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Towards Multiscale Multiphysical Modelling of Unconventional Gas Reservoirs

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Abstract

Modern computational techniques are invaluable components of every engineer's toolkit and every scientist's laboratory. The main challenge for computational analysis of unconventional gas mining is to consider the multiscale heterogeneity and the related multiphysical phenomena in natural and/or enhanced geo-materials. Heterogeneous geomaterials typically possess a multitude of physically significant scales and each of these scales requires appropriate modeling. Heterogeneous structures on the microscale (i.e. mineral grains, pore space and micro-cracks) are often close in size to a characteristic length for the macroscopic pattern for such as subsurface flow and transport. Hence, these structures strongly influence macroscale processes.

This presentation briefly introduces the current state in multiscale multiphysical modelling and then focuses on our research efforts in high performance simulation of unconventional gas behaviours across the different scales spanning from the pore to the lab and field scales. A novel supercomputer simulation model has been developing towards simulating the highly non-linear coupled geomechanical-fluid flow-heat transfer-chemical reaction systems involving heterogeneously fractured geomaterials at different spatial and temporal scales (Figure 1). It is applied here to simulate and analyse the unconventional gas system, such as: (1) analysis of non-Darcy flow behaviours in nanopore to account for the flow regimes of the continuum (non-slip), slip, transition and free molecular types. Fluid mechanics of gas in shale and coal seam involves nano-scale phenomena. Their formations' pore radii range from a few angstroms (A) to tens of angstroms. Under a certain reservoir condition, various effects of pore radius r, gas molecular diameter dm, pressure P and temperature T on the relative permeability K/K0 are investigated. Figure 2 shows an example of relative apparent permeability K/K0 variation with pore radius r for both the ideal and real gas; (2) extended Lattice Boltzmann method for simulating the microscale fluid flow behaviours based on a micro-structural high resolution X-ray/CT/MRI/SEM data for further permeability evaluation (Figure 3); (3) converting the available rock image/fracture data as well as the reservoir geological geometry involving the detailed description of fracture dimension and geometry to suitable unstructured meshes/grids and further simulating the multiphysical dynamic behaviours by using finite element method. Figure 4 shows an application example coal image based meshing and deformation analysis. In addition, microseismicity is widely used to monitor hydraulic stimulation processes. The recorded microseismicity data provides the detailed location and time where and when an underground dynamic rupture occurs. PANDAS/Pre has been developed and applied to visualize the microseismic events, to monitor and determine where/how the underground rupture proceeds during a hydraulic stimulation process, to determine the domain of the ruptured zone and to evaluate the material parameter permeability and further applied in fluid low and deformation analysis (Figure 5); (4) interacting fault system simulation to determine the relevant complicated rupture process for evaluating the geological setting and the in-situ reservoir properties for an optimised reservoir design and management. More application examples will be presented to show its usefulness in simulating the unconventional reservoir system.

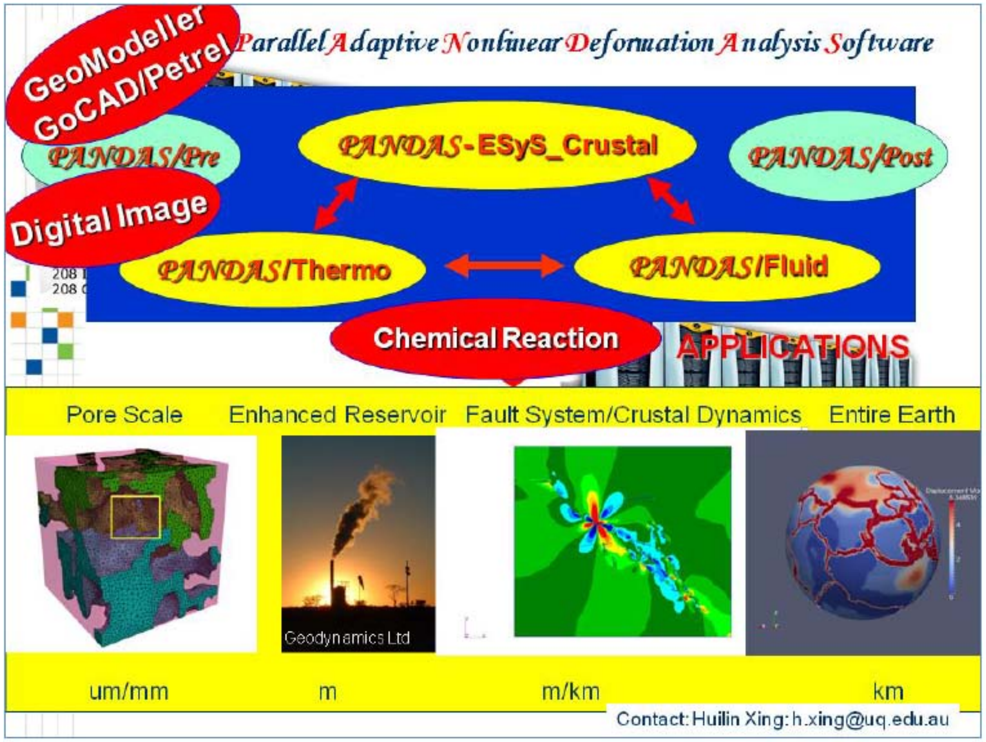

Figure 1. Research code PANDAS capability and flowchart.

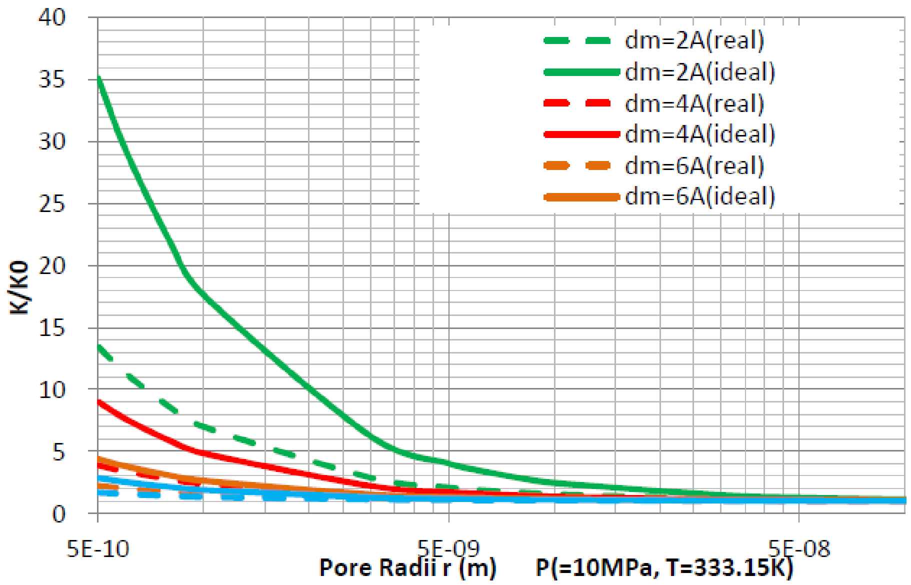

Figure 2. Relative apparent permeability K/K0 vs. pore radius r for both real and ideal gas.

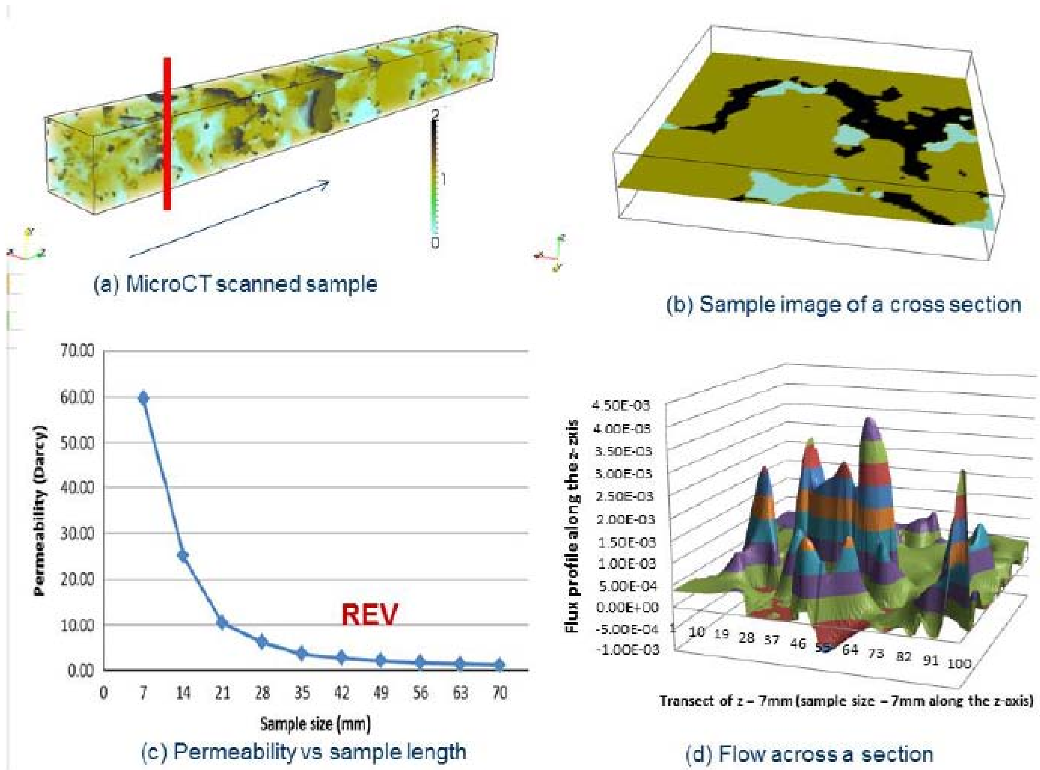

Figure 3. Pore scale flow simulation for permeability evaluation using LBM.

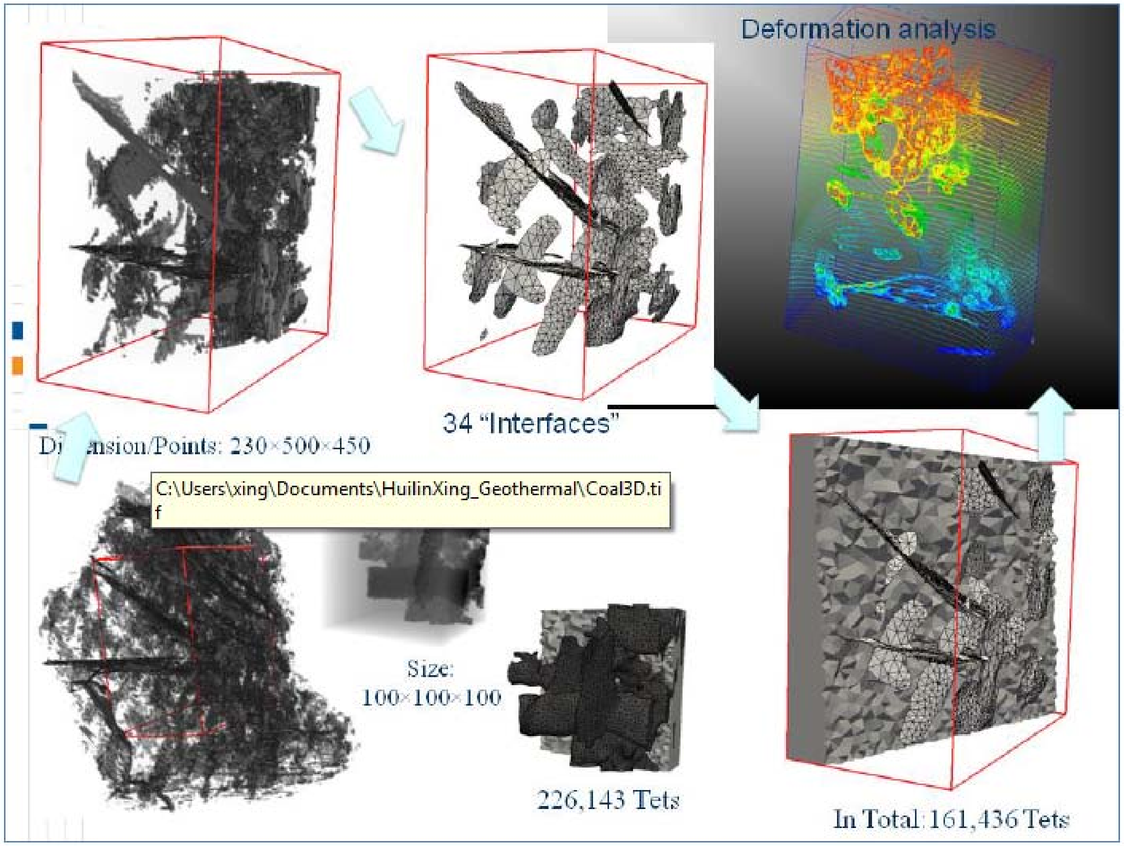

Figure 4. Coal image based meshing and finite element analysis.

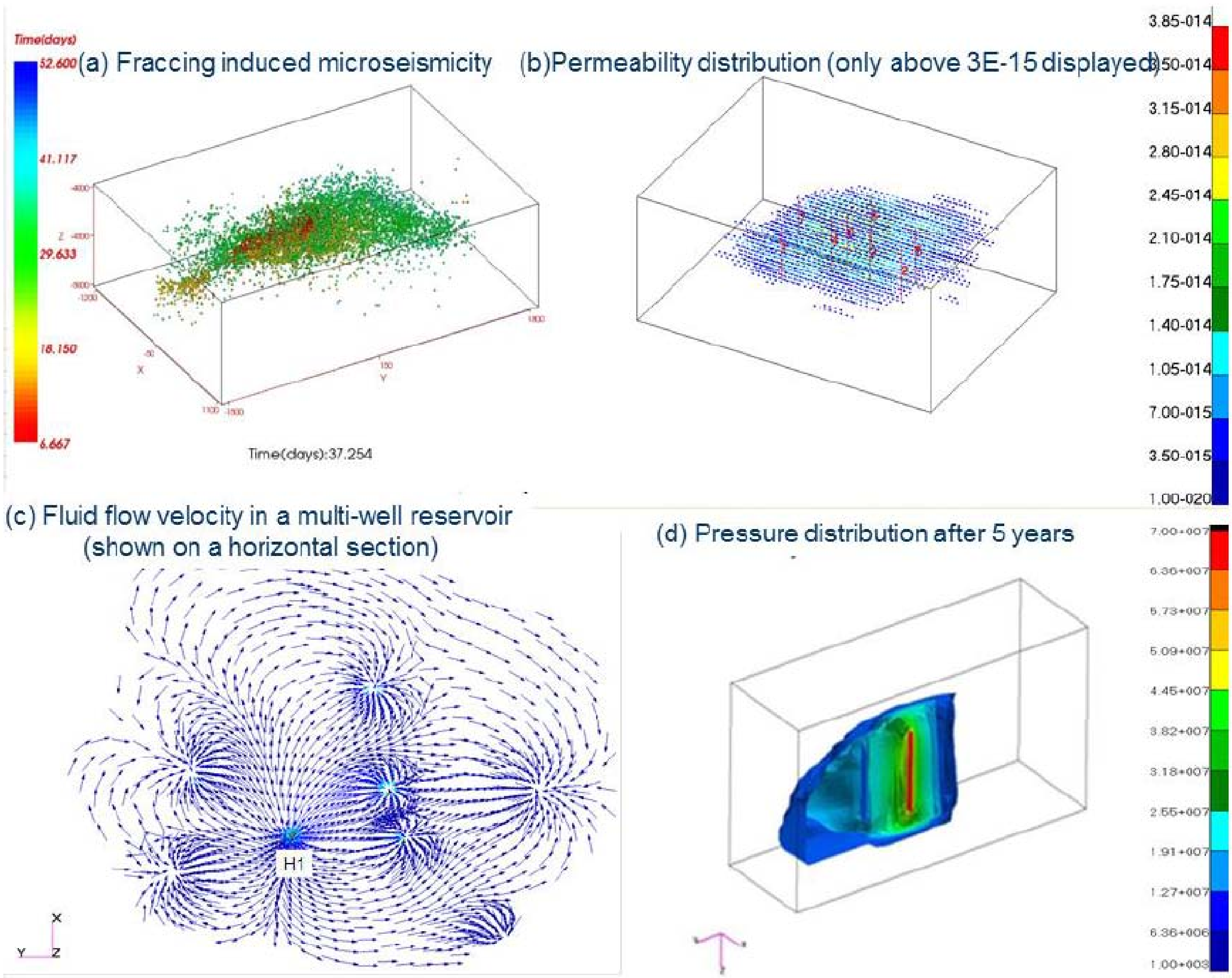

Figure 5. Multiple well coupled flow analysis. (a) Microsesimic events induced by hydraulic fracturing; (b) permeability evaluation through the recorded microseismic events; (c) simulated fluid flow and (d) pressure distribution after 5 years.