Geophysical Research Abstracts, Vol. 9, 11588, 2007
SRef-ID: 1607-7962/gra/EGU2007-A-11588

About deformation, reactions, and fluids: combining petrology and modelling to better understand deeper earthquakes

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In order to test which seismic failure modes are feasible at elevated pressures it is necessary to formulate numerical models that integrate deformation, fluid flow, and metamorphism. Major feedback mechanisms between these processes are (i) rheological weakening by fluids and phase transitions, (ii) volume and density changes resulting from metamorphism and (iii) thermal feedbacks through the latent heats of metamorphic reactions.

Two main hypotheses have been proposed to explain intermediate-depth (70-300km) seismicity in slabs and continental root zones: one suggests that high fluid pressures lead to dehydration embrittlement which facilitates seismic failure, the other suggests that melt shear instabilities lead to seismic slip. During dehydration embrittlement elevated fluid pore pressures counteract the lithostatic pressure and thereby lower the effective pressure to values at which tectonic stresses can lead to seismic failure. The fundamental unknown in this scenario is the pore pressure. Ductile shear instabilities are a different failure mode of rocks. Rapid deformation rates lead to frictional heating and melt lubrication resulting in self-accelerating deformation at seismogenic strain rates. The fundamental unknowns in this failure mode are the conditions at which a small perturbation of the system will self-amplify instead of decaying and thereby lead to extreme localization of deformation and frictional heating. Pseudotachylytes are the only certain geological evidence for paleo-earthquakes and more and more eclogite-facies pseudotachylytes localities have now been discovered. They were found in rocks of the deeply exhumed continental roots and in exhumed fragments of subducted slabs. Their existence indicate that frictional melting is possible and may be a requirement for earthquakes under pressure-temperature conditions reasonable for depths $>$60-70 km.

Here we will present results of a joint field, analytical and modelling approach to better understand the development and evolution of seismogenic shear zones. Field evidence shows that the seismic shear zones contain water-bearing minerals and that those are highly concentrated at the margin towards the wall rocks. The formation of the water-bearing minerals produces latent heat. We will present a model in which we incorporate the effect of latent heat release through metamorphic hydration reaction. This new model is mechanically and petrologically consistent and provides good constraints on the conditions at which thermal runway and ductile failure can occur.