New approaches to high-resolution geological simulations

Geological and reservoir modelling are critical for geological exploration, resource extraction, and geoengineering projects. Current workflows and datasets record geological variations on metre or decimetre scales. However, many relevant geological structures exist at sub-centimetre scales. Dr Achyut Mishra and Professor Ralf Haese at the University of Melbourne, Australia – part of the international research consortium GeoCquest – have developed a new approach for high-resolution geological modelling in sedimentary basins. The approach has greatly improved estimates of geological carbon storage – for example, by revealing carbon geological carbon storage – for greatly improved estimates of basins. The approach has developed a new approach for high-resolution geological data to capture millimetre-scale variations of the subsurface.

NEW WORKFLOW FOR GEOLOGICAL MODELLING

At GeoCquest, an international research consortium between the University of Cambridge, UK, the University of Melbourne, Australia, and Stanford University, USA, researchers Dr Achyut Mishra and Professor Ralf Haese have taken up this challenge. Through collaborations with numerous other scientists, Mishra and Haese have spent six years developing a new workflow for high-resolution models. The geological models built using their approach have improved predictions of fluid flow and fluid–rock reactions compared with traditionally built geological models. Under the GeoCquest banner, Mishra and Haese have applied the fundamental principles of sedimentary geology to conventional geophysical data. Their new workflow have improved predictions of fluid flow and fluid–rock reactions.

3. These sedimentary structures are directly compared to wireline log data (eg, apparent matrix density, neutron porosity, and gamma-ray) sampled at resolutions of ~15cm.

4. Finally, sedimentary structures below the resolution of the wireline logs are determined based on parameters such as grain size and sorting, the degree of cementation, and bed thickness.

ADDRESSING UNCERTAINTY WITH MACHINE LEARNING

As with any geo-survey method, Mishra and Haese’s approach has inherent limitations; however, a critical innovation has been the use of machine learning to mitigate these limitations. For example, steps three and four, where sedimentary structures below the resolution of the wireline logs are inferred based on other known parameters, can introduce errors and uncertainty to the model (eg, uncertainties in rock types). To address this issue, Mishra and Haese developed a machine learning code called Irida to automate this process. Irida learns millimetre-scale variability in rock types from high-resolution GEMECA data and uses it to improve the resolution of wireline logs. These enhanced logs can then serve as inputs for building improved geological models.

Another major limitation of high-resolution models is that the number of grid cells in the model can become too large to be efficiently handled in computations. Mishra and Haese have applied machine learning algorithms to identify regions within reservoir models where high-resolution data are actually useful, and regions where such data do not add significant value. Based on this, the number of grid cells in regions where high-resolution data are not required can be reduced via reservoir upscaling or averaging methods, significantly reducing the computational burden.

Harnessing subterranean resources requires detailed subsurface surveys and models.
APPLICATIONS AND OUTLOOK

Geological models built using this approach have confirmed that greater resolution can capture improved predictions of fluid flow and fluid–rock reactions compared with traditionally built geological models. For example, mineral trapping is an important mechanism for storing CO₂ in the subsurface; however, these fluid–rock reactions are very slow. Greater resolution can capture improved predictions of fluid flow and fluid–rock reactions compared with traditionally built geological models.

The results showed that the metre-scale modelling significantly underestimated carbonate mineralisation. In comparison, the centimetre-scale modelling showed carbon mineralisation predictions that were six orders of magnitude higher, and that had excellent agreement with field measurements. In particular, it was the inclusion of detailed lithological heterogeneity – such as thin siltstone and mudstone layers known as “intratidal baffles” – owing to the fine-scale resolution that allowed the more accurate and significantly higher estimates of carbon storage to be assessed.

The research team ran both metre- and centimetre-scale fluid–rock reaction simulations of a 630m long geological transect through the Paaratta Formation in the Otway Basin of Victoria, Australia. The site was chosen, in part, because it contains a large area of 150,000 km² and has a maximum thickness of 80m, first formed during rifting between Australia and Antarctica. This site was chosen, in part, because it offers a natural analogue (in this case, well-characterised natural CO₂ mineralisation) for which high-resolution data are available and can be used to validate simulation outcomes. The simulation results were compared with data from the Paaratta Formation, a natural CO₂ storage area in the same basin that shares a similar mineralogical composition and sedimentary strata. The Paaratta Formation is a sandstone reservoir containing 0.5–1cm thin lenses of low-porosity, low-permeability siltstones, which are similar to laminations observed in cores from the Paaratta Formation. The Paaratta Formation underwent extensive Palaeozoic carboniferous to Permian deposition, and the site was created during the Permian period by subduction and rifting between Australia and Antarctica. The site was chosen in part to validate simulation outcomes. The results showed that the metre-scale simulations are vital for estimating CO₂ storage capacities.

The team also applied their approach to modelling the flow of CO₂ through the subsurface, which is critical for carbon sequestration applications. They found that small-scale heterogeneities of the site were a major controlling factor in the behaviour of a CO₂ plume during the injection stage. In particular, fine-scale changes in the orientation of the reservoir strata had significant impacts on the shape and buoyancy-driven migration of the CO₂ plume. Further studies are planned to better understand the plume behaviour in the post-injection stage, although this will require even more computational complexity.

The innovative work of Mishra, Haase, and their research team offers the opportunity to revolutionise geological modelling, particularly in sedimentary environments. In turn, this will facilitate the more effective and efficient use of Earth’s natural resources, and allow us to better harness new and exiting technologies with the potential to address major climate-related challenges facing humanity.

References


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Behind the Research

The researchers developed a new approach for high-resolution geological modelling.

Research Objectives

To improve the prediction of CO₂ migration in the subsurface, it offers a rare natural analogue (in this case, well-characterised natural CO₂ mineralisation) for which high-resolution data are available and can be used to validate simulation outcomes. The approach has not been applied in an operational setting to-date. However, we are in the process of transitioning our workflow to a user-friendly software tool which can then be made available to researchers in the industry and academia. This would enhance the application of the workflow to geological modelling projects. The tool should be ready in a year’s time.