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Insights into the physics of geological processes (Arne Richter Award for Outstanding Young Scientists Lecture)

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The use of computational methods within the geological community has increased considerably over the last decade, partly thanks to advances in hardware and software. At the same time, there has been a tendency to increase the complexity of the models by adding ever more processes that are thought to be relevant (fluid migration, melting, metamorphic phase transitions, etc.). Whereas it can be argued that this makes the models more 'realistic', such complexity results in a situation where understanding the outcome of simulations becomes a difficult task. Yet, if the models are used in a systematic manner and are combined with dimensional analysis and (semi)-analytical solutions, one can obtain a thorough insight into the underlying physics of the processes. Scaling laws can be derived that allow *predicting* the outcome of numerical simulations before performing them. Once this is achieved, one can compare models with natural observations, and –in some cases– extract material parameters from natural observations that are otherwise difficult or impossible to obtain. Here, I will show two examples to illustrate how numerical models can be used to obtain insights into geological processes:

(1) Understanding the *rheology of crystal-bearing magma* is important for modelling volcano dynamics. Whereas laboratory experiments on pure melts show that the rheology of melt is Newtonian, more recent experiments show that melt with embedded crystals is strongly non-Newtonian and becomes weaker with faster deformation rates. Understanding the underlying causes for this has been tricky, partly because we typically only see the end-results of the laboratory experiments. We therefore performed numerical simulations in which digitized images of laboratory samples were used as model input, and the relative importance of mechanisms such as shear heating and finite strain was tested. Results show that brittle fracturing of crystals during the experiments is the most likely cause for the non-Newtonian rheology. These results can thus be used to design new laboratory experiments.

(2) The Zagros Mountains are a prime example of a *folding-dominated fold-and-thrust belt*, in which the folds have a spacing of $\sim$15 km. Thanks to its location in a desert and the importance of the region for hydrocarbon exploration, the surface and subsurface geology are very well constrained. It should thus be straightforward to apply models to the data and constrain the rheology of the crust in this manner. Yet, it turns out that this is not the case: if the basal salt layer is the only detachment layer, numerical simulations are dominated by faulting rather than by folding, irrespective of model parameters. Yet, in the Zagros there are up to 3 additional weak detachment layers within the crust, and if these are taken into account, the simulations are instead folding-dominated. We developed a technique to predict the spacing of folds in the presence of a brittle overburden and show that the effective friction angle of the crust and the viscosity of the weak layers are the two key parameters controlling this. Since we have independent constraints on salt viscosity, a friction angle no more than 10 degree is required to fit constraints. This suggests that the crust in this region was quite weak on geological timescales, likely the result of large fluid pressures.