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ScienceDirect

Energy Procedia 154 (2018) 145–150

Energy Procedia

www.elsevier.com/locate/procedia

Applied Energy Symposium and Forum, Carbon Capture, Utilization and Storage, CCUS 2018, 27–29 June 2018, Perth, Australia

The CO2CRC Otway shallow CO_2 controlled release experiment: Preparation for Phase 2

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Abstract

CO2CRC and its partners are undertaking a feasibility study for a planned CO_2 controlled release and monitoring experiment on a shallow fault at the CO2CRC Otway Research Facility. In this project we plan to image, using a diverse range of geophysical and geochemical CO2 monitoring techniques, the migration of CO_2 up a fault from a controlled release point at approximately 30 m depth. This paper describes the results of site characterisation and modelling work undertaken to date. It also includes a description of the activities planned that will enable for a more detailed characterization of the fault and proposed injection interval. Together these results will enable an assessment as to whether the planned injection experiment is feasible and how it can be optimally designed.

Keywords: fault; carbon dioxide; greenhouse gas; migration; modelling; monitoring

10.1016/j.egypro.2018.11.024

1. Introduction

Faults are widespread geological features in the crust, and can play a significant role in any carbon storage project. However, surprisingly our present understanding of faults is often insufficient to accurately predict how they are likely to influence CO_2 migration, either inhibiting or enhancing migration. In a 2016 review by the International Energy Agency Greenhouse Gas Research and Development Programme (IEAGHG), it was recommended that generic fault fluid-flow models be tested against in-situ CO_2 flow measurements in order to increase confidence in modelling predictions and establish guidelines for the inclusion of faults in geological storage risk assessments [1]. There is presently little empirical data to validate fault models against.

The CO2CRC and its partners are undertaking a feasibility study for a planned CO_2 controlled release and monitoring experiment on a shallow fault at the CO2CRC Otway Research Facility. In this project we plan to image, using a diverse range of geophysical and geochemical CO_2 monitoring techniques, the migration of CO_2 up a fault from a controlled release point at approximately 30 m depth. This will enable us to track where and how fast the CO2 migrates, and measure its geochemical impact on groundwater and soil. CO2CRC and its partners plan to model CO_2 migration in a strike-slip fault by targeting the injection at dilational bends and jogs in the fault as these are likely to be high permeability zones based on fault theory and observations from the mineral and oil and gas sectors. As part of the experiment, it is also planned to test predictions of CO_2 migration behaviour in the transition zone between saturated and unsaturated soil/rock. This behaviour is not well understood but is important for establishing an understanding of where CO_2 is likely to migrate in the near surface and for designing effective monitoring strategies.

2. Phase 1

In Phase 1 of the project (2016-2017), a series of geophysical surveys and groundwater permeability assessments were conducted at the Otway Research Facility to ascertain whether a shallow fault at the site was present [2,3]. The data from the surveys have been integrated into a 3D model of the upper faulted shallow geology of the CO2CRC Otway site. Based on this data, five key model properties (hydrostratigraphic unit, horizontal permeability, vertical permeability, fault permeability and P-velocity from refraction tomography) were populated in the 3D grid to produce the final static model. The model has been developed to assist with designing the experiment and conceptualising the shallow stratigraphy of the Otway site.

Based on the data collected to date, the shallow geology of the CO2CRC Otway study area can be described by three sequences [4]:

1. The uppermost relatively thin but clay-rich and impermeable Pliocene Hanson Plain Sand (3-5m thick);
2. The stratified and karstified Miocene Port Campbell Limestone, with wide ranging permeability depending on the depositional facies (121m thick); and
3. The comparatively impermeable and homogeneous Miocene Gellibrand Marl (335m thick).

Multiple depositional cycles have been interpreted within the Port Campbell Limestone sequence and, within each cycle, permeability is highly variable, ranging from marly carbonate of poor permeability to an uppermost porous and permeable bioclastic grainstone interval. The top of the Port Campbell Limestone is regarded as a significant unconformity with karst development and an accumulation of a residual iron rich regolith. The water table within the Port Campbell Limestone appears to lie just below the base of the Hanson Plain Sand creating an uppermost unsaturated zone. Locally this unsaturated zone may be absent due to the irregular base of the overlying impermeable Hanson Plain Sand. The presence or absence of an unsaturated zone beneath the clay layer at the field site will strongly influence CO_2 migration behaviour during the planned injection experiment and this is the subject of ongoing characterisation.

The high resolution seismic data clearly showed the presence of a shallow fault [3]. This newly-identified shallow Brumbys Fault disrupts the sequence below the Hanson Plain Sand and appears to extend to the base of the Gellibrand Marl. Although Brumbys Fault does have a small vertical offset (~4.5m downthrown to the east), the fault is interpreted to have a predominantly strike-slip component because it is very steeply dipping and has a strike that is approximately 30° to the local maximum horizontal stress direction [5,6]. The seismic reflection and refraction imagery define linear features and associated broader zones of lower P-wave velocity (Vp) that are oriented approximately parallel to the maximum horizontal stress. These are interpreted to be dilatant cracking and joint sets that have facilitated carbonate dissolution, enhancing permeability and porosity in the limestone sequence, as well as surface development of karst. Surface swales can be observed perpendicular to this trend and these may have been influenced by deposition or erosion processes aligning with folds that formed in advance of, or during fault formation. Such en-echelon fold sets are known to be associated with strike-slip faults. The contemporary stress regime has had a large influence on the orientation of newly-formed faults and also on the reactivation of previously existing faults [6]. Shallower rocks such as the Port Campbell Limestone would be expected to reflect the regional strike-slip faulting regime. Brumbys Fault is not uniformly linear, but rather possesses some bends and dilational jogs that are likely to be high strain zones. These may be of higher permeability and are the target of the planned CO_2 injection experiment.

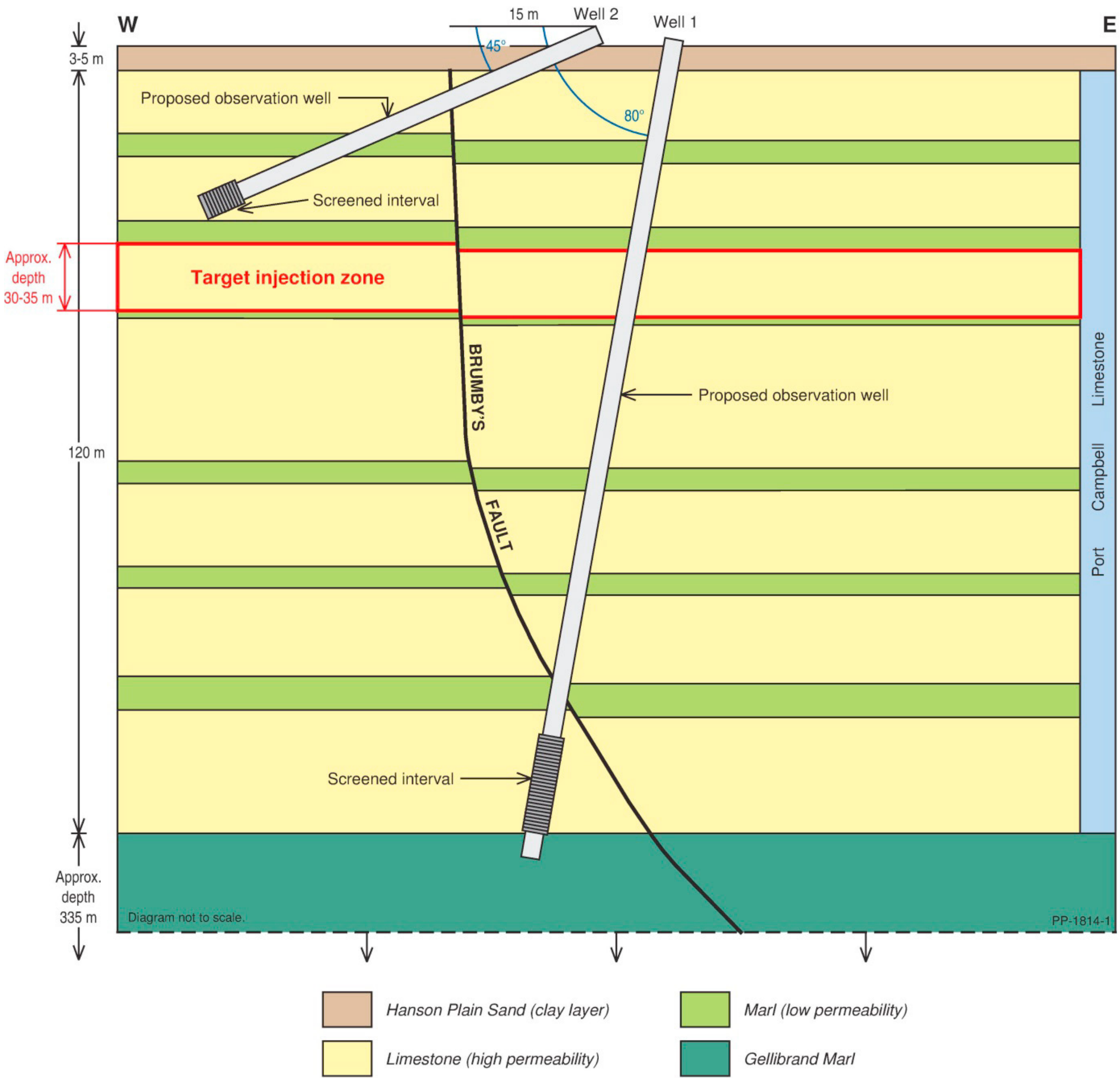

Fig. 1. Schematic illustration showing shallow stratigraphy below the CO2CRC Otway Research Facility, Brumbys Fault, and the proposed location of the groundwater observation wells. Well 1 will be equipped with a hydrid geophone- fibre optic cable and Well 2 will be equipped with dual fibre optic cables for distributed temperature sensing (DTS) measurements.

3. Planned Phase 2 Operations Program

3.1. Groundwater observation wells and core analysis

Phase 2 of the project will involve undertaking a more detailed characterisation of the site and fault. While the site appears suitable for the planned controlled release experiment, there is no core available for the Port Campbell Limestone to validate the 3D model against. In addition, the high resolution seismic can only image the fault to within 25m of the ground surface. It is presently unknown whether Brumbys Fault extends to the base of the clay layer and this is a significant gap in knowledge for the planned controlled release experiment.

The plan is to drill two inclined appraisal wells through the Brumbys Fault (Fig. 1), collect core, and undertake extensive wireline logging of the wells. Well 1, which will be near vertical (10° from vertical), will be cored through the entire Port Campbell Limestone and partially into the Gellibrand Marl. Its function is primarily as a stratigraphic well, to optimise drilling procedures and core recovery techniques, and enable installation of a hydrid geophone – fibre optic cable on the outside of the well casing. Well 1 will be orientated to target a suspected lower permeability section of the fault at approximately 100m depth (Fig. 2).

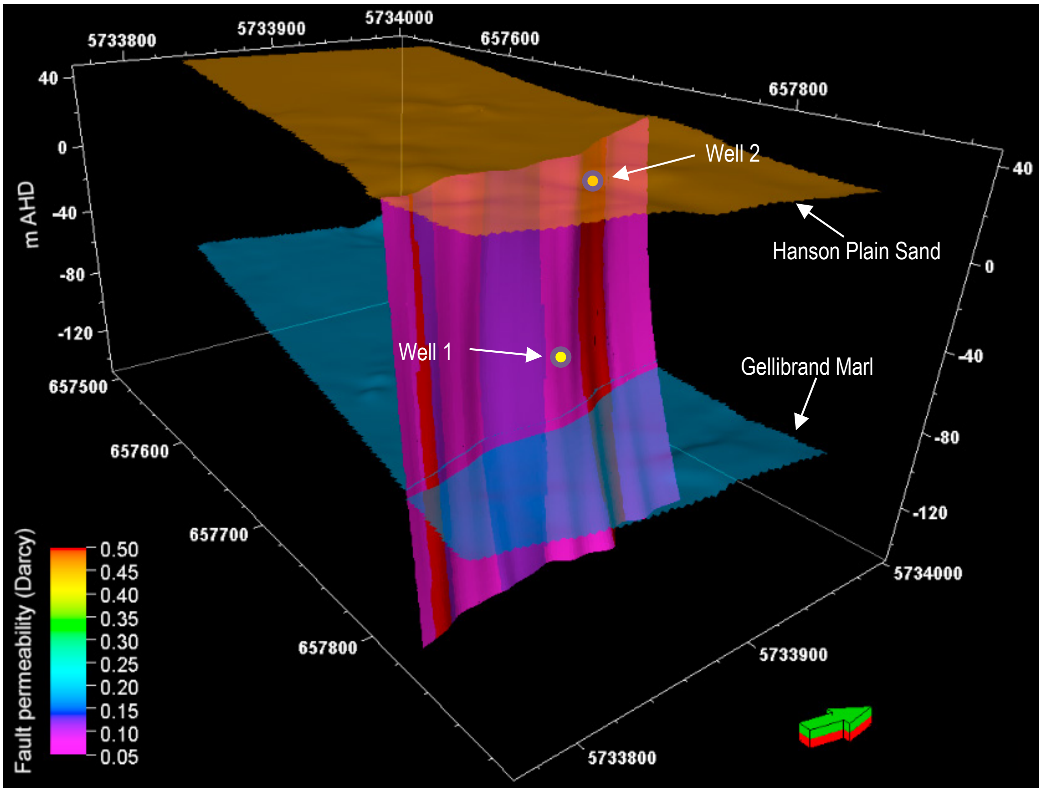

Fig. 2: Inferred variations in fault permeability on the modelled Brumby Fault surface, caused by alternating tight and dilational segments created with sinistral strike slip movement [4]. The planned fault intersection points for the proposed groundwater observation wells are shown (Well 1 = tight; Well 2 = dilated). XY coordinates are in metres.

Well 2 will be highly deviated and will be cored through the fault at 45° near the surface. The purpose of this well is to collect core from the suspected high permeability section of the fault (Figure 2), to determine the width of the fault and damage zone, ascertain whether the fault does extend towards to the surface, and to equip the well with dual fibre-optic cables for future Distributed Temperature Sensing (DTS) monitoring. Both wells will collect core through the fault enabling tie points for the fault model developed from the seismic data. It is planned to drill both wells using a combination of diamond and sonic drilling, optimized for core integrity and material recovery. Core from both wells will undergo extensive mineral and physical characterisation, which will enable estimation of the impact of CO_2 injection on groundwater chemistry and provide analytical porosity, permeability and capillary pressure data for modelling the CO_2 injection.

3.2. Piezometer array

The current nature of the shallow groundwater system at the Otway site is unclear. Analysis of groundwater levels during Phase 1 of this project suggested there may be a dual aquifer system, with groundwater in the upper clay layer (Hanson Plain Sand) separated from the lower Port Campbell Limestone aquifer. It is planned to install an array of shallow groundwater piezometers to accurately measure the groundwater levels across the site and determine whether there is soil gas beneath the clay layer. Four pairs of shallow piezometers (completed in clay layer and Port Campbell Limestone) would be located at the perimeter of the research area.

3.3. VSP survey

A vertical seismic profile (VSP) survey is planned for Well 1. The shallow VSP survey aims to provide an accurate velocity model of the near surface formations that will be used to complement processing of the surface seismic and the overall understanding of the geological model of the research area. The 3D VSP survey will be conducted using two sets of seismic receivers: 1) a hybrid cable housing fibre optic cores and hydrophones cemented behind the casing of the well; and 2) a string of 24 hydrophones deployed inside the bore. Acquiring data with various sensors (fibre optic and hydrophones) will enable a comparative feasibility study of application of different seismic technologies for shallow borehole monitoring.

3.4. Soil gas and soil flux survey

A high-density soil gas and soil flux survey will be conducted across Brumbys Fault to establish a baseline of in-situ conditions around the area above the fault. The survey will collect gas samples for baseline noble gas and isotopic analysis. A soil flux survey will be conducted to obtain background measurements of CO_2 flux across the fault to establish the existing condition of the area above the fault.

4. Phase 2 Analysis and Modelling

The information obtained for Phase 2 will be essential for correctly calibrating the 3D static model of the planned experimental site (i.e. stratigraphy, permeability, porosity). Coring provides material for rock strength testing, geomechanical analysis, CO_2-water-rock dissolution experiments and enables characterisation of the fault properties. With this additional data, more informed modelling simulations could be performed to optimize the location of the injection well and the required CO_2 injection rate and pressure. Dynamic CO_2 simulation efforts to date [7] suggest that, depending on the permeability of the fault and injection facies, CO_2 could be expected to migrate up the fault to the base of the clay layer, but better data on the maximum injection pressure and the permeability distribution in the near-surface region (including the continuity of the clay layer) is needed. Phase 2 is designed to enable collection of essential data from the Port Campbell Limestone and Hansen Plain Sand, including the key unknown parameters listed below:

- Rock strength, which will be used to determine the maximum and safe injection pressure for the experiment.

- Formation and fault permeability, which will enable modelling (+ max injection pressure) to estimate the total volume of CO_2 that can be safely injected.
- Mineralogy, which will enable modelling to estimate the extent of impact on groundwater chemistry.
- Relative permeability through special core analysis (SCAL), which determines the effective permeability of the water and gas phases to allow more accurate modelling of gas and water flow.
- Capillary pressure measurements (using a mercury injection capillary porosimeter, MICP), which determines the minimum pressure required to initiate gas flow through water bearing layers.

With these properties measured, an improved modelling assessment can be conducted which can be then used to estimate the quantity of CO_2 required for the experiment, the likelihood of CO_2 migration up the fault, and its impact on the Port Campbell Limestone aquifer. It will also enable improved design of the layout of the injection experiment and its monitoring program.

5. Future injection experiment (Phase 3)

Depending on the findings from Phase 2 and the modelling simulations, an assessment will be made as to whether the planned injection experiment is feasible. Early modelling results suggest that the size of the injection would be in the order of 10s of tonnes of CO_2 but this will be confirmed during Phase 2. If the experiment does proceed, the CO_2 injection is likely to take place over a period of weeks. The CO_2 migration behaviour would be monitored and imaged using a variety of geophysical and geochemical techniques (to be defined as part of Phase 3). It is envisaged that this will result in a rich dataset that could be used to validate and improve geomechanical and fluid flow fault modelling predictions.

Acknowledgements

We thank the CO2CRC and their corporate sponsors for supporting this project. A. Feitz, A. Kalinowski and E. Tenthorey publish this paper with the permission of the Chief Executive Officer, Geoscience Australia.

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