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Using natural laboratories and modeling to decipher lithospheric rheology

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Rheology is obviously important for geodynamic modeling but at the same time rheological parameters appear to be least constrained. Laboratory experiments give rather large ranges of rheological parameters and their scaling to nature is not entirely clear. Therefore finding rheological proxies in nature is very important. One way to do that is finding appropriate values of rheological parameter by fitting models to the lithospheric structure in the highly deformed regions where lithospheric structure and geologic evolution is well constrained. Here I will present two examples of such studies at plate boundaries.

One case is the Dead Sea Transform (DST) that comprises a boundary between African and Arabian plates. During the last 15- 20 Myr more than 100 km of left lateral transform displacement has been accumulated on the DST and about 10 km thick Dead Sea Basin (DSB) was formed in the central part of the DST. Lithospheric structure and geological evolution of DST and DSB is rather well constrained by a number of interdisciplinary projects including DESERT and DESIRE projects leaded by the GFZ Potsdam. Detailed observations reveal apparently contradictory picture. From one hand widespread igneous activity, especially in the last 5 Myr, thin (60-80 km) lithosphere constrained from seismic data and absence of seismicity below the Moho, seem to be quite natural for this tectonically active plate boundary. However, surface heat flow of less than 50-60mW/m2 and deep seismicity in the lower crust (deeper than 20 km) reported for this region are apparently inconsistent with the tectonic settings specific for an active continental plate boundary and with the crustal structure of the DSB. To address these inconsistencies which comprise what I call the “DST heat-flow paradox”, a 3D numerical thermo-mechanical model was developed operating with non-linear elasto-visco-plastic rheology of the lithosphere. Results of the numerical experiments show that the entire set of observations for the DSB can be explained within the classical pull-apart model assuming that (1) the lithosphere has been thermally eroded at about 20 Ma, just before the active faulting at the DST, and (2) the uppermost mantle in the region have relatively weak rheology consistent with the experimental data for wet olivine or pyroxenite.

Another example is modeling of the collision of India and Eurasia in Tibet. Our recent thermo-mechanical model (see abstract by Tympel et al) reproduce well many important features of this orogeny, including observed convergence and distance of underthrusting of Indian lithosphere beneath Tibet, if long-term friction at India-Eurasia interface is about 0.04- 0.05, which is typical for oceanic subduction zones, but is unexpected low for continental setting.