Geophysical Research Abstracts
Vol. 14, EGU2012-10944-1, 2012
EGU General Assembly 2012

Seismicity and fluid injections: numerical modelling of fault activation

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Injection of fluid into the subsurface is a common technique and is used to optimise returns from hydrocarbon plays (e.g. enhanced oil recovery, hydrofacturing of shales) and geothermal sites as well as for the sequestering carbon dioxide. While it is well understood that stress perturbations caused by fluid injections can induce/trigger earthquakes; the modelling of such hazard is still in its infancy. By combining fluid flow and seismicity simulations we have created a numerical model for investigating induced seismicity over large time periods so that we might examine the role of operational and geological factors in seismogenesis around a sub-surface fluid injection. In our model, fluid injection is simulated using pore fluid movement throughout a permeable layer from a high-pressure point source using a lattice Boltzmann scheme. We can accommodate complicated geological structures in our simulations. Seismicity is modelled using a quasi-dynamic relationship between stress and slip coupled with a rate-and state friction law. By spatially varying the frictional parameters, the model can reproduce both seismic and aseismic slip. Static stress perturbations (due to either to fault cells slipping or fluid injection) are calculated using analytical solutions for slip dislocations/pressure changes in an elastic half space. An adaptive time step is used in order to increase computational efficiency and thus allow us to model hundreds of years of seismicity.

As a case study, we investigate the role that relative fault – injection location plays in seismic activity. To do this we created three synthetic catalogues with only the relative location of the fault from the point of injection varying between the models. In our control model there is no injection meaning it contains only tectonically triggered events. In the other two catalogues, the injection site is placed below and adjacent to the fault respectively. The injection itself is into a permeable thin planar layer with less permeable layers above and below it. On comparing the injection catalogues with the control, we observe that it is the injection of fluid below the fault that produces the biggest change in seismicity which persists for more than 50 years after injection.