Geophysical Research Abstracts
Vol. 13, EGU2011-4310, 2011
EGU General Assembly 2011

Coupled fluid flow and deformation in sedimentary basins over geological timescales: A numerical modelling approach for accretionary prisms.

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Deformation of sedimentary basins by plate tectonic forces is a potential mechanism for driving fluid flow within them. How much of an influence deformation has seems to be linked to the speed at which it occurs relative to the permeability of the rocks that are affected. However, permeability itself can be generated by tectonic processes in basins, whilst fluid pressures, and in particular overpressures, can alter the rate or ease of rock deformation locally. Thus, a numerical model aimed at tackling these questions has to address the likely coupling of fluid pressure, deformation, permeability and fluid flow.

This study uses a distinct element model of deformation, coupled to a finite element model of pressure driven fluid flow to attempt this. The distinct element technique models solids as systems of particles which interact with each other through forces across their mutual contacts. The sum of these forces is then applied to each particle iteratively to solve the equations of motion for the system. Thus, using large "particles" ($\sim$500m radius), it is possible to simulate geological systems such as sedimentary basins which generally deform with a friction-controlled rheology. The geometry of the system is set using rigid walls which can have variable length and orientation. A moving wall can also be used to apply a velocity boundary condition.

Coupling this to a finite element model involves multiple steps. Firstly, the discrete elements have to be matched to a finite element grid. One way to achieve this is to treat the centres of particles as nodes of the grid. These can then be triangulated (for instance) and the geometry at different stages of deformation used to set the boundary and initial conditions for a fluid flow calculation. Thus, in the case of a submerged accretionary prism for example, the top surface boundary condition is set to hydrostatic pressure determined by water depth, whilst the basal boundary condition might be one of no flow. Initial conditions are taken from the end state of the preceding fluid calculation, but can be updated for increases in lithostatic pressure if a node is buried more deeply due to deformation. This increase in pressure between fluid calculation cycles will then affect the way fluid flow occurs in the next step.

Secondly, the effect of fluid pressure on deformation has to be expressed. This can be tackled directly by calculating a net fluid force exerted on a distinct element from fluids acting on all of its exposed perimeter. Thus, the pressure field from a fluid cycle calculation is directly applied to the perimeters of all the particles in the mechanical model. The net forces influence deformation and the resulting change in geometry of the model.

Thirdly, permeability has to be linked to deformation. This can be done by making an assumption that fluid flow conduits exist along particle contacts, linking the "pore space" between particles. The openness of these conduits determines their individual hydraulic conductivity and can be made a function of the normal force acting across them (thus linked to the deformation state of the model). When multiple contacts of variable orientation are present in a single finite element, their conductivities can be summed spatially to give a tensor for that element. High fluid pressures will tend to drive particles apart from one another, thus giving higher permeabilities around regions of higher pressure and simulating assumed "pumping" mechanisms in deforming regions.

We show an example of this technique applied to a case of a deforming accretionary prism and compare some of the results to geophysical and geological data from the Sunda margin in Java Indonesia.