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The influence of fluvial incision on the lithospheric stress field: a numerical approach

Felipe Baiadori da Silva and Victor Sacek
Universidade de São Paulo, Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Geophysics, São Paulo, Brazil (felipe.baiadori.silva@usp.br)

Fluvial denudation along large valleys moves important sedimentary volumes across continents over time, inducing isostasy-related stresses due to unloading of the crust. This work reports numerical experiments with a visco-plastic lithosphere aimed at understanding the patterns and evolution of stresses and uplift associated with differential erosion in wide, tectonically quiescent valleys over 30 million years (Myr). We simulate valleys 30 to 150 km wide and a few hundred meters deep, and observe horizontal deviatoric stresses with maximum magnitudes larger than 10 MPa, the distribution of which is largely controlled by the degree of mechanical coupling between upper crust and lithospheric mantle, associated with the viscosity of the lower crust. The upper crust in simulations with a weakly-coupled lithosphere is strongly compression-dominated beneath the valley. In contrast, scenarios with higher lithospheric coupling are characterized by similar amounts of compression and extension over crustal depths. Moreover, our simulations suggest that a significant part of these stresses persists for tens of Myr after erosion rates have diminished, gradually focusing around the central valley due to progressive viscous relaxation in the lower crust and lithospheric mantle. The adequacy of an elastic plate model in reproducing modeled surface uplift and subsurface stresses in response to fluvial incision is discussed in terms of lithospheric rigidity for each scenario, revealing important departures between stresses predicted from flexural theory and those resulting from our simulations. We conclude that large rivers are an important factor to consider when studying stress fields in stable continental regions, especially if the valley is being actively excavated, and that these might contribute to moderate seismic activity in intraplate settings.