Geophysical Research Abstracts
Vol. 18, EGU2016-8706, 2016
EGU General Assembly 2016

Scaling the sandbox: New insights from detailed mechanical testing and quantitative comparison to nature

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Analogue sandbox experiments are an important tool to understand tectonic deformation. In combination with modern imaging techniques they provide a spatio-temporal resolution no other method can achieve. The downside is that information on stress distribution within the sandbox model is not readily available, which is the reason for most experiments to date being interpreted kinematically only. However, with the advent of reliable force sensors with a suitable dynamic range the dynamic evolution of sandbox models becomes available for analysis, offering new insights into the transient evolution of tectonic systems.

The interpretation of sandbox dynamics and its transfer to natural systems requires a much stricter scaling approach than usually considered. In particular it requires that not only the strength of the model material, but also its transient strength evolution, i.e. its weakening, be properly scaled to that of the natural prototype. No such scaling of transient strength exists up to now. Furthermore, published mechanical test data have mostly been obtained under normal load conditions not representative for analogue experiments.

To derive a scaling of transient strength we therefore measured and analysed two standard analogue model materials (quartz sand and glass microbeads) using ring-shear tests at low normal loads similar to common analogue experiments. We find that strain weakening under these conditions ($<$ 1 kPa normal load) is governed by a reduction of cohesion, not friction, which is the case for higher normal loads ($>$ 1 kPa) only. We show that this basically restricts proper scaling of transient strength of the tested materials to crustal scale models, with a length scaling factor of (nature/model) = 10^6. For this scale range we quantitatively compare the model materials' transient strength evolution both laboratory measurements of natural rocks and to estimates for the earth' crust. Accounting for lithostatic and hydrostatic conditions, respectively, we find that proper dynamic scaling – also of transient properties – is achieved in either case.