic continental plate model in 3D large-scale plume-mantle-lithosphere interaction context. This model accounts for stratified structure of continental lithosphere, ductile and frictional (Mohr-Coulomb) plastic properties and thermodynamically consistent density variations. The experiments reveal a number of important differences from the predictions of the conventional models. In particular, plate bending, mechanical decoupling of crustal and mantle layers and intra-plate tension-compression instabilities result in transient topographic signatures such as alternating small-scale surface features that could be misinterpreted in terms of regional tectonics. Actually thick ductile lower crustal layer absorbs most of the “direct” dynamic topography and the features produced at surface are mostly controlled by the mechanical instabilities in the upper and intermediate crustal layers produced by MLI-induced shear and bending at Moho and LAB. Moreover, the 3D models predict anisotropic response of the lithosphere even in case of isotropic solicitations by axisymmetric mantle upwellings such as plumes. In particular, in presence of small (i.e. insufficient to produce solely any significant deformation) uniaxial extensional tectonic stress field, the plume-produced surface and LAB features have anisotropic linear shapes perpendicular to the far-field tectonic forces, typical for continental rifts. Compressional field results in singular sub-linear folds above the plume head, perpendicular to the direction of compression. Small bi-axial tectonic stress fields (compression in one direction and extension in the orthogonal direction) result in oblique, almost linear segmented normal or inverse faults with strike-slip components (or visa verse , strike-slip faults with normal or inverse components)