Multiscale analysis of geo-reservoirs-- correlating pore scale information to reservoir scale inputs

M Knackstedt*[1], A. Herring[1], L. Deakin[1], M Saadatfar[1], R.M. Sok[1], L. Ruspini[2] and P.E. Øren[1,2]
[1] Australian National University, Canberra ACT 0200 Australia
[2] Petricore Norway, Trondheim, Norway

Keywords: x-ray tomography, multiscale imaging, geological sequestration, predictive modelling

Summary: We describe the development of a multiscale 3D imaging and modelling workflow which offers improved predictions of CO_2 storage in geological media. The workflow is based on multiscale 3D imaging calibrated with laboratory and experimental probe analysis at multiple scales. The work illustrates the importance of incorporating small (micron) scale geological heterogeneity when modelling multiphase flow at >meter scales.

1. INTRODUCTION

Carbon capture and storage (**CCS**) is the process of capturing waste carbon dioxide (CO_2) from large point sources, such as biomass or fossil fuel power plants, transporting it to a storage site, and depositing it where it will not enter the atmosphere-- into an underground geological formation [1]. Carbon capture and storage (CCS) is critical for meeting international climate change targets and deployment must therefore be both rapid and global. CCS demonstration projects require accurate predictions of the extent of CO_2 plume movement within the storage complex. Confidence in CCS can be further developed by the successful comparison of an injected plume with the forward modelling of the plume distribution (e.g., accurate prediction of the spatial extent and assurances of no leakage). A central part of the modelling process is the construction of realistic numerical models of rock and dynamic flow properties at a wide range of scales. The outcomes from the large scale simulations form the basis of plume model predictions critical for the public and government trust in CCS and consequential for optimal planning of the storage development (e.g. well placement, depth of injection, storage capacity estimation).

Accurate predictions of plume movement require reservoir (up to kilometer) scale models that capture geological heterogeneities and that are populated with representative multiphase flow properties. Laboratory measurements are limited to sample sizes of <10 cm. In this program we use 3D and 4D CT imaging experiments, advanced image registration and multiphase modeling methods to build a calibrated multistep method to gain greater confidence in relevant static and multiphase flow predictions in core material for two CCS projects.

2. METHODS

The multistep methodology is outlined below:

- *Imaging*—We utilise improved industrial scale x-ray CT acquisition to provide a quantitative bridge from pore scale imaging and plug scale measurements to meter scale core. Smaller samples are also imaged at micron scale to characterise pore structure at the highest resolution. The images at different scales are correlated to enable one to incorporate critical fine scale information at larger scales.
- *Classification*—at each scale a novel morphological description of the 3D image data is used in a clustering analysis to identify the distribution of rock types. This data can be used to locate representative volumes of multiple rock types. Classification at the coarsest (whole core) scale assists in sample selection for experimental measurement or imaging at higher resolution. The process can be repeated at descending scales until the elementary pore structures (individual pores/grains) are captured in 3D.
- *Calibration of single phase flow properties*-- probe the hydraulic conductivity at the millimetre scale along >50 m of continuous slabbed rock surfaces. Anchor the measured values to values predicted from the 3D digital rock modelling. Propagate flow property predictions to similar rock types and QC the static property predictions at the meter scale.
- *Calibration of Dynamic Properties*— undertake experimental 3D pore scale SCAL imaging studies on plugs acquired from core samples and image drainage and imbibition at aquifer conditions using time-lapse 3D CT imaging.
- *Calibration of multiphase flow models*-- generate anchored multiphase flow data for important reservoir rock types including the prediction of the extent of CO_2 trapping at different depths and the movement of fluids with time. Provide QC of the models on a pore-by-pore basis.
- *Populate/Propagate*—populate properties at a larger scale. Property measurements and saturation dependent properties derived from digital or laboratory data at small scales are propagated along the continuous core material (up to 100m).
- *Upscaling*—extend measurements of static and dynamic properties to the whole core scale-- illustrate the impact of small-scale geological heterogeneity on the static and dynamic rock properties along meter scale lengths of core material.

3. RESULTS

The workflow is shown schematically in Fig. 1. Key results from the research program include:

- **Continuous core scanning** along >10 meters is acquired at resolutions of 25 microns. This enables one to clearly observe subtle changes in pore structure at the sub-mm scales along continuous lengths of whole core material. Along 40 m of rock we observe over 1000 transitions between different rock lithofacies or types. One can correlate high resolution image data directly to coarse scale information along the full length of core and generate property maps at discrete points.
- **A tool is developed to rapidly classify rock types** and identify geological boundaries in 3D space in tomographic data. We test the ability to propagate property measurements at discrete points to the full length of core with good agreement.
- **Supercritical CO_2/Brine flooding** at reservoir P/T has been built and tested. Direct, three-dimensional pore-scale experimental imaging of drainage and imbibition in rock core using x-ray microCT is undertaken. The direct visualisation of the distribution of fluids is used to validate pore scale modelling and to build an understanding of the impact of heterogeneity in upscaling.
- **A pore-scale model for multiphase flow** can generate representative curves for multiphase flow properties at the plug scale. The model results are directly compared with experimental measurements and show a match between >90% of the displacements defined at a pore scale. The illustrates the predictive capability of the models. This adds a further tool of calibration as we upscale flow solvers to larger scales.
- **The impact of geological heterogeneity** on dynamic properties is illustrated. We find that upscaled data for multiphase flow properties need not lie within the envelope of the master curves for individual rock types. This will greatly impact on the upscaled equivalent flow properties used in a reservoir model, and ultimately impact the predictions of global flow and plume movement at large scales.

References

[1] P. S. Ringrose, A. S. Mathieson, et al., *Energy Procedia*, 37, 6226-6236, 2013.

Acknowledgement

The authors wish to acknowledge financial assistance provided through Australian National Low Emissions Coal Research and Development (ANLEC R&D). ANLEC R&D is supported by Australian Coal Association Low Emissions Technology Limited and the Australian Government through the Clean Energy Initiative

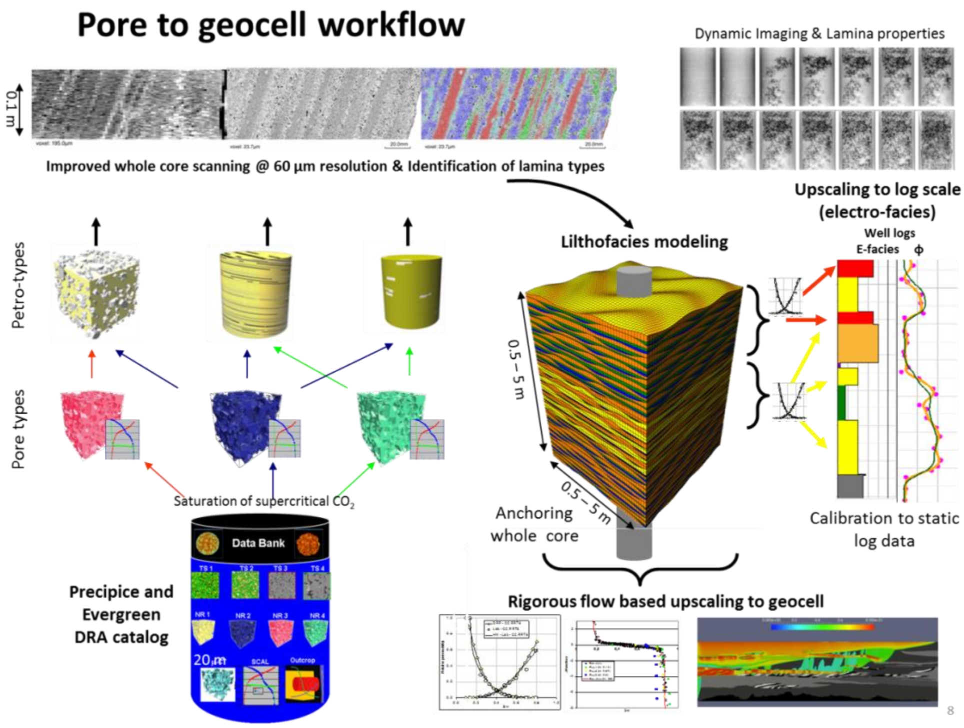

Figure 1: Multiscale flooding dynamics workflow. The scales span from pore scale to whole core and towards reservoir modelling input scales

*e-mail: mark.knackstedt@anu.edu.au