AAPG/SEG/SPE HEDBERG CONFERENCE
"GEOLOGICAL CARBON SEQUESTRATION: PREDICTION AND VERIFICATION"
AUGUST 16-19, 2009 – VANCOUVER, BC, CANADA

A Workflow for Storage Site Characterisation: A Case Study from the CO2CRC Otway Project

Tess Dance
CO2CRC/CSIRO Petroleum, Kensington, Western Australia, Australia

Introduction

The development of acknowledged procedures for the selection and characterisation of CO2 storage sites has been the topic of many national and intergovernmental studies aiming to establish a consistent approach around the world [1]. While it will be problematic to employ a prescriptive approach for all storage sites, regulators are aiming to identify a common practice and inform a set of recommendations and guidelines necessary for large scale commercial projects. Reservoir characterisation is not a new science, drawing on tried and tested practices such as sequence stratigraphy, advanced geophysical mapping, formation evaluation, engineering and Modelling, long used in the oil and gas industry. Understanding subsurface fluid behaviour at a CO2 storage site will use the same methods but place a particular emphasis on characterizing injectivity, effects of vertical permeability, large scale hydrodynamics, geochemical interactions and long term containment. In the case of saline aquifer storage, it may be challenging as these characteristics must be addressed over large areas often with very little data available. A few significant research papers have laid the foundations for site selection methodology. [2-4]. Similarly, a few case studies have fully documented their workflows in the public domain as "best Practice" site characterisation for CO2 storage sites [5]. All advocate a mulitidiciplinary approach bringing together available data in order to identify potential risks. This in turn identifies where more data needs to be gathered in order to reduce uncertainties. When this is not practical, characterisation will depend heavily on analogues and multi-case scenario modelling to perform sensitivity analysis and provide ranges rather than a definitive answer to questions surrounding injection rates, migration times, total capacity, and trapping.

As may be observed from the few Carbon Capture and Storage (CCS) projects either underway, or proposed, site characterisation, in a risk management framework, is undeniably site and project specific. The level of characterisation needs to be risk appropriate, as well as source and sink appropriate. What defines an adequate or "fit for purpose" site assessment will become evident as more and more practical examples can be examined. The case study presented herein, describes a basic workflow for a small scale storage project where the intrinsic uncertainties in reservoir heterogeneity were addressed by a series of geo-cellular models.

The CO2CRC Otway Project Phase2: Storage in a Saline Formation.

Australia's first Carbon Dioxide sequestration pilot project is currently underway in the Otway Basin, Victoria. The CO2CRC has been injecting CO2 into an onshore depleted natural gas reservoir, the Naylor field, since March of 2008 as part of Phase 1 of the project, which aims to demonstrate the viability of geological storage of CO_2 and various monitoring techniques to verify containment. As part of Phase 2, the Otway Project intends to extend research objectives to understanding of non-structural trapping mechanisms for storage in heterogeneous saline aquifers. Using the same source as Phase 1, up to 10,000 tonnes of CO2-rich gas (80 mol% carbon dioxide; 20 mol% methane) will be produced from the Buttress field. It is then dried, compressed, and transported along the existing 2km pipeline to the site for injection via a new injection well. Rather than injecting into the same depleted gas field, the target this time is an unconfined saline aquifer in the upper part of the Late Cretaceous Sherbrook Group sediments within the Paaratte Formation, approximately 700 metres above the current injection interval (the Waarre C Formation). Injection tests and time lapse monitoring will be used to better understand the influence of relative permeability hysteresis, fluid mixing, and gas-rock interactions on CO_2 storage in a heterogeneous reservoir environment. Remote imaging of the plume, using surface seismic methods, will be increased due to the absence of residual hydrocarbons in this formation.

The primary objective of the characterisation and modelling is to determine the optimal location for the new well. The Paaratte formation itself is over 400m thick, comprising a succession of interbedded fine-to-coarse-grained quartz sandstones (potential reservoirs) and carbonaceous mudstones (potential seals). 4 key intra-formational reservoir/seal pair intervals, each with varying potential for CO_2 storage, were investigated. Effects of reservoir dip, location of faults, hydrodynamic communication, vertical permeability, sand body anisotropy and geometry were evaluated using all available data on both a regional and local scale.

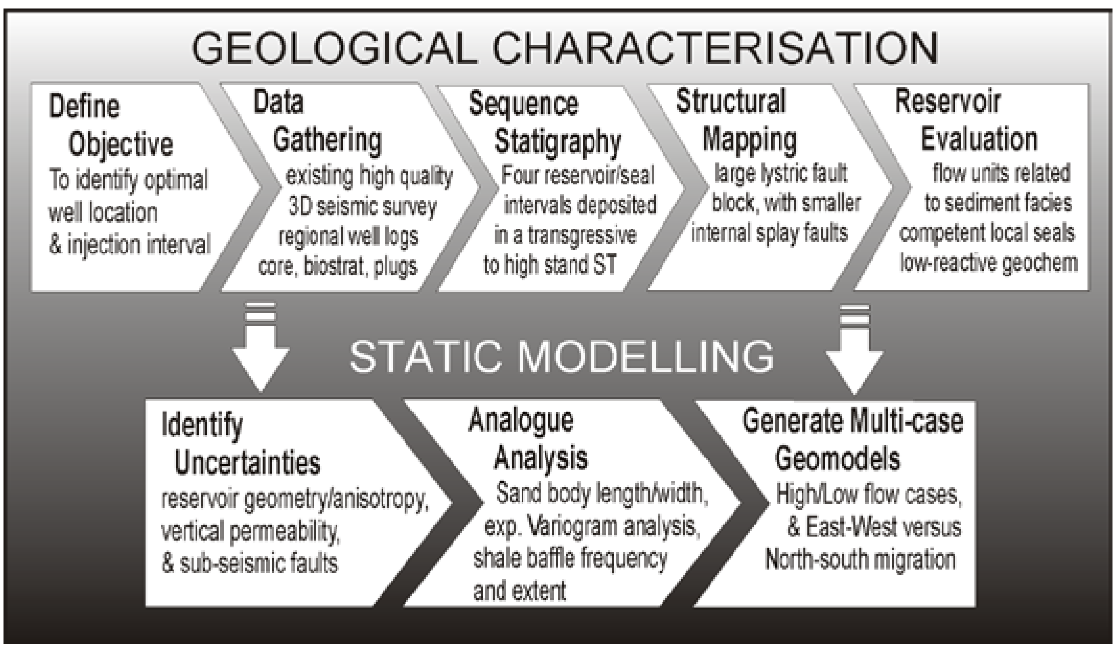

Figure1: Workflow for characterisation and modelling of the Paaratte Formation.

Data

Regional: Whilst 42 petroleum wells were drilled in the onshore Port Campbell region of the Otway Basin, very few have relevant information about the Paaratte as the Waarre C was the target of exploration. Four older wells (1960s vintage) have standard and side-wall core samples and log evaluations in the Paaratte Formation, but generally, the only data available are standard well logs (including GR, SP and sonic logs) and well cuttings samples.

Local: Over the Naylor field there exists an extensive and high quality 3D seismic volume, as well as the newly acquired 3D base-line survey as part of the phase 1 monitoring. In addition are walk-away zero offset VSPs and a 3D VSP. Data from the phase 1 injection well ("CRC-1") has provided 8 metres of core from the Paaratte, MDTs (Modular formation Dynamics Tester), fluid samples, pressure, temperature and additional high resolution wire-line logs including CMR, NMR, and Formation Micro-Imaging.

Sequence Stratigraphy

Defined by the biostratigraphic scheme of Partridge (2001), the Paaratte grades from the pro-deltaic deposits of the Skull Creek Mudstone and is directly overlain by the fluvial Timboon Sandstone, a relatively fresh water aquifer [6]. Deposited in the Campanian to early Maastrichtian (80-72 Ma BP), it comprises two major sequences: a low stand mostly fluvial deposit overlain by a transgressive sequence of shallow marine mudstone followed by a thick (~350m) sequence of stacked deltaic sandstones and mudstones deposited in a prograding deltaic environment during a high stand system [7]. On a local scale, these sequence boundaries can be correlated on well logs with confidence as well as several well defined Para sequence boundaries that mark 4 key reservoir seal pairs (8 zones).

Hydrodynamics

A hydrodynamic interpretation of the formation pressure measurements was conducted by Hennig (2007) to determine the vertical hydraulic relationship within and between the reservoir and seal units [8]. Results suggest that overall the Paaratte formation and overlying aquifers are in regional pressure communication, however, the shale units are locally inhibiting vertical pressure equilibration and hence flow. This implies that the proposed volume of injected CO2 will encounter significant barriers to vertical migration and will be contained within the Paaratte formation. This conclusion supported by capillary pressure measurements conducted using an air-mercury capillary pressure apparatus (MICP) on shale samples that calculated intra formational shales could hold a CO2 column height up to a 200m [9].

Geophysical Mapping:

The structure, faults, and stratigraphy were mapped in detail on the 3D seismic. This defined the top and base of the reservoirs and formed the basis of a full earth geomechanical model. Modelling was used to establish well ties and conduct depth conversion uncertainty analysis. Attribute mapping provided useful insight into stratigraphic features and depositional trends. The proposed site is located within a large half graben bound by a major lystric fault with a minor synthetic splay fault to the south. Faulting is predominantly east-west. Stratigraphic dip is very gentle (less than 4 degrees) with an inferred CO2 migration direction to the east.

Formation Evaluation

Geochemistry and petrography characterised the mineral facies including mineral composition and pore size distribution [10]. CO2-induced digenetic products within the sandstone units of the Paaratte Formation are expected to be minor due to the absence of cations suitable for mineral trapping of CO2. Storage capacity (porosity) and injectivity potential (permeability) were evaluated from log and core data. Reservoir quality is considered good with average porosity 25-30% and permeability (from logs and MDT) up to several Darcy. SCAL (Special Core Analysis) was carried out to test for capillary pressure, relative permeability and displacement characteristics of CO_2-brine systems. Coreflood experiments under reservoir pressure were used to determine relative permeability for CO_2 displacing water (drainage) and water displacing CO_2 (imbibition).

Design of the Static Models

Vertical variogram analysis using the existing well information indicates the Paaratte Formation is highly heterogeneous with stacked shale and sand bedding in the order of 1-3 metres thick. Small scale shale lamina, ripples, and bioturbation structures are also expected to influence CO2 movement. Models were designed to capture fine vertical heterogeneity <1m resolution. Layering of the grid was designed reflect the prograding (down lap) nature of the formation and cells were aligned with structural dip. High and Low flow scenarios were created using high and low estimates for permeability, net to gross, connectivity and dip. Analogue studies were fundamental for estimating sand body and baffle dimensions used in the modelling. Azimuthal variations (e.g. east-west versus north-south) for depositional trends were also investigated to test the impacts on plume migration.

References

[1] Aarnesa J.E., Selmer-Olsena S., Carpentera M. E., and Todd A. Flacha, 2009. Towards guidelines for selection, characterisation and qualification of sites and projects for geological storage of CO2.

[2] Bachu, S, 2003. Screening and ranking of sedimentary basins for sequestration of CO_2 in geological media in response to climate change. *Environmental Geology*, vol. 44, pp. 277-289.

[3] Gibson-Poole, C M, Root, R S, Lang, S C, Streit, J E, Hennig, A L, Otto, C J and Underschultz, J R, 2005. Conducting comprehensive analyses of potential sites for geological CO_2 storage. *In*: E S Rubin, D W Keith & C F Gilboy (eds.) *Greenhouse Gas Control Technologies: Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies*, Volume I - Peer Reviewed Papers and Overviews, 5-9 September 2004, Vancouver, Canada. Elsevier, Oxford, pp. 673-681

[4] Cook, P J, 2006. Site Characterization. *In*: *International Symposium on Site Characterization for CO_2 Geological Storage*, 20-22 March 2006, Berkeley, California, USA. Lawrence Berkeley National Laboratory (LBNL), pp. 3-5.

[5] Chadwick A., Arts R., Bernstone C., May F., Thibeau S., and Zweigel P. (Eds.), Best practice for the storage of CO2 in saline aquifers, in: Observations and Guidelines from the SACS and CO2STORE Projects, 2007.

[6] Partridge A.D., 2001. Revised stratigraphy of the Sherbrook Group, Otway Basin. In: Hill KC, Bernecker T, editors, PESA Eastern Australasian Basins Symposium, p.455-464.

[7] Faulkner A., 2000. Sequence stratigraphy of the late Cretaceous Sherbrook Group, Shipwreck Trough, Otway Basin; B.Sc. (Hon) Thesis, National Centre for Petroleum Geology and Geophysics, University of Adelaide.

[8] Hennig A., 2007. Hydrodynamic interpretation of the formation pressures in CRC-1: Vertical and horizontal hydraulic communication. Cooperative Research Centre for Greenhouse Gas Technologies, Canberra. Co2CRC Report Number RPT07-0626.

[9] Daniel, R.F., Carbon Dioxide Seal Capacity Study, CRC-1, CO2CRC Otway Project, Otway Basin, Victoria. CO2CRC Report No: RPT07-0629**,** August 2007, 67pp.

[10] Schacht, U., 2008. Petrological Investigations of CRC-1 Core Plug Samples: Waarre C, Flaxman, and Paaratte Formation. CO2CRC internal report July, 2008.