Title: Digital-Rock Micro-Mechanics Approach to Derive Poroelastic Behaviours

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Summary:

This project represents a major new direction for digital-rock research, going beyond the current perspective that the solid framework is rigid. The project builds on a new paradigm for fluid-solid geomechanical interactions, creating numerical methods to implement this new process understanding in realistic digital-rock models. The project adopts a quasi-static perspective that accounts for changes in states, but with a design philosophy that envisages a subsequent move to full dynamic conditions.

Context

Recent work, enabled by a Royal Society Theo Murphy Blues Skies Award, developed a fundamentally new understanding of the interactions between pore fluids and the geomechanics of the solid framework of rock materials. That work developed a digital-rock micro-mechanics approach, using a simple model configuration, which challenges the existing theory of poroelasticity (10.1190/geo2018-0577.1). These concepts have repercussions for the idea of 'effective stress', with implications for fractured reservoirs, hydraulic fracturing, vein injection, and seal integrity (journal papers in review). This PhD project represents a key step towards using these concepts in practical ways.

Scientific objectives

This PhD project involves the enhancement of existing digital-rock approaches that are primarily focused on the pore space (including pore-network modelling, lattice-Boltzmann simulations, finite-volume methods, AI approaches, etc) so as to create equivalent models (and methods) for the solid framework as for the pore space. A key idea is that the pore space and the solid framework are exact volume complements, so that any changes or uncertainties in one are mirrored in the other. The objective is to devise methods that generate solid-framework models from pore-system models, including the cases of pore systems comprised of multi-scale components (matrix pores, fracture-like elements). Such combined models (networks of solid and void) then have to be transformed into meshed models that suit numerical simulations, with the meshing designed to accommodate the spatial uncertainties. The project will also involve numerical simulations of the fluid/solid interactions, progressing as far as possible, and certainly identifying and addressing the key issues of how to apply boundary constraints to a non-solid domain. Subsequent and/or parallel research will extend the methods to the dynamic (acoustic) version of poroelastic response. Still further work will use the approach as the basis for digital-rock methods that calculate electrical conduction, radar responses (10.1109/ACCESS.2020.3002147), and provide the basis of *in operando* experiments with direct observation of deformation and fluid flow (10.1029/2018JB016522).

Expected results

The student is expected to develop deep understanding of the issues that arise in creating compatible digital-rock models of linked pore space and solid-framework elements, and how the uncertainties can be usefully captured in simulation models that are able to discriminate which uncertainties matter against those which do not. The progress towards creating numerical process simulations will provide the student with strong skills that will be important in the wider digital-rock subject area. The project outcomes will underpin a significant suite of follow-on work.

Subject Areas

Geology (192); Hydrology (189); Civil and Structural Engineering (280); Materials Science (734); Environmental Engineering (305)

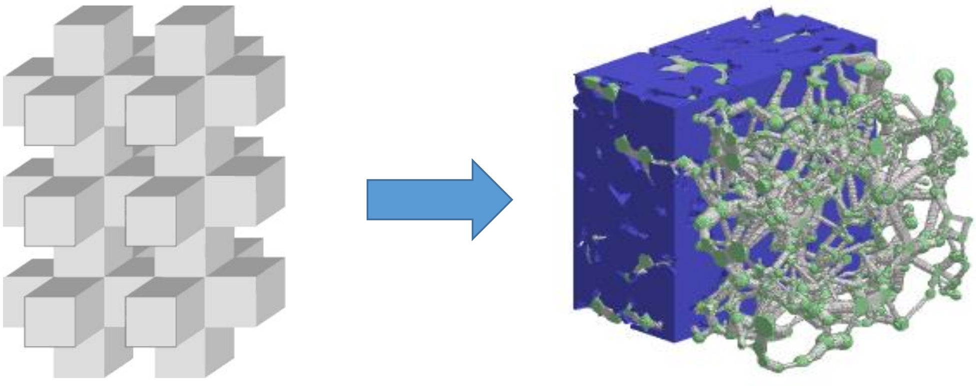
Desired Skills and Expertise

This project requires the student to have strong numerical skills and understanding, along with contextual awareness. In particular, we seek students who have documented experience in either, or both, of the topics of numerical simulation/programming of geomechanics, or digital-rock methods. There is scope for learning one of these topics within the project timescale, but it is not possible to learn both to a sufficient level in time to achieve useful outcomes.

Numerical geomechanics: here, we seek students who understand and have experience in aspects such as: finite element (or finite volume) methods; the design and manipulation of simulation meshes; how to distinguish the cause of any anomalies that emerge in simulations (separating numerical artefacts from physical process interactions); how to present key findings that tell a coherent story about the physical reality, etc. The student should have skills in creating and modifying input files, and extracting and assembling the right information needed to support the interpretations derived. Some programming ability is needed. Experience in using graphics tools is a plus. Note that the numerical simulations envisaged are quite different to the types of models normally encountered in mechanics and geomechanics, so this project demands the ability to adapt whatever tools are used to be appropriately employed for the model types required.

Digital-rock methods: here, we expect students to be able to document prior experience in working with digital-rock models and associated numerical manipulations of model data and the results of numerical simulations of, for example, flow processes.

In a graphical depiction (below), the project aims to transform from the simplified model on the left, to reach the realistic model on the right. This development involves much more than mere conversion of shapes. There are geometric and phenomenological uncertainties that must be addressed, along with numerical errors and artefacts. This project provides an opportunity to become the world expert in a brand-new topic area. The challenge is large, as befits the outcomes that can be achieved. The project is appropriate for an exceptional student.



Simplified lattice arrangement of solid rock, with fluid located within the void (pore) space. Calculations of fluid//solid interactions.

Realistic arrangement of solid rock (blue), with fluid-filled void (pore) space. Simulations of fluid//solid interactions.