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Impact of lithosphere rheology on the dynamic topography

Evgueni Burov (1,2), Taras Gerya (3), Alexander Koptev (1,2)

(1) Sorbonne Universités, UPMC Univ Paris 06, UMR 7193, Institut des Sciences de la Terre Paris (iSTeP), F-75005 Paris, France, (2) CNRS, UMR 7193, Institut des Sciences de la Terre Paris (iSTeP), F-75005 Paris, France, (3) ETH-Zurich, Institute of Geophysics, Sonnegstrasse 5, 8092 Zurich, Switzerland

Dynamic topography is a key observable signature of the Earth's and planetary (e.g. Venus) mantle dynamics. In general view, it reflects complex mantle flow patterns, and hence is supposed to correlate at different extent with seismic tomography, SKS fast orientations, geodetic velocity fields and geoid anomalies. However, identification of dynamic topography had no systematic success, specifically in the Earth's continents. Here we argue that lithosphere rheology, in particular, rheological stratification of continents, results in modulation of dynamic topography, converting commonly expected long-wavelength/small amplitude undulations into short-wavelength surface undulations with wide amplitude spectrum, superimposed onto "tectonic" topography. These ideas are explored in 3D using unprecedentedly high resolution numerical experiments (grid step size 2-3 km for 1500x1500x600 km computational area) incorporating realistic rheologically stratified lithosphere. Such high resolution is actually needed to resolve small-scale crustal faulting and inter-layer coupling/uncoupling that shape surface topography. The results reveal strikingly discordant, counterintuitive features of 3D dynamic topography, going far beyond the inferences from previous models. In particular, even weak anisotropic tectonic stress field results both in large-scale small-amplitude dynamic topography and in strongly anisotropic short-wavelength (at least in one direction) dynamic topography with wide amplitude range (from 100 to 2000-3000 m), including basins and ranges and large-scale linear normal and strike-slip faults. Even very slightly pre-stressed strong lithosphere yields and localizes deformation much easier , than un-prestressed one, in response to plume impact and mantle flow. The results shed new light on the importance of lithosphere rheology and active role of lithosphere in mantle-lithosphere interactions as well as on the role of mantle flow and far-field stresses in tectonic-scale deformation. We show, for example, that crustal fault patterns initiated by plume impact are rapidly re-organized in sub-linear rifts and spreading centers, which orientation is largely dictated (e.g., perpendicular to) by the direction of the tectonic far-field stress field, as well as the plume-head material soon starts to flow along the sub-linear rifted shear zones in crustal and mantle lithosphere further amplifying their development. The final surface deformation and mantle flow patterns rapidly loose the initial axisymmetric character and take elongated sub-linear shapes whereas brittle deformation at surface is amplified and stabilized by coherent flow of mantle/plume-head material from below. These "tectonically" looking dynamic topography patterns are quite different from those expected from conventional models as well as from those directly observed, for example, on Venus where plume-lithosphere interactions produce only axisymmetric coronae domal-shaped features with radiating extensional rifts, suggesting that the Venusian lithosphere is rheologically too weak , and its crust is too thin, to produce any significant impact on the dynamic topography.