Ancient CPU-GPU simulation of evolving fracture networks in a poro-elasto-plastic medium with pressure-dependent permeability

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Fluid flow in the earth is controlled by fracture networks that evolve in response to far field stress, local stress perturbations, and the pressure state of the fluid within them. The se-processes are very important for many geophysical systems, including earthquakes and volcanoes. Modelling the underlying physics is challenging because the time scales involved, from the elastic wave speed of crack growth to pressure diffusion and flow, make the se-problems numerically cumbersome. Our approach to model the se-processes is to couple the elastic-plastic response of the solid porous matrix to a pressure dependent (nonlinear) diffusion model for the fluid flow. Changes in the fluid pressure introduce changes in stresses in the porous media, which may lead to either hydro-facture or shear fracture

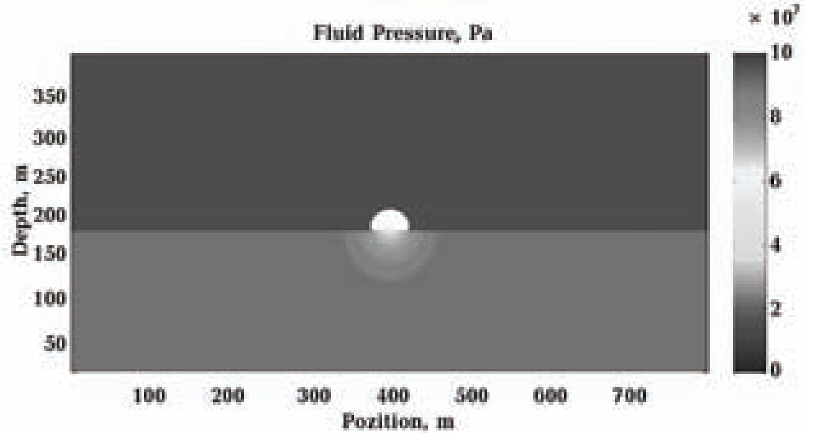

Fig. 1. CPU-GPU Poro-elasticity: 800×400points, grid size of 25 m. One day of simulation. Computation time: 42 min.

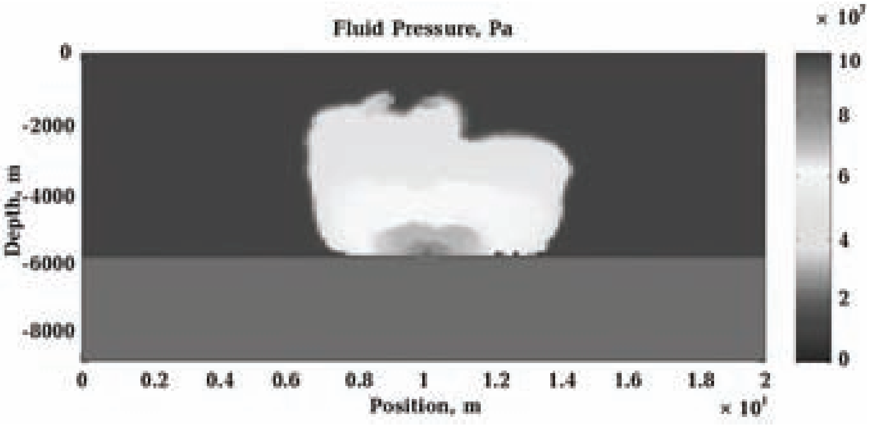

Fig. 2. Poro-elasto-plastic CPU (MATLAB): 150×100 points. Grid size is133 min *X* and 90 min *Y*. One day of simulation. Computation time: about 7 hours.

within the solid. See page forces, forces related by gradients of pore pressure, can also promote delocalized crack formation. Many models of fracture propagation have been developed using finite elements or other numerical methods in order to overcome the high deformation of the grid, however costly re-meshing algorithms are necessary to accurate model the evolving crack. The complete model, nonlinear diffusion and poro-elasto-plasticity, is very computationally expensive. GPU technology allows high resolution modelling and easy implementation of explicit finite difference methods in an efficient way. We have taken advantage of many-cores GPU technology together with CPU and developed a high-resolution fully explicit finite difference model of nonlinear diffusion coupled with the mechanical response of poro-elasto-plastic medium (Fig. 1). In our algorithm, we can model both the propagation of previously de?ned fractures and fracture generation and growth in response to the evolving stress field. Our model includes shear and tensile cracking, which plays a dominant role in the hydraulic properties of the poro-elastic media as well as changes in the rheological properties. High resolution 2D simulations are presented showing the hydro-mechanical evolution of systems driven by high pressure sources at depth, such as some aftershock sequences and with application to volcano-mechanics. Using CPU-GPU approach numerical resolution can be increased to more than three times and computational time is decreased as much as at enth-compared with the CPU alone approach (Fig. 2).