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Controls of continental and oceanic rheologies on reactivation of passive margins

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The passive margins are usually seen as quiet geodynamic features, only affected by a subsidence. However, several observations point out that they undergo a significant deformation. Several processes are involved: an isostatic response due erosion, ice loading/unloading, and sedimentary accumulation, a mantle plume, a ridge push or a regional compression. The most ubiquitous process is the ridge push that may act on all the margins: shortening features are expected along the margins, but they are not systematically documented. Why?

To answer this question, analogue modelling was processed to evaluate the rheology impact of continental and oceanic lithosphere rheology on the deformation pattern of ocean-continent transition. The rheology of the oceanic lithosphere is mainly controlled by its age: the strength increases with the age. On the other hand, the strength and the rheological layering of the continental lithosphere depend on the crustal composition, crustal thickness, and its thermal state. We have conducted a series of analogue experiments in which we subjected scaled multilayered models of the lithosphere (made of sand and viscous layers) to horizontal shortening. The models rested on an asthenosphere of small viscosity that allowed isostatic adjustments. We process an experimental modelling based on shortening of small-scale models formed by two domains analogue to oceanic and continental lithosphere. Two sets of modelling were realised: one with changes in “ocean” strength and the second one with heterogeneities inside the continental domain.

To an applied boundary velocity, the continental lithosphere reacted differently, according to the strength and density of oceanic lithosphere that was calibrated relative to the continental domain. Where oceanic lithosphere was stronger and heavier than continental lithosphere, it subducted; where oceanic crust was stronger and lighter than continental crust, it obducted. When the strength and the density of the two domains are similar, the deformed zone is wide without faulting polarity. On this basis, we suggest that the style of incipient shortening of a passive margin depends on the age of oceanic lithosphere. If the ocean is young, we expect obduction; if it is old, we expect incipient subduction. In nature, ophiolites and shortened passive margins appear to conform to this simple rule.

The second set of modelling evaluates the effect of the continental domain rheology. Inside the “continental” domain, a low viscosity body is included as an analogue of a rheological heterogeneity. After a small shortening, the deformation is located at the transition between the two domains and around the continental heterogeneity. The “oceanic” domain is few deformed in compared to the “continental part”. Folds and thrusts of “continental” domain on the oceanic part affect the transition between the two domains. Around the deep heterogeneity, the deformation displays a strike-slip component at northern and southern part and thrusting the eastern front. The field of the vertical motions displays undulation along the domain transition with a maximum vertical displacement at the intersection with the heterogeneity. Around the deep heterogeneity, the uplift displays north/south bands with “en echelon” pattern. Underneath the deep heterogeneity and outside, the vertical displacement is null or downward.

The study highlights the contribution of the rheology lithosphere of oceanic and continental domains during a compressive reactivation of a passive margin: 1) the density and strength differences between the two domains control the deformation polarity (obduction versus subduction) and 2) the rheological heterogeneity localises the deformation on its boundaries.A comparison with natural example is done about the southern Africa where topography and marginal depots-centers are compatible with the modelling.