Geophysical Research Abstracts,
Vol. 11, EGU2009-2008, 2009
EGU General Assembly 2009

Numerical modeling of Tibetan Plateau formation: Thin-sheet versus fully 3D models

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Knowledge about the tectonic evolution of the Tibetan Plateau is still incomplete and many open questions remain concerning the deformation style of the crustal thickening, causing the abnormally high elevation of the Tibetan Plateau. Different models have been suggested explaining the crustal thickening by (1) homogeneous, continuous deformation using thin-sheet models, (2) discrete movement along thrusts developing crustal wedges and (3) lateral crustal flow due to pressure gradients resulting from topography. Most existing models are not fully three-dimensional (3D) models (e.g. thin-sheet models) and assume a certain deformation style a priori, which makes it difficult to judge the applicability of such constrained models to the formation of the Tibetan Plateau.
We present a comparison of deformation styles during continent indentation resulting from a fully 3D numerical model and a thin-sheet model. The rheology for both models is power-law. The 3D model consists of four layers representing a simplified lithosphere: strong upper crust, weak lower crust, strong upper mantle and weak lower mantle. From the effective viscosity distribution of the 3D model a vertically averaged effective viscosity is calculated and used for the thin-sheet model to make direct comparisons between the two models.
Simulating indentation is achieved by assigning free slip at one lateral side of the model, and fixing two other sides. The boundary at which indentation is taking place, exhibits a tripartite velocity profile: Next to the free slip side a section with constant horizontal velocity is applied. The velocity then gradually decreases towards zero, applying a cosine-function. The last section of the indenting boundary next to the fixed side is also fixed. The 3D model additionally exhibits a free surface and a bottom boundary allowing free slip.
The 3D code employs the finite element method with a mixed velocity-pressure formulation to simulate incompressible flow. A Lagrangian mesh with 27-node brick elements and 27 integration points is employed. The thin-sheet model is also based on the finite element method using 7-node triangles.
In the 3D model folding and lower crustal flow can take place, which are two deformation styles that are ignored in the thin-sheet model. We quantify the differences in velocity and strain rate fields resulting from the two models. We focus on areas around the indentation corners (the so-called syntaxes) because there the differences in both models are expected to be largest. Also, the Himalayan syntaxes are full 3D structures where 3D deformation effects are expected to be strongest. Consequences of the modeling results concerning the tectonic evolution of the Tibetan Plateau are discussed.