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Multiscale Rock Image Pore Structure Feature Identification, Quantification and Modelling using AI

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Due to the complexity of rock structure with features on scales ranging ten orders of magnitude, the multiscale fractured carbonates require more complex analysis tools than the macroscopic simulation approaches currently used which have been developed for and validated against siliciclastic rocks primarily. Digital Rock Technology (DRT) offers a means to determine the system's transport properties on a pore-scale basis. DRT allows the investigation of fluid flow mechanisms in a comprehensive setting (e.g. single/multiphase flow, reactive flow). Furthermore, pore network models (PNM) have been used to model complex rocks due to their superior efficiency (improved computational speed, carbon footprint, and scalability) and ease of characterising the porous media using representative geometrical and topological statistics. However, current PNM open-source codes rely on strict definitions of the pore elements with symmetrical convex bodies and pores which can be challenging or even impossible to define the necessary irregular pore geometries in carbonate. Moreover, PNM does not consider heterogeneous multiscale features like fractures and vugs, which are difficult to discriminate and segment but have distinctive flow properties that can critically change the overall system behaviour.

In this talk, we will present a novel machine-learning algorithm for the semantic segmentation of rock matrix, porous/vugular elements, fractures, and secondary mineralogy, which was optimised considering its accuracy, complexity (measured using the total number of parameters, number of operations, run-time, energy consumption, and carbon footprint), and explainability based on the Green-AI philosophy. After comparing several techniques, shallow machine learning methods were preferred due to their superior computational efficiency and explainability whilst achieving comparable segmentation accuracy. The workflow proposed is a hybrid algorithm relying on both region-based and filter-based techniques to achieve the best accuracy and speed. Firstly a 2.5D (slice-by-slice) analysis is performed to separate pores from larger features, with the size threshold selected via a Gaussian mixture model. Subsequently, the micro-fractures and pores are separated via watershed, and the resulting elements are separated into pore elements and over-segmented fracture elements. Following this procedure, pixel-level segmentation is performed to distinguish and potentially separate large fractures and vugs, using this more computationally intense method only on the uncertain areas, hence optimising performance. The matrix class is also analysed to identify secondary mineralogy, which has the potential to alter wettability.

Each feature class is further segmented into instances and idealised, creating a multiscale network. The preexisting open-source codebase is expanded by increasing its flexibility to complex geometries and introducing multiscale features, which will remove one of the main weaknesses in current approaches. Moreover, fracture elements are also modelled distinct from pores, observing the typical flow regime. Validation of the algorithm against the solution via direct simulation methods (namely the finite volume method) and experimental results of known samples is ongoing.

The outcome of this research is that of a resource-efficient and explainable algorithm that can discriminate between pores, fractures and vugs (and optionally secondary mineralogy) enabling automatic linking of the semantic segmentation result with the pore-fracture-vug network extraction, hence improving the modelling accuracy.

Participation

In-Person

References

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Primary authors: PANAITESCU, Ciprian; WU, Kejian (The University of Aberdeen); Dr TANINO, Yukie (University of Aberdeen); Dr STARKEY, ANDREW (UNIVERSITY OF ABERDEEN)

Presenter: PANAITESCU, Ciprian

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