# NSW $CO_2$ Storage Assessment Program

## Final Report on Stage 1B - Darling Basin Drilling Program


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Cover Image: Aerial shot of Tiltagoonah-1 site

# Abstract

The NSW Government undertook a drilling program in the Darling Basin as fulfilment of Stage 1B of the NSW $CO_2$ Storage Assessment Program aimed at filling gaps in knowledge of the deeper geology of the NSW sedimentary basins, assessing the $CO_2$ geological storage potential of these basins, and at shedding light on the reservoir and sealing characteristics of these strata. The geothermal potential of the Darling Basin was also explored as part of the program. The NSW $CO_2$ Storage Assessment Program is broadly equally co-funded by the New South Wales Government, Geoscience Australia on behalf of Commonwealth Government, and the Australia Coal Association Low Emissions Technology Ltd (ACALET).

Two holes, Tiltagoonah-1 and Mena Murtee 1, were drilled in the Nelyambo and Pondie Range Troughs respectively, within the greater Darling Basin area. Both holes were lithologically and geophysically logged and were subjected to well tests. Conventional and sidewall cores were also acquired from each well, with extensive laboratory analyses performed. The new and existing data underpinned collaborative work programs with the CO2CRC, CSIRO, and ANLEC R&D, instigated to increase understanding of the geological storage potential and geothermal potential of the regions explored in the drilling campaign.

Results from Tiltagoonah-1 indicate that the sandstone units intersected lacked porosity and permeability and hence were unsuitable for $CO_2$ storage. The Mena Murtee-1 results were positive with several sandstone and sealing units identified as having porosity and permeability suitable for $CO_2$ storage. Additional wells are required to define the extent of the potential storage areas and to evaluate the Pondie Range Trough for large-scale $CO_2$ storage. This discovery highlights the storage potential of the Darling Basin and provides reasonable justification for the expansion of an exploration program within the Pondie Range Trough and also in other underexplored areas in the Darling Basin.

Stage 1B in the Darling Basin achieved its aims and objectives. In addition to providing new information on the geology and storage potential of the Nelyambo and Pondie Range Troughs, an enhanced understanding of the geology of the Darling Basin has been gained, and a large volume of subsurface data and drill core (114.39 m) acquired. These data and cores are now available for continued assessment and study by government agencies, academia and industry involved in carbon capture and storage and mineral/petroleum exploration activities. Concomitantly, key learnings were acquired that will assist in enhancing the outcomes of further exploration required to ascertain the storage potential of the Darling Basin as part of planned Stage 2 of the NSW $CO_2$ Storage Assessment Program.

# Table of Contents

# List of Figures



# List of Tables

# Executive Summary

The NSW Government is committed to reducing greenhouse gas emissions from current and future electricity generation by way of supporting research and development of low emission coal technologies including carbon capture and storage (CCS). Integral to any conventional CCS project is the ability to store carbon dioxide ($CO_2$) in geological formations permanently. Compared to most Australian states the deep sedimentary basins of NSW are virtually unexplored and the little data available indicate there is $CO_2$ storage potential in a number of the major sedimentary basins in NSW.

To fill this knowledge gap, the Division of Resources & Energy (DRE) within the NSW Department of Trade and Investment, Regional Infrastructure and Services (DTIRIS) is undertaking an initial phase of geological assessment of deep sedimentary basins within NSW through a program titled the NSW $CO_2$ Storage Assessment Program. The program aims to undertake a state wide assessment of potential storage opportunities and prepare pre-competitive data associated with future acreage releases. The NSW $CO_2$ Storage Assessment Program is broadly equally co-funded by the New South Wales Government, Geoscience Australia on behalf of Commonwealth Government, and ACALET.

A combination of stratigraphic drilling and 2D seismic surveys were used in the NSW $CO_2$ Storage Assessment Program to obtain information on the prospectivity of sedimentary units as suitable for $CO_2$ sequestration. Seismic surveys were used to evaluate the well locations and provide a seismo-stratigraphic correlation tool that can be linked to drilling information to produce a more robust geological model of the area.

Having commenced in 2008, the NSW DRE has thus far drilled four stratigraphic wells in the Sydney Basin and two wells in the Darling Basin, both of which were identified as national priorities for pre-competitive exploration by the Carbon Storage Taskforce (2009). The well programs were based on a need to fill knowledge gaps in storage suitability close to major emissions sources in the Sydney Basin, and to identify the potential for large-scale $CO_2$ storage in the Darling Basin. Stage 1A in the Sydney Basin was completed in 2012, with the results indicating limited $CO_2$ storage prospectivity in the four sites investigated. Stage 1B drilling activities were undertaken in early 2014 with the aim of investigating the $CO_2$ storage potential and geothermal potential within the Nelyambo (Tiltagoonah-1 well) and Pondie Range (Mena Murtee-1 well) troughs in the northern half of the Darling Basin. Rather than comprehensively characterising each formation, a data acquisition program was designed for Stage 1B with the aim of providing data that will eventually support a pre-competitive assessment of the potential of each targeted geological formation to safely and securely store $CO_2$.

The bore holes were geophysically logged and selectively cored using side wall coring and either wireline or conventional coring techniques. The suite of downhole logs and tests conducted included: conventional and advanced geophysical logs, a well velocity survey, imaging, and Extended Leak Off Tests. Wireline formation tests were also conducted in permeable sandstone units identified through log interpretation. The downhole data were complemented by core data acquired through lithological logging, hylogging, routine core analysis, petrographic analysis, Mercury Injection Capillary Pressure tests (MICP) and relative permeability analyses. The substantial data and sample sets acquired from this exploration was sufficient to meet the needs of an initial geological interpretation of the near

well lithology, which included the identification of reservoir/seal pairs as prospective intervals for $CO_2$ geological storage.

Results from Tiltagoonah-1 indicated that the sandstones intersected were heavily silicified and lacked porosity and permeability, thereby rendering them unsuitable as a storage site for $CO_2$. In contrast, three sandstone units overlain by extensive claystone units were identified in Mena Murtee-1as prospective storage reservoirs for $CO_2$.

The existing offset well data along with seismic data and newly acquired data sets from Stage 1B exploration were used by collaborative researchers from the CO2CRC to undertake studies on the geological storage system characterisation, injection and plume migration modelling, geomechanical evaluation, and geochemical analysis and modelling. These studies provided some positive indications for large scale storage of $CO_2$ within the Darling Basin. The prospective intervals encountered in Mena Murtee-1 were identified through low resolution injectivity and capacity modelling to have suitable porosity and permeability for $CO_2$ storage. The CO2CRC concluded that the results acquired from the Pondie Range Trough provided reasonable justification for the expansion of an exploration program within this sub-basin and also in other underexplored areas of the Darling Basin.

Further collaborative research is also underway with the CSIRO investigating aspects of the geothermal regime in both troughs, and with ANLEC R&D studying the wettability of the Mena Murtee-1 cap rocks. These two projects are due for completion by early 2015.

Stage 1B in the Darling Basin achieved its objective of investigating the $CO_2$ storage potential and geothermal potential within the Nelyambo and Pondie Range troughs. The discovery of prospective storage and seal units highlight the geosequestration potential of the Darling Basin and begins to confirm previous (limited data) Basin studies. An enhanced understanding of the geology of the basin has also been gained, and a large volume of subsurface data and drill core (114.39 m) were acquired that will be made publicly available for continued assessment and study by government agencies, academia and industry. Concomitantly, key learnings were acquired that will assist in enhancing the outcomes of further exploration required to ascertain the storage potential of the Darling Basin as part of planned Stage 2 of the NSW $CO_2$ Storage Assessment Program.

# Recommendations

The substantial data and sample sets acquired from this exploration have proven valuable in providing a considerable volume of new subsurface information. The data acquisition program met the needs of an initial geological interpretation of the near well lithology, principally the identification of reservoir/seal pairs as prospective intervals for $CO_2$ geological storage, thereby achieving the aims and objectives of the NSW $CO_2$ Storage Assessment Program.

All data and reports produced as part of Stage 1B of the NSW $CO_2$ Storage Assessment Program will be made publicly available for future research and exploration purposes.

Based on the results and learnings gained from Stage 1B it is recommended that the NSW $CO_2$ Storage Assessment Program now focus on developing a Stage 2 which will involve further exploration of suitable $CO_2$ storage reservoirs in the Darling Basin in western NSW.

# 1. Introduction

The New South Wales Government is committed to reducing greenhouse gas emissions from current and future electricity generation by way of supporting research and development of low emission coal technologies in NSW including carbon capture and storage (CCS). Integral to a CCS project's viability is the ability to store carbon dioxide ($CO_2$) in geological formations permanently.

The generic requirement for geosequestration of $CO_2$ is the existence of permeability and porosity within reservoirs at a depth greater than approximately 800 metres to allow the injection and volumetrically efficient storage of $CO_2$ in a supercritical state (can be shallower given the right formation pressures and temperatures), and overlying seals to confine the $CO_2$ within the reservoirs. It is also critical to avoid major faults and fractures which can provide leakage pathways towards the surface.

Compared to most Australian states the deep sedimentary basins of NSW are virtually unexplored. Prior petroleum exploration has demonstrated that NSW sedimentary basins may have suitable reservoir and seal rocks for $CO_2$ storage, however the seismic and well data density and quality in the basins are poor (Blevin et al., 2007; Hill et al., 2008). The available seismic data are widely spaced, and deep drilling data is absent to sparse in many areas, making further assessment of the potential for $CO_2$ sequestration within these basins very difficult.

To fill this knowledge gap, the Division of Resources & Energy (DRE) within the NSW Department of Trade and Investment, Regional Infrastructure and Services (DTIRIS) (formerly the Mineral Resources branch of the NSW Department of Primary Industries) is undertaking an initial phase of geological assessment of deep sedimentary basins within NSW through a program titled the NSW $CO_2$ Storage Assessment Program. The program aims to undertake a state wide assessment of potential storage opportunities in NSW and compile pre-competitive data and geological studies for future acreage releases.

Having commenced in 2008, the program is comprised of two stages to be completed by the end of 2015. Stage 1A involves exploration within the Sydney Basin and Stage 1B in the Darling Basin. The proposed Stage 2 involves further data acquisition and assessment activities which will be defined based on the results from Stage 1. The Sydney and Darling basins were identified as a national priority for pre-competitive exploration by the Carbon Storage Taskforce (2009), based on a need to fill knowledge gaps in storage suitability close to major emissions sources (Sydney Basin), and on indications from limited data of large $CO_2$ storage potential (Darling Basin). Stage 1A in the Sydney Basin was completed in 2012, with the results indicating limited $CO_2$ storage prospectivity in the four sites investigated (Bell and Knight 2012).

The purpose of Stage 1B was to investigate the potential for $CO_2$ storage in two sub-basins of the Darling Basin in central western NSW. Previous petroleum exploration indicates that extensive sandstone reservoirs may exist in the Darling Basin at a suitable depth for $CO_2$ storage although verification is required (Blevin et al. 2007). There is also uncertainty as to whether regional and/or intraformational seals exist to trap injected $CO_2$ (Blevin et al. 2007). In addition to possibly offering $CO_2$ storage prospectivity, the Darling Basin has existing gas transport infrastructure (a 1 m t/yr supercritical ethane gas pipeline between Moomba to

Botany Bay) that may offer a future route for transporting $CO_2$ captured from the east coast power stations.

Stage 1B drilling activities were undertaken in early 2014 within the Nelyambo (Tiltagoonah-1 well) and Pondie Range (Mena Murtee-1 well) troughs in the northern half of the Darling Basin. These two sub-basins were identified by Blevin et al. (2007) as potential storage areas for $CO_2$. A data acquisition program was designed for Stage 1B with the aim of providing data to support an initial pre-competitive assessment of the potential of each targeted geological formation to safely and securely store supercritical $CO_2$ rather than to comprehensively characterise each formation. Data acquisition included coring and extensive geophysical logging and testing programs to generate data to accurately assess the $CO_2$ storage and geothermal potential. Collaborative research programs were developed with the CO2CRC, CSIRO, and ANLEC R&D to add value to the program and use the newly generated data to assess the geological $CO_2$ storage potential and geothermal potential of the sites.

This report summarises the main findings from Stage 1B of the NSW $CO_2$ Storage Assessment Program. Individual Well Completion Reports (WCR) containing detailed descriptions of aspects of the drilling activities undertaken at each drill site can be found in Appendix 1. The report generated from the collaborative work with the CO2CRC is provided in Appendix 2.

# 2. Work Program

## *2.1. Drilling and Data Acquisition*

On 19 March 2013, the Minister for Resources & Energy approved, under the *Mining Act 1992*, two exploration licences, EL8065 and EL8066 to the Department of Trade & Investment. The Department appointed NSW Public Works as procurement and contract advisors, and on 25 March 2013, the Director General of Trade & Investment awarded Aztech Well Construction (Aztech) as the Principal Contractors. These two entities assisted NSW DRE staff with the planning and delivery of the Stage 1B drilling program.

Site selection was of considerable importance in the successful delivery of the program. Potential $CO_2$ storage formations in the basin were identified and referenced from the Darling Basin Reservoir Prediction Study (Blevin et al. 2007). This study utilised the most extensive collection of available data ever collated on the basin to identify 'areas of interests', where high reservoir quality units were predicted to be present and favourably located and accessible for drilling. Based on cut-off criteria on porosity, permeability and depth range, at least 16 'areas of interest' in the Darling Basin were determined as good candidates for drilling and testing the thick late Devonian sediments. The NSW DRE built upon this work by rigorously compiling data from previous petroleum exploration activities and seismic surveys to produce data packages and geological models containing all the technical information critical in the selection of candidate sites for exploration drilling.

The drilling site selection process was based in part on technical performance criteria for $CO_2$ storage such as capacity, injectivity and containment. A minimum depth range of 800 m was chosen as a primary cut-off criterion to provide a sufficient minimum depth for $CO_2$ to remain in the supercritical state. In addition to this, petrophysical properties and seismic data were analysed to identify and prioritise high quality sandstone reservoir units with >10% porosity and >20 mD permeability. Regional seal units and intraformational shale and siltstone were also investigated as part of the site selection process. Sites were selected in areas with existing offset data and also in frontier areas predicted to contain reservoir units. The two drill sites selected in this process were located within discrete sub-basins of the Darling Basin and contained potential plays (reservoir/seal) with fair information of the structural settings. Figure 1 shows the location of the Tiltagoonah-1 well north-west of Cobar and the Mena Murtee-1 well north of Wilcannia.

Drilling was conducted using a mid-sized petroleum rig capable of drilling to depths required for this program of up to 2400 m. Stratigraphic prognosis was based on scant offset well data and modelled seismic data. The data acquisition program included a suite of laboratory core analyses and downhole logs and tests, which are detailed in Table 1 and Table 2 below. The coring program was designed to capture a representative sample of rocks from within the well using the NOV wireline coring system. All retrieved core is now stored in the W.B. Clark Centre, Londonderry, NSW.

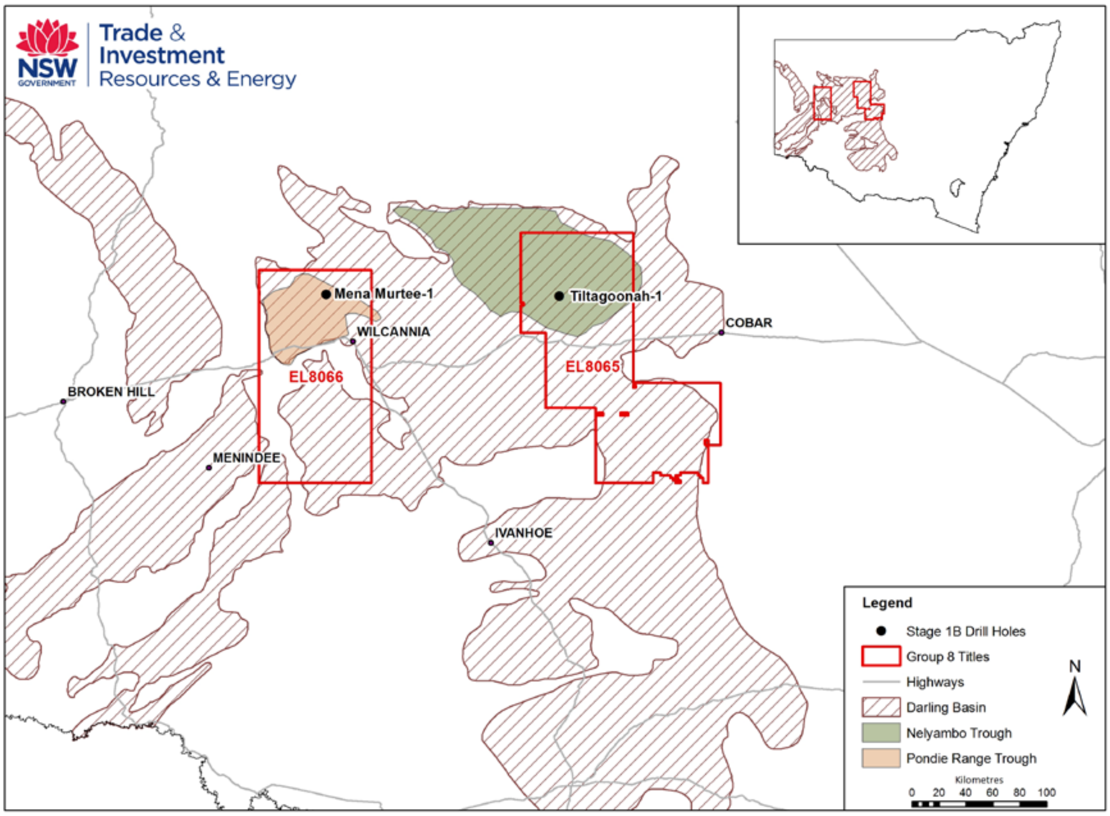


**Figure 1. Location of the Stage 1B wells, Darling Basin, central western NSW.** The Group 8 Titles awarded to the NSW DTIRIS for the purposes of the Darling Basin Drilling Program are also shown.

**Table 1. Laboratory core testing program for the Darling Basin Drilling program.**

| **Activity** | **Details** |
|---|---|
| Core Logging | Reservoir and seal characteristics including lithotype, grain size variations, bedding characteristics, rock heterogeneity and diagenetic effects. |
| Routine Core Analysis (RCA) | Horizontal and vertical permeability, porosity, and grain density of sandstone cores. |
| Core flood test | Estimates of relative permeability of reservoir cores. |
| Mercury Injection Capillary Pressure test (MICP) | Sampling of conventional core in the seal interval to determine seal capacity of caprock. |
| Petrographic analysis – TS (Thin Sections), XRD (X-Ray Diffraction), QEMSCAN (Quantitative Evaluation of Minerals by Scanning electron microscopy), SEM-EDS (Scanning Electron Microscopy-Energy Dispersive X-Ray Spectroscopy) | Assessment of core plugs to determine mineralogy and how diagenetic processes have affected porosity and permeability and hence fluid flows. TS petrology to identify grain framework, cements, clay minerals, and diagenetic effects. XRD & QEMSCAN to investigate mineral composition and clay typing. SEM-EDS to understand clay composition and morphology and pore space alterations. |
| Hylogging | Semi-quantitative interpretation of mineralogy of cores. |

**Table 2. Down-hole data acquisition program for the Darling Basin Drilling Program.**

| **Activity** | **Details** |
|---|---|
| Conventional & advanced geophysical logging | Logs included: gamma ray, spontaneous potential, sonic, caliper, neutron porosity, bulk density, resistivity, photoelectric effect, borehole temperature, and Nuclear Magnetic Resonance. |
| Well velocity survey | Checkshot survey to tie well log interpretations to seismic data. |
| Imaging survey | Borehole imaging to identify sedimentary features, dip directions, structures, fractures and stress patterns. |
| Wireline formation test | Formation pressures and permeability at specific zones of interest. |
| Reservoir fluid sampling | Determine chemistry of reservoir fluids collected by wireline formation test tool. Included the addition of a unique tracer (fluorescein) to the drilling mud to allow back calculation of the original formation water composition. |
| Extended leak off test (XLOT) | Assessment of the magnitude of the minimum horizontal stress over a broad zone and borehole stability during drilling. |

Table 3 contains a summary of the information generated during the Stage 1B drilling program, with the core analysis and analytical reports provided as a separate supplement to this report. The full suite of logs and tests were acquired from the Mena Murtee-1 exploration activities. However, due to heavily silicified and low porosity sandstones encountered at Tiltagoonah-1, a reduced sampling program was implemented with a modest amount of cores acquired, no wireline formation testing, reservoir fluid sampling or relative permeability core testing undertaken (Table 3).

**Table 3. Data sets, analyses and collaborative research generated from the Stage 1B drilling program.** WCR = Well Completion Report. Tests in parentheses under Core Analysis were conducted as part of a collaborative project with the CSIRO (for details refer to the Section 2.2 below) and hence were in addition to those outlined in Table 1 and Table 2 above. Likewise, the need to undertake the palynology work was identified post drilling.

| Well Site | WCR | Total Depth (m) | Lithologic logs | Geophysical logs | Site specific logging / testing | Core Analysis | Collaborative Research |
|---|---|---|---|---|---|---|---|
| **Tiltagoonah-1** | ✓ | 1434 | Chips; 27.89m of 3 1/2" core recovered*. 15 side wall cores recovered* | Gamma, neutron porosity, bulk density, spontaneous potential, resistivity, temperature, calliper, sonic, photoelectric effect, NMR, image log, checkshot | Hylogging of core, XLOT, core gamma, mud gas data | Permeability, Porosity, Grain density, thin section, SEM, XRD, MICP, QEMSCAN, palynology, (seismic velocity, NMR core testing, thermal conductivity and diffusivity, heat capacity, p-wave and s-wave velocities, heat producing element analysis, Young's modulus, shear modulus and Poisson's ratio) | Petrophysical interpretation, geomechanical and geochemistry analysis, geothermal analysis |
| **Mena Murtee-1** | ✓ | 2270 | Chips; 86.50m of 4" core recovered*. 19 side wall cores recovered* | Gamma, neutron porosity, bulk density, spontaneous potential, resistivity, temperature, calliper, sonic, photoelectric effect, NMR, image log, checkshot | Pressure probe, formation tests and fluid sampling, Hylogging of core, XLOT, core gamma, mud gas data | Permeability, Porosity, Grain density, Relative Permeability, thin section, SEM, XRD, MICP, QEMSCAN, palynology, (seismic velocity, NMR core testing, thermal conductivity and diffusivity, heat capacity, p-wave and s-wave velocities, heat producing element analysis, Young's modulus, shear modulus and Poisson's ratio) | Petrophysical interpretation and static model, reservoir modelling, geomechanical analysis, geochemistry analysis, geothermal analysis, shale wettability study |

* Core is stored at the W.B. Clark Centre, Londonderry

## *2.2. Collaborative Research*

Collaborative research and modelling projects were established with the CO2CRC, CSIRO, and ANLEC R&D to assist in maximising the amount of information extracted from the data acquisition program.

### 2.2.1. The CO2CRC Darling Basin $CO_2$ Storage Study

A collaborative work program was developed between the DRE and the CO2CRC to use the new and existing data to better understand the geosequestration potential of the rock formations intersected during the drilling campaign. Four Work Packages were developed that had the following corresponding objectives:

1. *Geological Characterisation* - Undertake a detailed facies analysis and seal capacity analysis to describe the geological character of prospective storage sites within the troughs targeted by drilling, and develop static models.
2. *$CO_2$ Injection & Plume Migration Modelling* - Perform numerical simulations of $CO_2$ injection at each of the two well locations based on the new well data and geological information assessing injectivity, leakage potential, and the overall storage capacity of the two troughs.
3. *Geomechanical Evaluation* – Deliver a first pass Geomechanical assessment to understand the basin scale in situ stress field, and in doing so, gain some understanding into the stability of regional scale faults as they pertain to any future CO2 injection projects.
4. *Geomechanical Analysis & Modelling* – Determine the in situ formations water composition using a combination of an in situ water sampler and a tracer added to drilling mud to determine the degree of contamination, and model fluid rock reactions under CO2 storage conditions using formation water composition, mineralogy and digital image analysis data.

Efforts focused mainly on analysing the Mena Murtee-1 data set with all of the Work Packages completed for this well. The reduced sampling and testing program for Tiltagoonah-1 resulted in a reduction in scope for Work Packages 1 (Geological Characterisation) and 4 (Geochemical Analysis), and the removal of Work Package 2 ($CO_2$ Injection & Plume Migration Modelling) (Figure 2).

The collaborative work has added new data and understanding of the Nelyambo and Pondie Range Troughs, and the implications of rock properties on injection rates and plume migration, geological stress fields and $CO_2$ brine/rock fluid interactions. The full report is provided in Appendix 2 and a summary of the key findings and recommendations is provided below in Section 3.3.

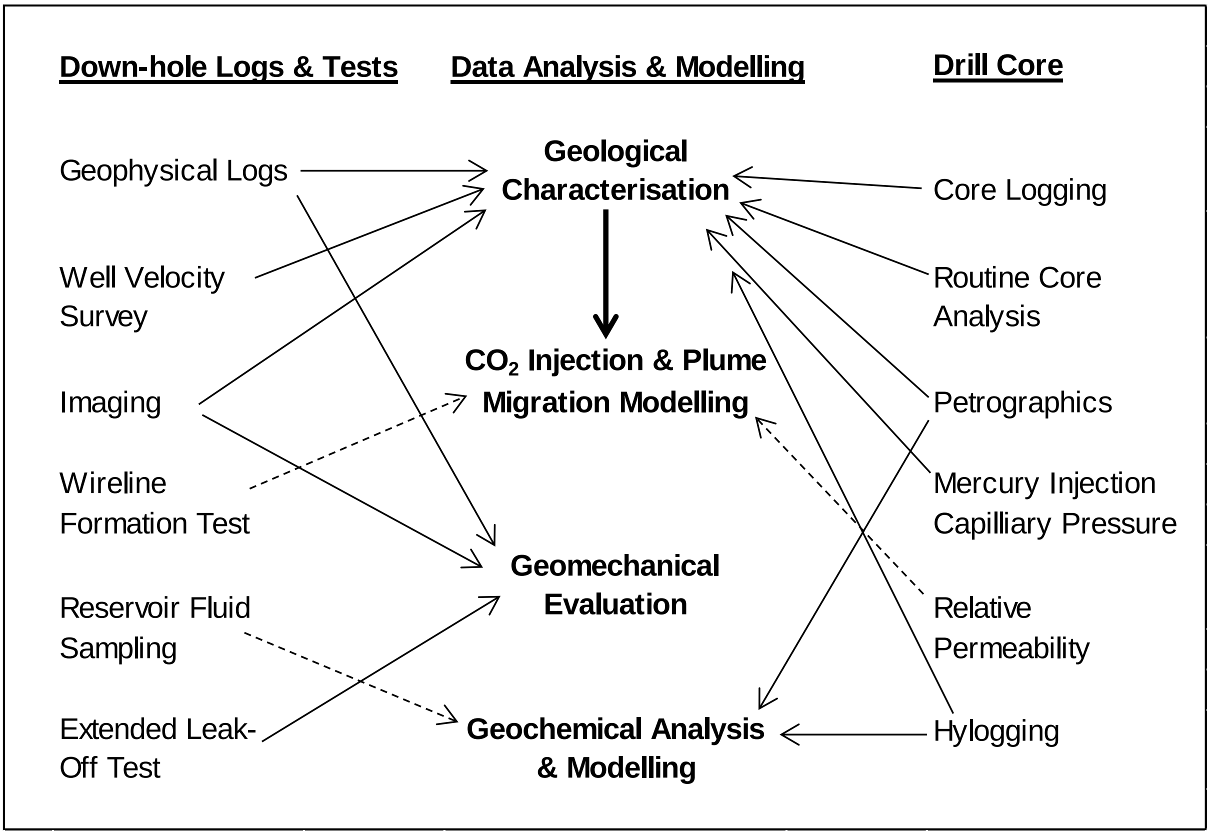


**Figure 2. Utilisation of well and core data by each CO2CRC Data Analysis and Modelling Work Package.** Solid lines indicate data acquired from both wells. Dashed lines indicate data acquired from Mena Murtee-1 only.

### 2.2.2. Geothermal project with the CSIRO

A collaborative program of work was also established between the DRE and CSIRO to collect additional data from the wells to provide information on the thermal regime of the Darling Basin. This information will assist in evaluating the $CO_2$ storage potential, the thermal maturity, and the geothermal potential of the basin. The additional data acquisition activities included accurate collection of drilling fluid circulation and bottom hole temperatures; Nuclear Magnetic Resonance (NMR) logging of the wells; and petrophysical and thermal conductivity measurements on selected core samples. Cash funding was secured through the AGOS fund for the acquisition of the NMR logs and laboratory data. The final component of the geothermal project is to collate and interpret the thermal data and deliver a report to the DRE on the thermal regime at each well. The geothermal work program is due to be completed by early 2015 and the report will become available at that time.

### 2.2.3. ANLEC R&D Shale Wettability project

ANLEC R&D offered an in-kind contribution to the Stage 1B drilling program by including some of the fresh drill cores in one of their existing projects at Curtin University aimed at measuring the $CO_2$ wettability of cap rocks and how these wettabilities influence structural trapping. $CO_2$ contact angles derived from the research feed directly into MICP-based calculations of seal capacity. The wettability study will be completed by early 2015 and the report will become available at that time. It should be noted that the seal capacity estimates undertaken by the CO2CRC as part of Work Package 1 included sensitivity analysis of $CO_2$ contact angles from 0 to 60 degrees in 20 degree increments (Appendix 2). Hence, once the wettability study is completed the derived contact angles will indicate which seal capacity estimates in the sensitivity analysis are the most realistic for the two Darling Basin wells.

#### 2.2.4. Mud gas analysis with Geoscience Australia

A collaborative project was established between the DRE and Geoscience Australia aimed at analysing mud gas samples from each well. However, this project did not proceed due to the very 'dry' nature of both wells with extremely low levels of gas encountered.

## *2.3. Core Laboratory Services*

Intertek Geotech Geotechnical Services Pty Ltd and Core Laboratories were engaged to provide the laboratory testing services set out in Table 1 for the Stage 1B cores. Core Laboratories, which undertook the core flood tests, provided a quality service and met agreed timelines for the delivery of results as set out in the signed contract with the DRE. However, Intertek Geotech, which did the RCA, MICP and petrographic analyses, failed to meet the agreed timelines and was unresponsive to efforts by the DRE to manage and rectify the delays. This in turn impacted on the timely provision of data to collaborative researchers. This type of failure to meet crucial deliverable deadlines will need to be addressed in future contracts.

# 3. Drilling Activities and Results

The following chapter provide an overview of the drilling activities for each well and associated results, taken from the WCRs, core analysis reports, and the collaborative CO2CRC research report generated from this project.

## *3.1. Tiltagoonah-1*

### 3.1.1. Drilling Activities

Tiltagoonah-1 was the first borehole to be drilled in Stage 1B of the NSW $CO_2$ Storage Assessment Program and was located in the Nelyambo Trough, within the Darling Basin. Previous work by Blevin et al. (2007) identified the Nelyambo Trough as having potential for $CO_2$ storage. Site location was determined from previous geological work, proximity to the Moomba Gas pipeline corridor, modelling of seismic lines undertaken by Departmental geologists, and supportive landholder sentiment.

Tiltagoonah-1 was the first well to be drilled in the Nelyambo Trough. Drilling commenced on the 21st of February 2014 and reached total depth (TD) of 1,434 m on the 19th of March 2014. The TD was reached after 26 days of drilling, 12.5 days behind forecast time to reach this depth. The average overall drilling rate was 55 m/day. During operations a number of modifications were made to the drilling program and well design due primarily to the unexpectedly (in comparison to offset wells) high compressive strength and abrasiveness of the rocks encountered below 500 m. Given to the extreme down hole conditions, the original time-depth estimates were not achievable, with open-hole drilling and coring rates much slower than forecast. Aztech engineers tried different bit and weight combinations to determine which would achieve the best drilling rate, although most made little difference. The fastest drill rates were generally achieved by applying approximately 17 to 20 tonnes of weight on the drill bit. However, design limitations with the NOV wireline coring system meant that no more than approximately 8 tonnes of weight could be placed on the drill bit whilst drilling and about half of this again during coring operations. In addition to this, the hard abrasive nature of the rocks led to lost drilling time as numerous drill bit changes were required as bits rapidly became ‘blunt’ and/or gouged out (reamed) with a total of 11 bits used in the 8½” section of the hole (Figure 3; Appendix 3). For these reasons, the decision was taken to reduce TD from a planned 2,400 m to 1434 m and greatly reduce the amount of core cut in order to maintain the project within budget and time constraints.

**Figure 3. Photos of unused (left) and reamed (right) 7 blade PDC drill bits from Tiltagoonah-1.** Photos courtesy of Antonio Ribeiro.

Although a total of 800 m of core was planned to be cut, only 27.89 m of 3 ½" core was recovered from the 8 ½" open hole at Tiltagoonah-1 from depths between 675.5 m – 1288.9 m (Table 4). The modest amount of core recovered was a heavy reduction from the planned 800 m brought about by the wireline coring system inability to efficiently cut through the heavily silicified rocks, coupled with the extreme conditions encountered down hole.

A Side Wall Coring (SWC) program was designed to sample the top 12 ¼" section of the well prior to installing the casing. Fifteen SWC samples were retrieved between 552 – 150 m (Table 5). A 100% success rate was achieved with the Tiltagoonah-1 SWC Program, an unusually high result attributed to the rock properties that hindered the rest of the drilling program.

**Table 4. Tiltagoonah-1 cored intervals.**

| Core No. | Top | Base | Recovered (m) | Recovered (%) |
|---|---|---|---|---|
| 1 | 675.5 | 683.7 | 7.83 | 95.5 |
| 2 | 683.7 | 691.8 | 7.93 | 97.9 |
| 3 | 691.8 | 695.3 | 3.5 | 100 |
| 4 | 1279.9 | 1288.9 | 8.63 | 95.9 |

**Table 5. Tiltagoonah-1 Side Wall Cores.**

| Core No. | Sample Depth (m) | Sample Length (cm) |
|---|---|---|
| SWC_1 | 552.0 | 4 |
| SWC_2 | 549.7 | 4 |
| SWC_3 | 543.5 | 4 |
| SWC_4 | 532.0 | 4 |
| SWC_5 | 528.0 | 4 |
| SWC_6 | 498.0 | 5 |
| SWC_7 | 487.0 | 4.5 |
| SWC_8 | 462.0 | 5 |
| SWC_9 | 448.0 | 4.5 |
| SWC_10 | 404.0 | 3.5 |
| SWC_11 | 352.7 | 4.5 |
| SWC_12 | 298.3 | 4.5 |
| SWC_13 | 290.7 | 4.5 |
| SWC_14 | 190.0 | 4 |
| SWC_15 | 150.0 | 2.5 |

An extended leak off test comprised of three cycles was carried out directly below the casing shoe in the Top Shale 3 Formation at 580 m. The full suite of conventional geophysical logs, an NMR log, check shot survey and imaging was also run in the hole to gather information on porosity, permeability, density, rock type, fracture risk/propensity/orientation, and to improve seismic interpretation. Two logging runs were performed: from 577 m to surface prior to casing of this section and from TD to the casing shoe following completion of drilling. Due to the silicified, low porosity sandstones encountered, no wireline formation testing was undertaken at Tiltagoonah-1 (Table 3).

### 3.1.2. Lithology and stratigraphy

A full lithological description was completed of the cores and of the chip samples from ~30m to TD. Analysis of the cores and geophysical logs identified lithological units intersected at Tiltagoonah-1 that consisted primarily of sequences of massive claystone sections and some sandstone units (Figure 4). Interbedded claystone and sandstones were also intersected, along with some limestones. The density and thickness of the shallower claystone units would have proved an excellent seal if a suitable reservoir had been identified. The sandstones, however, were generally hard, fine to very fine grained, highly cemented and lacked porosity thereby rendering them unsuitable as gas storage reservoirs.

The stratigraphy intersected in Tiltagoonah-1 is not understood at this time. Additional sampling (from four samples from mud rich sections of the core) has been undertaken by the DRE for palynology examination for dating to clarify the stratigraphy. To date, palaeontological evidence from a limestone sampled in the well (interval 685.90 – 688.83 m) has not been able to constrain the age of the core. Accordingly, the stratigraphic section encountered in Tiltagoonah-1 is based largely on the lithology and wireline log response depicted below in Figure 4 and summarised below in Table 6.

**Table 6. Tiltagoonah-1 Formation/Stratigraphic Tops.**

| Age | Formation | Depth (mRT) | Depth (mTVDSS) | Thickness (mTVT) |
|---|---|---|---|---|
| ?Post Devonian | Post- Devonian? sands | 5.5 | -140 | 119.5 |
| ?Devonian | Top Shale 1 | 125 | 20.5 | 190 |
| ?Devonian | Top Shale 2 | 315 | -169.5 | 130 |
| ?Devonian | Unconformity | 445 | -299.5 | N/A |
| ?Devonian | Top Shale 3 | 445 | -299.5 | 205 |
| ?Devonian | Middle Sand 1 | 650 | -504.5 | 120 |
| ?Devonian | Middle Sand 2 | 770 | -624.5 | 115 |
| ?Devonian | Middle Shale 1 | 885 | -739.5 | 215 |
| ?Devonian | Basal Sand 1 | 1270 | -998.5 | 214 |
| ?Devonian | Basal Shale 1 | 1314 | -1168.5 | 121+ |
| | Total Depth | 1434 | -1288.5 | |

To date most of the wells drilled in the Darling Basin have been located over antiformal structures and/or near sub-basin margins. Tiltagoonah-1 differs in that it is located in the depocentre of the Nelyambo Trough. New information gained from the well in the upper units of the Devonian indicate that they may have been eroded in other previously drilled locations. The thick claystone units intersected near the top of the well suggest that thick shallow marine or marginal claystones may exist in other depocentres of the Darling Basin. There is some similarity with the intersected rock types from the Blantyre well which also shows minor limestones and claystones in the upper part of the Devonian section.

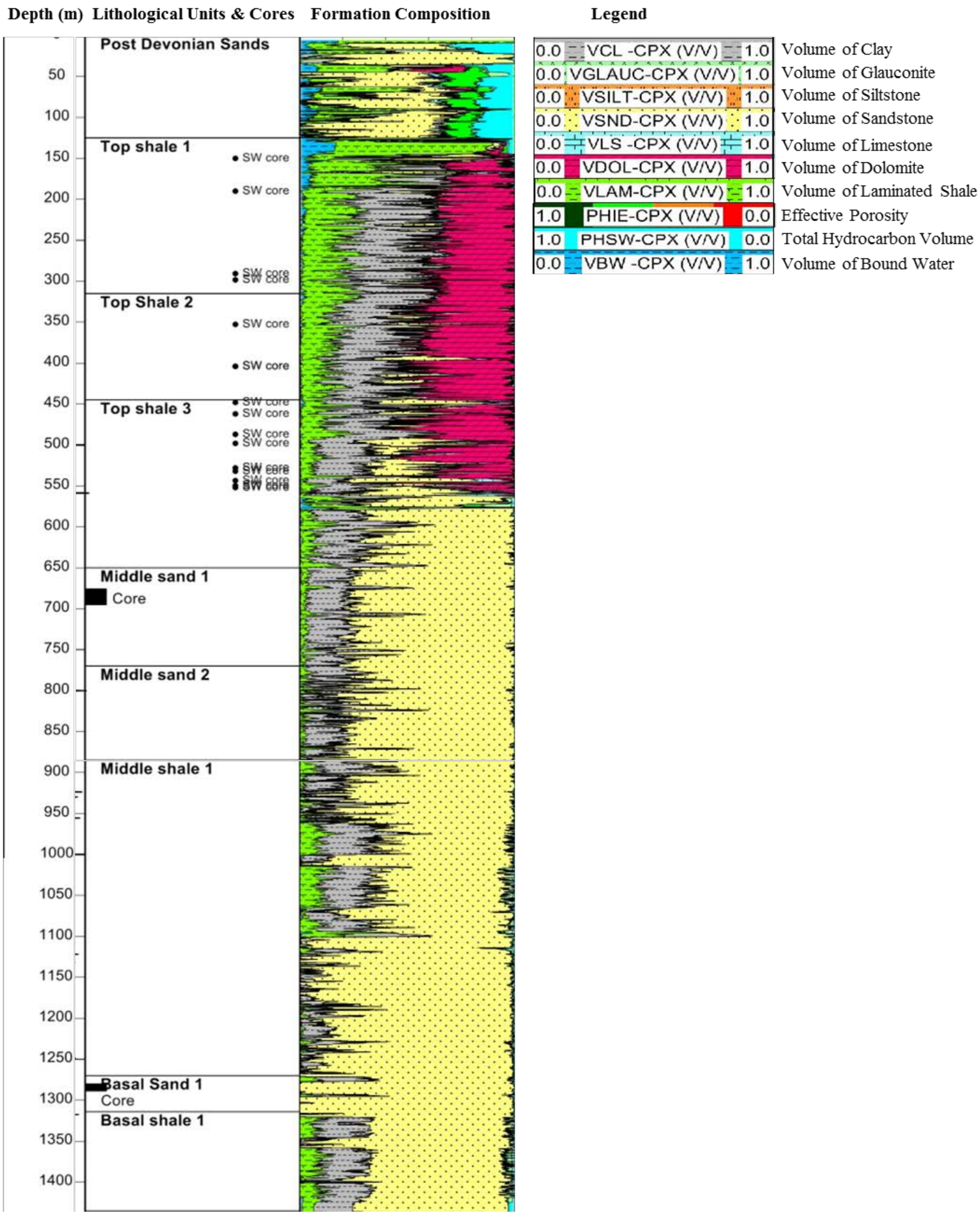


**Figure 4. Graphic representation of the identified geological units and interpreted formation composition at Tiltagoonah-1.** Coring depths are also given.

The rocks intersected at Tiltagoonah-1 were silicified and tenacious. The presence of limestone and the extremely high compressive strength of the sandstones are not typical of the Late Devonian rocks intersected in offset wells in the Darling Basin. This suggests that the evolution of the Nelyambo Trough may differ to other sub-basins and has raised questions about age, diagenesis and the evolution of the northern part of the Darling Basin. Previous work in adjacent sub-basins has placed an Upper Devonian age on the Ravendale Formation. As indicated in Table 6, the age of the Ravendale Formation cannot be confirmed from the data gathered in Tiltagoonah-1 because of low core recoveries and significant diagenesis of what samples were obtained. This has made age dating using standard palaeontology, palynology and radiometric methods difficult. No intervals were intersected that could be correlated to rocks of known age in adjacent sub-basins, and hence determining the ages of the rocks intersected at Tiltagoonah-1 remains an important avenue of investigation. A detailed diagenetic study is also required as part of any future program, aimed at understanding the timing of the digenetic phases and how they affect the cementation as well as the potential to produce secondary porosity and permeability.

### 3.1.3. Well Tests

The results of the extended leak-off test at 580 m are shown below in Table 7. A leak off value of 25.16 ppg EMW (Pounds Per Gallon Equivalent Mud Weight) was calculated from the results, which is very high reflecting a highly competent, strong formation. The test data was used by the CO2CRC in undertaking a geomechanical assessment of the site (Appendix 2).

**Table 7. Extended leak off test results for Tiltagoonah-1.** bbl = oil barrel. psi = pounds per square inch.

| Cycle | Volume (bbl) | Leak off point (psi) | Pump volume (bbl) | Shut in Pressure (psi) | Time (min) | Bleed (psi) | Return (bbl) |
|---|---|---|---|---|---|---|---|
| 1 | 1.15 | 1730 | 0.25 | 1612 | 30 | 1552 | 0.58 |
| 2 | 1.08 | 1664 | 0.25 | 1560 | 30 | 1446 | 0.76 |
| 3 | 0.79 | 1645 | 0.25 | 1524 | 30 | 1400 | 0.35 |

### 3.1.4. Geothermal Gradient

Bottom hole temperatures recorded during wireline logging were analysed using a Horner Plot to estimate a geothermal gradient of 2.9 degrees Celsius per 100 m. This data will serve to improve knowledge of the state’s geothermal potential and increase the accuracy of existing heat flow mapping.

### 3.1.5. Laboratory Analysis

A total of 16 conventional (3 ½”) core samples and six side wall cores were sent to Intertek Geotech for a range of tests:

- 8 x 3 ½” sandstone cores for RCA (horizontal and vertical permeability, porosity, grain density)
- 16 x 3 ½” cores and 6 SWCs representative of the range of lithologies for petrographic analysis (thin section, optical microscopy, SEM, XRD – bulk and clay)
- 10 x 3 ½” cores representative of the range of lithologies for QEMSCAN analysis
- 6 claystone SWCs for MICP analysis

*Porosity and Permeability*

The visual porosity in core and chip samples was low and recorded as nil during lithological logging. This observation was confirmed by the RCA results (Figure 5).

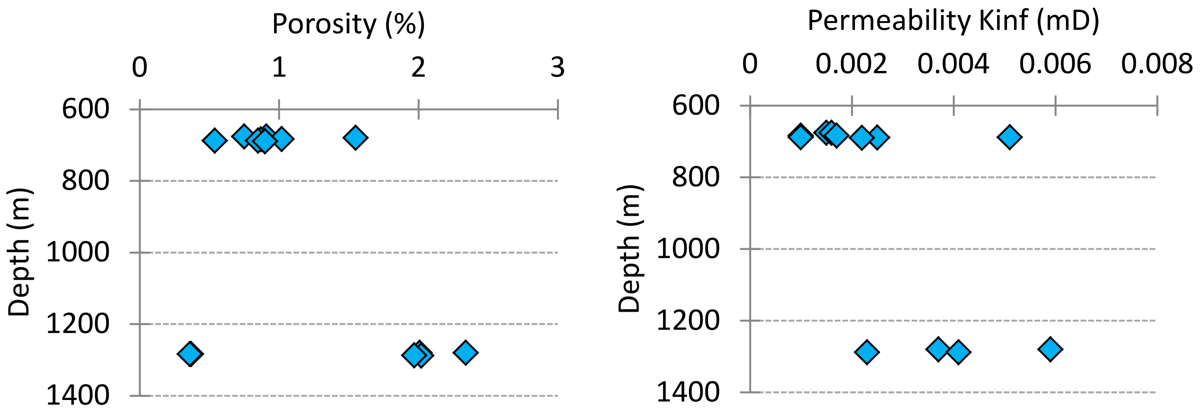


**Figure 5. Porosity and permeability of cores tested at 800 psi from Tiltagoonah-1.**

The highest porosity and permeability occurred in Sample 015H and the lowest porosity and permeability occurred in Sample 017 (Table 8). Figure 6 and Figure 7 are photomicrographs of these two samples. The blue sections illustrate where porosity exists and comparison of the two images highlights the reduction in porosity from Sample T1-015 (2.34%) to Sample T1-017 (0.36-0.37%) and the overall lack of porosity.

**Table 8. Tiltagoonah-1 RCA results.** H & V = horizontal & vertical plug.

| Plug ID | Depth (m) | Porosity at 800psi (%) | Grain Density (g/cc) | Permeability at 800 psi (mD) | Klinkenberg Permeability Kinf (mD) |
|---|---|---|---|---|---|
| T1-002H | 676.28 | 0.91 | 2.66 | 0.0017 | 0.0015 |
| T1-002V | 676.32 | 0.75 | 2.66 | 0.0018 | 0.0016 |
| T1-005H | 680.3 | 1.55 | 2.66 | ND | ND |
| T1-005V | - | ND | ND | ND | ND |
| T1-006H | 683.91 | 1.02 | 2.67 | 0.0019 | 0.0017 |
| T1-006V | 683.99 | 0.87 | 2.67 | 0.0012 | 0.001 |
| T1-010H | 688.31 | 0.85 | 2.66 | 0.0053 | 0.0051 |
| T1-010V | 688.18 | 0.54 | 2.66 | 0.0019 | 0.001 |
| T1-012H | 689.89 | 0.9 | 2.67 | 0.0027 | 0.0025 |
| T1-012V | 689.98 | 0.9 | 2.67 | 0.0026 | 0.0022 |
| T1-015H | 1279.94 | 2.34 | 2.65 | 0.0065 | 0.0059 |
| T1-015V | 1280 | 2.01 | 2.65 | 0.0039 | 0.0037 |
| T1-017H | 1283.85 | 0.37 | 2.68 | <0.001 | ND |
| T1-017V | 1283.89 | 0.36 | 2.68 | <0.001 | ND |
| T1-019H | 1288.03 | 2.02 | 2.65 | 0.0043 | 0.0041 |
| T1-019V | 1287.91 | 1.97 | 2.65 | 0.0027 | 0.0023 |

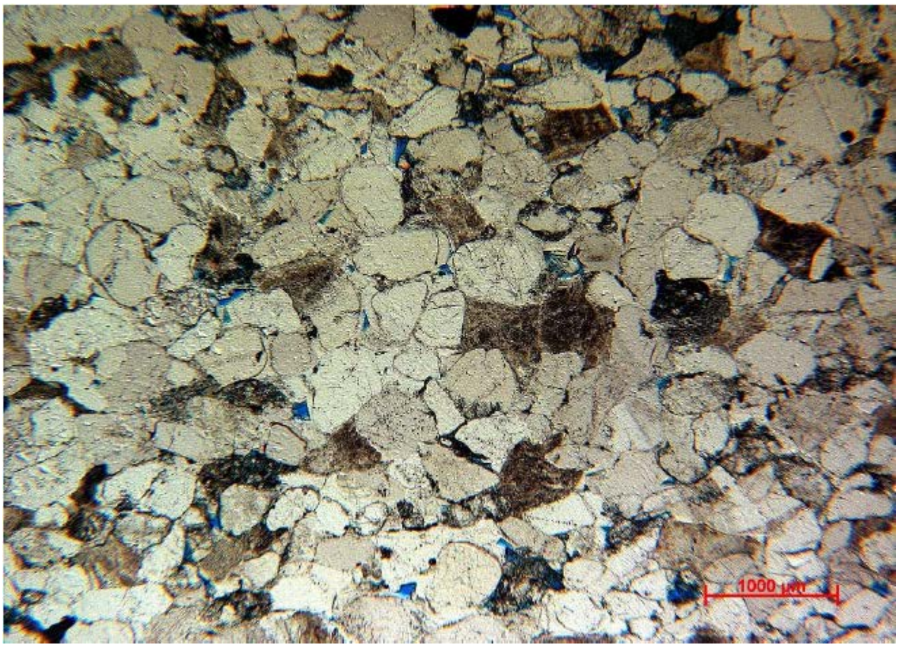


**Figure 6. Sample T1-015 (40x magnification).**
Fine to medium grained sandstone with subrounded to angular grains. Porosity is moderate to good and is held as mostly primary, intergranular pores.


**Figure 7. Sample T1-017 (40x magnification).**
Fine to medium grained sandstone with subrounded quartz grains that exhibit extensive overgrowth development and cementation. Porosity is poor and may be held in micropores between grains.

The petrographic samples are predominantly fine to very fine grained and moderately well sorted argillaceous sandstones. The granular framework of tested samples is well compacted and as a result grains are more efficiently packed and elongate grain contacts are common. The grain assemblage is mature and several of the samples are calcareous and contain scattered calcite and dolomite grains that form as intergranular cements. Diagenetic cementation is dominated by quartz overgrowth development as well as intergranular clay formation. Overgrowth crystals are common and fill the intergranular areas as does argillaceous material and clay. The porosity and permeability of the samples has been affected by diagenetic and metamorphic processes during formation and subsequent deformation, greatly reducing the pore space that could hold $CO_2$ and the interconnectedness between the grains that would facilitate movement of the $CO_2$.

*XRD Analysis*

X-Ray powder Diffraction (XRD) analysis was conducted on all 22 samples and measured the bulk composition of each sample and separately the clay composition. XRD testing provides a mineral composition by weight% for each sample and is especially good for identifying fine grained minerals. XRD also determines which form of a mineral is present which is useful in understanding metamorphic processes. The XRD data were used in the collaborative research projects.

*MICP Analysis*

Analysis of the side wall cores cut from the thick claystone units in the top 600 m of Tiltagoonah-1 revealed the high seal capacity of this interval. $CO_2$ column heights (i.e. $CO_2$ containment heights) calculated as part of the CO2CRC collaborative research project ranged between a maximum of 124 and 986 m using a contact angle of 0 degrees, and a minimum of between 62 and 493 m using a contact angle of 60 degrees (Appendix 2).

*Hylogger™ Analysis*

Core from Tiltagoonah-1 underwent HyLogger analysis at the W. B. Clark Geoscience Building, Londonderry, NSW. The HyLogger analysis provided semi-quantitative information on the mineralogical composition of the core which was used to identify areas of interest not visible by macroscopic examination or from log data (Figure 8). The data correlated with well log data thereby highlighting the usefulness of HyLogging for calibration and data gathering.

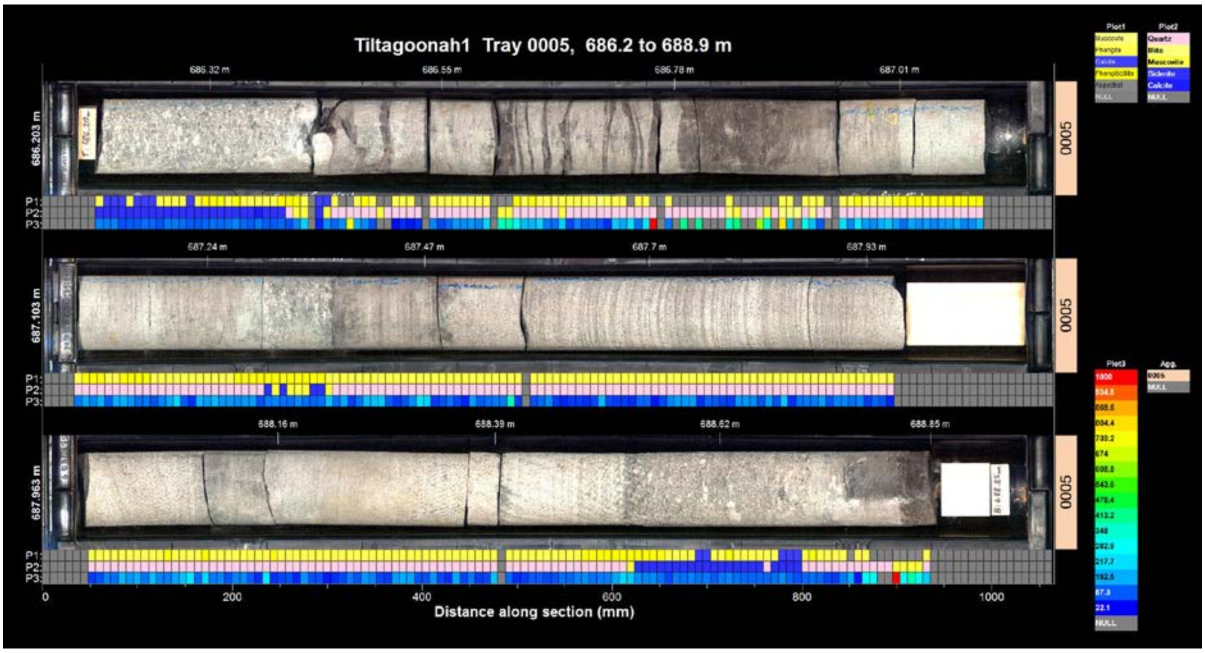


**Figure 8. Example of Tiltagoonah-1 HyLogger image.** Included is the compositional analysis and mineral concentrations.

Information on diagenesis and metamorphism can also be gained from the HyLogger data, important when determining what processes may have affected an area of interest. Additional to the mineralogical composition data is the high definition imaging of the core which is of benefit when looking at depositional environment conditions, boundaries and intrusives. The

Hylogger data also assisted with sample selection for core analysis and was used extensively in the collaborative CO2CRC research project.

#### 3.1.6. Conclusion

The sandstone units encountered at Tiltagoonah-1 were of an unexpectedly hard, dense and highly silicified nature not predicted from the data used in modelling and from adjacent sub-basins. Whilst the high sealing capacity of the thick claystone section indicates that these overlying units would make an excellent seal, the lack of a deeper permeable sandstone reservoir renders this site unsuitable for $CO_2$ storage. It is hoped that the palynology work will provide an age or at least constraints on deposition to determine where within the stratigraphy the deeper Nelyambo Trough rocks sit. Future detailed diagenetic studies are also warranted to assist in understanding the evolution of this sub-basin. Drilling of Tiltagoonah-1 has greatly increased the amount of data for the sub-basin, which will be available for continued research by government authorities, academia and industry.

### *3.2. Mena Murtee-1*

#### 3.2.1. Drilling activities

Mena Murtee-1 was the second hole drilled in the Darling Basin as part of Stage 1B of the NSW $CO_2$ Storage Assessment Program. It is also only the second well to be drilled in the Pondie Range Trough and the first to intersect the area of thickest sediment deposition of this sub-basin (i.e. the depocentre). Selection of the Pondie Range Trough was based on previous work by Blevin et al. (2007). Site location was determined from the previous work, proximity to the Moomba gas pipeline corridor, modelling of seismic lines undertaken by Departmental geologists and positive landholder sentiment.

Figure 9 shows the location of Pondie Range-1, the approximate location of Mena Murtee-1 and a series of seismic reflectors modelled from seismic data and Pondie Range-1 well data. The structure of the basin can be seen with Mena Murtee-1 located to intercept depocentre stratigraphy and Pondie Range-1 located towards the southern edge of the basin over a structural high. The Ravendale Unit, identified in Pondie Range-1 at ~200 m was anticipated to be intersected at ~1520 m at Mena Murtee-1 and was the target reservoir interval.

Prior to the commencement of drilling at this site, a decision was taken to release NOV Coring from the project due to the inability of their coring/drilling system to effectively work in the hard rocks encountered at Tiltagoonah-1. Instead, a conventional 4" coring system was sourced from Halliburton for Mena Murtee-1. Although additional time is required to trip out and change the drill head for coring it was agreed that overall drilling speed should be greater in rocks with high compressive strength with a conventional drilling and coring assembly. The new coring program was developed within time and budget constraints with four x 27 m core sections planned. The coring plan was developed to take advantage of drill bit changes and also to core at strategic points in key lithologies based on examination of drill cuttings.

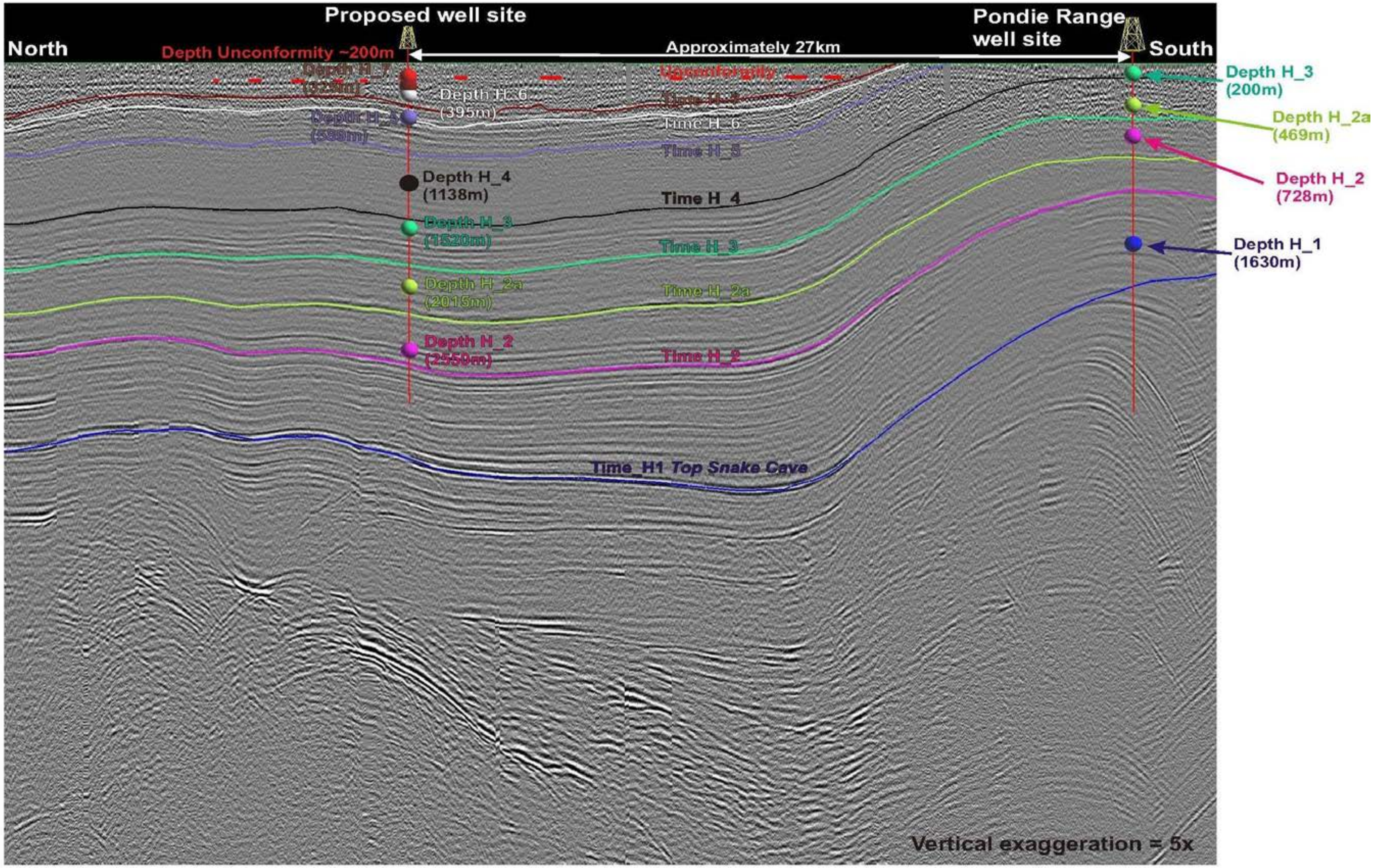


**Figure 9. Seismic section of the Mena Murtee-1 well site with modelled surface horizons (coloured) (NSW DRE, 2012).**

Drilling commenced on the 4th April 2014 and reached total depth (TD) of 2,270 m after 30 days of drilling on the 2nd May 2014. The rocks encountered at Mena Murtee 1 were much easier to drill than at Tiltagoonah-1, resulting in drilling being ahead of schedule for most of the hole. Harder rocks were encountered below 2,000 m where drilling rates dropped. The decision to call TD 130 m short of the targeted 2,400 m was made to maintain the project within time and budget constraints. The average overall daily drilling rate was 75.6 m/day.

In comparison to Tiltagoonah-1, the less abrasiveness of the rocks at Mena Murtee-1 and the switch from wireline to conventional coring resulted in improvements in bit usage; three drilling bits and one core head were used in the 8½” section at Mena Murtee-1. Given that decisions on when to core were based on a consistent show of sandstones or claystones in the cuttings and also a change of bit when possible, some control of cored sections was lost, with a total of 86.5 m of 4” core recovered from four depths between 1598 – 2039 m (Table 9).

**Table 9. Mena Murtee-1 conventionally cored intervals.**

| Core No. | Top | Base | Cut | Recovered (m) | Recovered (%) |
|---|---|---|---|---|---|
| 1 | 1598.0 | 1625.6 | 27.6 | 27.25 | 98.75 |
| 2 | 1625.6 | 1632.7 | 7.1 | 6.75 | 95.1 |
| 3 | 1850.0 | 1877.0 | 27.0 | 26.5 | 98.1 |
| 4 | 2012.5 | 2039.0 | 26.5 | 26.0 | 98.1 |

A Side Wall Coring (SWC) program was designed from logging data to sample additional areas of interest not covered by the conventional coring program. Nineteen SWC samples were retrieved between 2098 – 1417 m (Table 10). Conventional coring captured most of the lower section of a thick (88 m) sandstone that commenced at 1553 m (Cores 1 and 2) but missed two thinner sandstone sections of significant interest commencing at 1489 m (9 m thick) and 1526 m (12 m). SWC samples, 2.6, 2.7, 2.9 and 2.10 were taken in these sections.

**Table 10. Mena Murtee-1 Side Wall Cores.**

| Core No. | Sample Depth (m) | Sample Length (cm) |
|---|---|---|
| SWC_1.1 | 2098.0 | 4.0 |
| SWC_1.2 | 2050.0 | 3+ |
| SWC_1.3a | 1979.0 | 4.0 |
| SWC_1.3b | 1979.0 | 4.0 |
| SWC_1.4 | 1746.5 | 4.0 |
| SWC_1.5 | 1633.5 | 5.0 |
| SWC_1.6 | 1618.5 | 4.5 |
| SWC_2.2 | 1584.0 | 3.0 |
| SWC_2.3 | 1562.0 | 3+ |
| SWC_2.4 | 1555.0 | 4.5 |
| SWC_2.5 | 1547.0 | 4.0 |
| SWC_2.6 | 1532.0 | 4.5 |
| SWC_2.7 | 1527.0 | 3.0 |
| SWC_2.8 | 1506.0 | 4.5 |
| SWC_2.9 | 1496.0 | 4.0 |
| SWC_2.10 | 1490.8 | 3.5 |
| SWC_2.11 | 1482.5 | 2.5 |
| SWC_2.12 | 1426.5 | 4.5 |
| SWC_2.13 | 1417.0 | 4.0 |

An extended leak off test comprised of three cycles was carried out directly below the casing shoe in Unit 4 at 759 m. The full suite of conventional geophysical logs, an NMR log, check shot survey and imaging was also run in the hole to gather information on porosity, permeability, density, rock type, fracture risk/propensity/orientation, and to improve seismic interpretation (Table 3). Two logging runs were performed: 756 m to surface prior to casing of this section and from TD to the casing shoe following completion of drilling. Following on-site analysis of the geophysical logs, a program of wireline formation testing and fluid sampling was undertaken between a depth of 1406 and 1634 m that targeted four sandstone intervals.

### 3.2.2. Lithology and stratigraphy

A full lithological description of chip samples was done from ~30 m to TD and the core was also logged. Seven distinct lithological units were identified at Mena Murtee-1 and consisted primarily of sequences of massive claystone sections, massive sandstone sections, interbedded claystone and siltstone and sandstone with interbedded claystone and minor limestone sections (Table 11). The sandstone section described in Unit 5 is overlain by 1120 m of interbedded claystone (Units 3 and 4). This stratigraphic configuration is suitable for $CO_2$ storage and analysis of core and wireline logs indicates that the sandstone sections of Unit 5 may be prospective as $CO_2$ storage reservoirs.

Uncertainty remains regarding the lithology at depth within the Pondie Range Trough, with work continuing to determine where in the sequence the retrieved core sits. Palaeontological evidence from a limestone sampled in the well at 2036.4 m was inconclusive in constraining the age of the core. Consequently, an additional six samples have been taken from mud-rich sections of the cores for palynological analysis by Geoscience Australia. The palynology study aims to locate and identify ancient spores and pollen that may provide more detailed information about the age of the sediments penetrated in Mena-Murtee-1, and hence where the retrieved core sits within the stratigraphy. Once the stratigraphy is correctly identified, comparison with adjacent sub-basins can be evaluated, which will aid in understanding the evolution of the Pondie Range Trough and the greater Darling Basin. At the time of writing of this report results were still pending.

**Table 11. Mena Murtee-1 formation/stratigraphic tops.**

| Age | Formation | Depth (mRT) | Depth (mTVDSS) | Thickness (mTVT) | Description |
|---|---|---|---|---|---|
| post-Devonian | Unit 1 | 5.5 | +92.2 | 69.5 | Claystone laterite and weathered sandstone |
| post-Devonian | Unit 2 | 75.0 | +22.7 | 95.0 | Massive sandstone |
| post-Devonian | Unit 3 | 170.0 | -72.3 | 50.0 | Interbedded claystone and siltstone |
| Late Devonian | Unit 4 | 220.0 | -122.3 | 1120.0 | Interbedded claystone and minor siltstone stringers |
| Late Devonian | Unit 5 | 1290.0 | -1192.3 | 351.0 | Sandstone with minor interbedded claystone |
| Late Devonian | Unit 6 | 1641.0 | -1543.3 | 367.0 | Claystone with minor interbedded sandstone |
| Late Devonian | Unit 7 | 2008.0 | -1910.3 | 252.0+ | Sandstone and minor interbedded claystone |
| | Total Depth | 2270.0 | -2172.3 | | |

Figure 10 is a graphic representation of geophysical log data. The upper 170 m contains significant sandstone sections which are unsuitable as reservoir units as they are above the 800 m depth required for $CO_2$ storage. The 1,120 m of claystone that make up Units 3 and 4 is clearly discernible, as are four deeper sandstone units between 1388 and 1641 m within Unit 5. The depths of these units are suitable for geosequestration. The depths of coring and testing are also depicted in Figure 10, and close up views of the four sandstone units accompanied by porosity and permeability results from cores and wireline formation tests are presented in Figure 11.

### 3.2.3. Well Tests

The results of the extended leak-off test at 759 m are shown below in Table 12. A very high leak off value of 23.3 ppg EMW (Pounds Per Gallon Equivalent Mud Weight) was calculated from the results, reflecting a highly competent, strong formation. The test data was an essential input into the reservoir modelling and geomechanical assessment undertaken by the CO2CRC (Appendix 2)

**Table 12. Extended leak off test results for Mena Murtee-1.** bbl = oil barrel. psi = pounds per square inch.

| Cycle | Volume (bbl) | Leak off point (psi) | Pump volume (bbl) | Shut in Pressure (psi) | Time (min) | Bleed (psi) | Return (bbl) |
|---|---|---|---|---|---|---|---|
| 1 | 1.55 | 1947 | 0.25 | 1694 | 30 | 1637 | 1.3 |
| 2 | 1.35 | 2118 | 0.25 | 1618 | 30 | 1576 | 1.1 |
| 3 | 1.20 | 1900 | 0.25 | 1581 | 30 | 1554 | 1.05 |

Wireline formation testing was undertaken to gather in-situ permeability, pressures and reservoir fluid samples from sandstone units of interest. Draw down – build up tests (mini-DST) straddling 1 metre intervals were attempted at five depth intervals (Figure 10 and Figure 11; Table 13). Tests were successfully completed at four intervals, including repeats at two intervals, and reservoir fluids were collected from three intervals (Table 13). A failed test at Station 8 was due to a mechanical failure that prevented pressure to build up in the packers. The tests at the four successful stations gave good data quality sufficient to get an accurate indication of permeability. The results suggest that three of the four intervals have permeability suitable for $CO_2$ storage (Stations 7, 10 and 13). The high skin for the Station 7 test is probably due to incomplete clean-up of the near wellbore region. The permeability data and fluid samples formed an essential input into the reservoir and geochemical modelling undertaken by the CO2CRC, although high mud contamination levels in the samples prevented a full interpretation of the chemistry of the reservoir fluids (Appendix 2).

**Table 13. Summary of results from wireline formation tests at Mena Murtee-1.** Pi = reservoir initial pressure. K = permeability.

| Station # | Interval (m) | Pi (psia) | K (md) | Skin factor | # of fluid samples |
|---|---|---|---|---|---|
| 7 – 1 | 1633.00 – 1634.00 | 2295.2 | 233.7 | 58.1 | No sampling |
| 7 – 2 | 1633.00 – 1634.00 | 2295.7 | 260.1 | 50.4 | --- |
| 8 – 1 | 1618.00 – 1619.00 | Test failed | | | |
| 10 – 1 | 1531.50 – 1532.50 | 2150.2 | 553.8 | 15.3 | 1 sample |
| 13 – 1 | 1490.30 – 1491.30 | 2089.5 | 573.4 | 10.2 | 6 samples |
| 14 – 1 | 1406.50 – 1407.50 | 1981.6 | 24.7 | 6.3 | 5 samples |
| 14 - 2 | 1406.50 – 1407.50 | 1977.8 | 24.3 | 5.8 | --- |

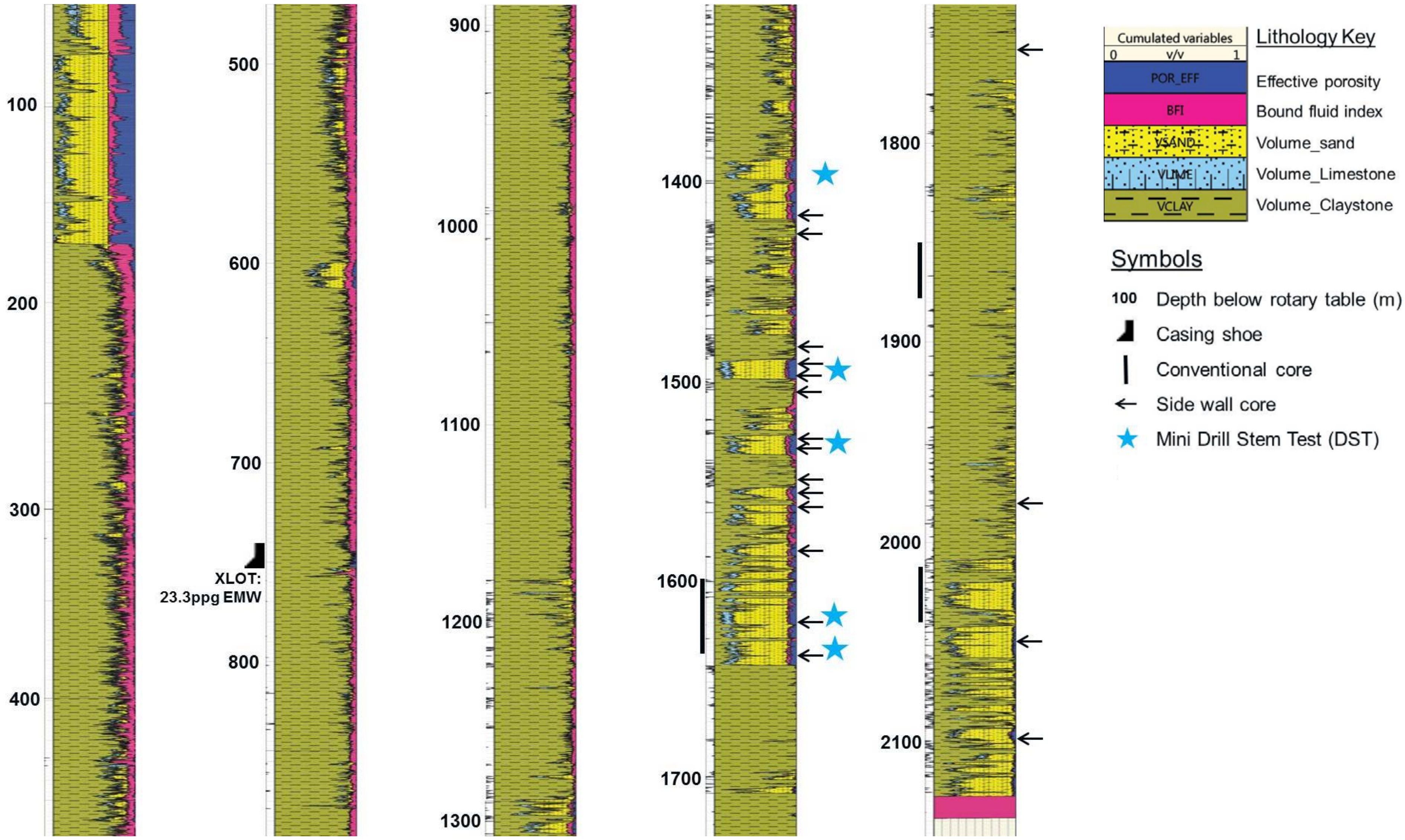


**Figure 10. Petrophysical interpretation of the lithology intersected at Mena Murtee-1.** Four sandstone units of interest are discernable between 1388 and 1641m beneath a massive claystone of >1km in thickness. Coring and testing depths are also depicted.

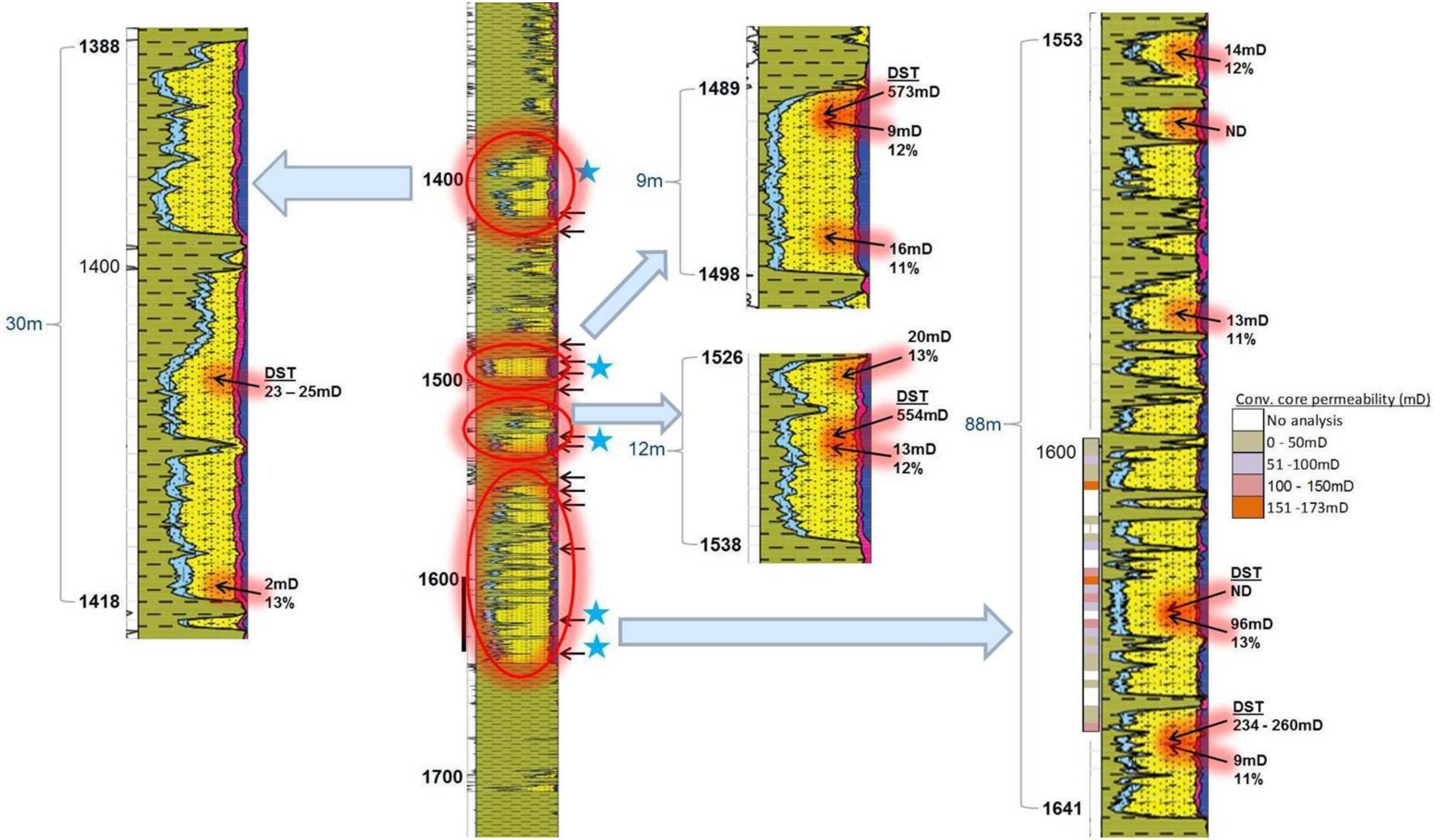


**Figure 11. Petrophysical interpretation of sandstone units of interest at Mena Murtee-1.** Porosity (%) and permeability (Kinf mD) results from side wall cores, conventional cores, and mini DSTs are given. Refer to Figure 10 for symbol and lithology legends. ND = No Data.

### 3.2.4. Geothermal Gradient

Bottom hole temperatures recorded during wireline logging were analysed using a Horner Plot to estimate a geothermal gradient of 2.8 degrees Celsius per 100 m, which was similar to the gradient calculated for Tiltagoonah-1. This data will serve to improve knowledge of the state's geothermal potential and increase the accuracy of existing heat flow mapping.

### 3.2.5. Laboratory Analysis

A sampling and testing program was developed to systematically sample the cored sections. A total of 68 samples were selected from the conventional cores and side wall cores and subjected to a range of tests:

- 44 sandstone samples for horizontal RCA, 13 for vertical RCA (permeability, porosity, grain density)
- 4 sandstone samples for relative permeability testing
- 64 samples representative of the range of lithologies for petrographic analysis (thin section, optical microscopy, SEM-EDS, XRD)
- 12 samples representative of the range of lithologies for QEMSCAN analysis
- 10 claystone samples and 2 drill cuttings samples for MICP analysis
- 8 claystone samples for wettability testing

Most of the analyses were done by Intertek Geotech. Exceptions included the relative permeability (core flood) testing undertaken by Core Laboratories, three MICP tests done by the University of Adelaide as a component of the CO2CRC research project, and the QEMSCAN analysis done by FEI also for the CO2CRC project.

*Porosity and Permeability*

An intensive program of porosity and permeability testing of the Mena Murtee-1sandstone cores was undertaken to gain a detailed understanding of the rock properties. The results are presented below in Figure 12, Figure 13 and Table 14. The core porosity results closely matched the porosity estimates from wireline logging. In addition, the core permeability results from 1598 and 1631 m (max. 173 mD) also closely matched the permeability results from the mini-DST at 1633 m (233-260 mD). Together these datasets indicate that the sandstone units may be prospective for $CO_2$ storage.

The porosity and horizontal and vertical permeability (Kinf) of the conventional 4" cores averaged 7.8%, 59.6 mD, and 40.0 mD, respectively. However, there were large differences between the petrophysical properties of relatively porous sandstones cored above 1632 m and the tight sandstones cored below 2012 m (Figure 12, Figure 13 and Table 14). Hence, the average values for porosity and horizontal and vertical permeability increased to 8.7%, 70.2 mD, and 53.4 mD, respectively, for the cores from the prospective sandstone reservoir between 1553 and 1641 m only. The median porosity and horizontal permeability for this prospective interval was 9.0% and 65.0 mD. The average and median horizontal permeability allow the injectivity (kh – permeability times thickness) of this 88 m thick interval to be quickly estimated to be 6,177 and 5,720 mDm, respectively. Considering an ideal reservoir interval for injectivity is above 6000 mDm, and 3000 mDm represents a good reservoir interval (Bradshaw et al., 2013), these estimates are encouraging. Another interesting feature of this prospective reservoir is that the ratio of vertical to horizontal permeability (kv:kh) averaged 0.95, indicating an isotrophic sandstone lithology with little difference in permeability in either a horizontal or vertical direction. This is typical of a braided stream depositional environment (M. Bunch, CO2CRC, pers. comm.; Appendix 2).

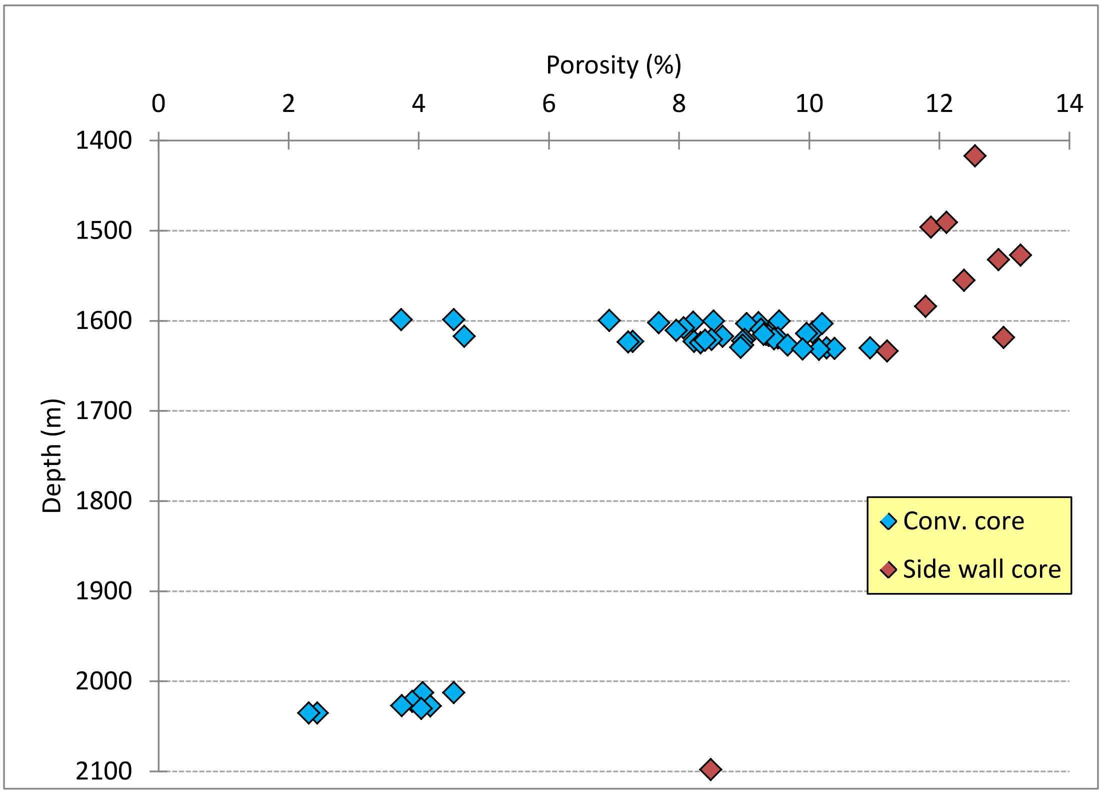


**Figure 12. Porosity of cores tested at 800 psi from Mena Murtee-1.**

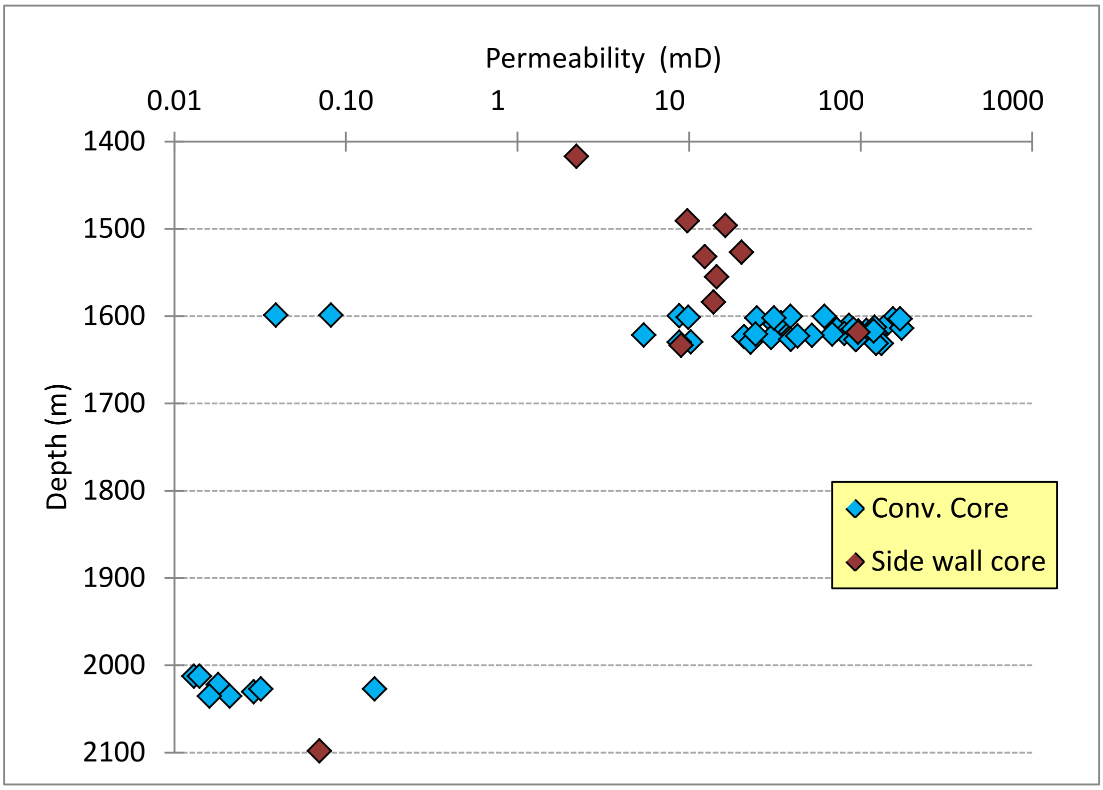


**Figure 13. Permeability (Kinf) of cores tested at 800 psi from Mena Murtee-1.**

**Table 14. Mena Murtee-1 RCA results.** H & V = horizontal & vertical plug.

| Plug ID | Depth (m) | Porosity at 800psi | Grain Density (g/cc) | Permeability at 800 psi Kair (mD) | Klinkenberg Permeability Kinf (mD) |
|---|---|---|---|---|---|
| MM1_001H | 1598.79 | 3.73 | 2.67 | 0.0892 | 0.0820 |
| MM1_001V | 1598.82 | 4.54 | 2.67 | 0.0460 | 0.0390 |
| MM1_003H | 1599.59 | 6.93 | 2.65 | 9.044 | 8.778 |
| MM1_005H | 1600.22 | 8.53 | 2.65 | 64.64 | 61.64 |
| MM1_005V | 1600.26 | 9.54 | 2.65 | 40.62 | 39.07 |
| MM1_006H | 1601.49 | 8.22 | 2.65 | 10.66 | 9.91 |
| MM1_007H | 1602.05 | 7.69 | 2.65 | 25.55 | 24.85 |
| MM1_007V | 1602.10 | 9.22 | 2.65 | 32.07 | 31.31 |
| MM1_009H | 1603.05 | 9.04 | 2.65 | 157.2 | 154.7 |
| MM1_014 | Unable to cut plug | | | | |
| MM1_016H | 1607.61 | 8.07 | 2.65 | 35.32 | 34.44 |
| MM1_017H | 1609.36 | 9.26 | 2.65 | 33.63 | 31.63 |
| MM1_018H | 1610.50 | 7.96 | 2.65 | 86.19 | 85.52 |
| MM1_019H | 1613.04 | 9.39 | 2.65 | 139.9 | 135.9 |
| MM1_019V | 1612.93 | 10.05 | 2.65 | 122.9 | 120.7 |
| MM1_020H | 1613.90 | 9.96 | 2.65 | 176.3 | 173.5 |
| MM1_022H | 1615.14 | 9.34 | 2.65 | 74.06 | 72.76 |
| MM1_023H | 1616.31 | 9.38 | 2.65 | 111.9 | 108.0 |
| MM1_024H | 1617.16 | 8.67 | 2.65 | 100.8 | 97.1 |
| MM1_024V | 1617.20 | 4.70 | 2.65 | 123.6 | 118.9 |
| MM1_026H | 1619.12 | 9.52 | 2.65 | 123.6 | 122.3 |
| MM1_027H | 1620.07 | 9.46 | 2.65 | 83.01 | 80.37 |
| MM1_028H | 1620.65 | 9.01 | 2.65 | 71.86 | 68.36 |
| MM1_028V | 1620.69 | 8.50 | 2.65 | 25.46 | 24.42 |
| MM1_030H | 1622.16 | 8.98 | 2.65 | 53.81 | 51.97 |
| MM1_031H | 1622.70 | 7.29 | 2.65 | Fractured | |
| MM1_031V | 1622.75 | 8.23 | 2.65 | 44.65 | 42.98 |
| MM1_032H | 1623.35 | 7.22 | 2.65 | 22.44 | 20.92 |
| MM1_033H | 1624.54 | 8.33 | 2.65 | 31.82 | 30.14 |
| MM1_034H | 1626.84 | 8.98 | 2.65 | 41.44 | 39.19 |
| MM1_034V | 1626.88 | 9.67 | 2.65 | 95.38 | 93.88 |
| MM1_036H | 1629.55 | 8.95 | 2.65 | 11.80 | 10.23 |
| MM1_037H | 1630.00 | 10.27 | 2.65 | 23.51 | 22.80 |
| MM1_037V | 1630.03 | 10.94 | 2.66 | 9.027 | 8.762 |
| MM1_038H | 1630.82 | 10.39 | 2.66 | Fractured | |
| MM1_040H | 1631.50 | 10.15 | 2.65 | 135.3 | 132.4 |
| MM1_045H | 2012.58 | 4.06 | 2.67 | 0.0145 | 0.0130 |
| MM1_045V | 2012.65 | 4.54 | 2.67 | 0.0154 | 0.0140 |
| MM1_047H | 2022.27 | 3.90 | 2.66 | 0.0197 | 0.0180 |
| MM1_048H | 2027.23 | 4.18 | 2.66 | 0.1501 | 0.1470 |
| MM1_048V | 2027.15 | 3.74 | 2.65 | 0.0334 | 0.0320 |
| MM1_049H | 2030.23 | 4.04 | 2.65 | 0.0304 | 0.0290 |
| MM1_050H | 2035.35 | 2.44 | 2.68 | 0.0222 | 0.0210 |
| MM1_050V | 2035.27 | 2.31 | 2.68 | 0.0165 | 0.0160 |
| Rel K 10 | 1603.17 | 10.2 | 2.64 | 172 | 170 |
| Rel K 21 | 1615.00 | 9.3 | 2.65 | 91.9 | 90.9 |
| Rel K 29 | 1621.54 | 8.4 | 2.96 | 5.99 | 5.44 |
| Rel K 39 | 1631.28 | 9.9 | 2.64 | 127 | 123 |
| SWC _1.1 | 2098.00 | 8.49 | 2.65 | 0.0738 | 0.0700 |
| SWC _1.5 | 1633.50 | 11.20 | 2.65 | 9.219 | 8.986 |
| SWC_ 1.6 | 1618.50 | 12.99 | 2.65 | 97.67 | 96.85 |
| SWC_ 2.2 | 1584.00 | 11.79 | 2.65 | 14.37 | 13.90 |
| SWC _2.4 | 1555.00 | 12.38 | 2.65 | 15.64 | 14.46 |
| SWC_2.6 | 1532.00 | 12.91 | 2.65 | 13.43 | 12.34 |
| SWC_2.7 | 1527.00 | 13.25 | 2.65 | 20.22* | Plug too small |
| SWC_2.9 | 1496.00 | 11.87 | 2.65 | 16.28* | Plug too small |
| SWC_2.10 | 1490.80 | 12.11 | 2.65 | 9.76* | Plug too small |
| SWC_2.13 | 1417.00 | 12.55 | 2.65 | 2.41 | 2.21 |

* indicates permeability data which are indicative only due to the small plug size

There was an overall positive correlation between porosity and permeability (Figure 14). In addition, there was also a distinct clustering of the results from conventional cores and the side wall cores (Figure 12, Figure 13, Figure 14), suggesting some sort of sampling bias may be present. The cause is undetermined; however it may occur due to differences in the techniques for cutting and handling the two types of cores and/or by differences in the way they were treated in the lab.

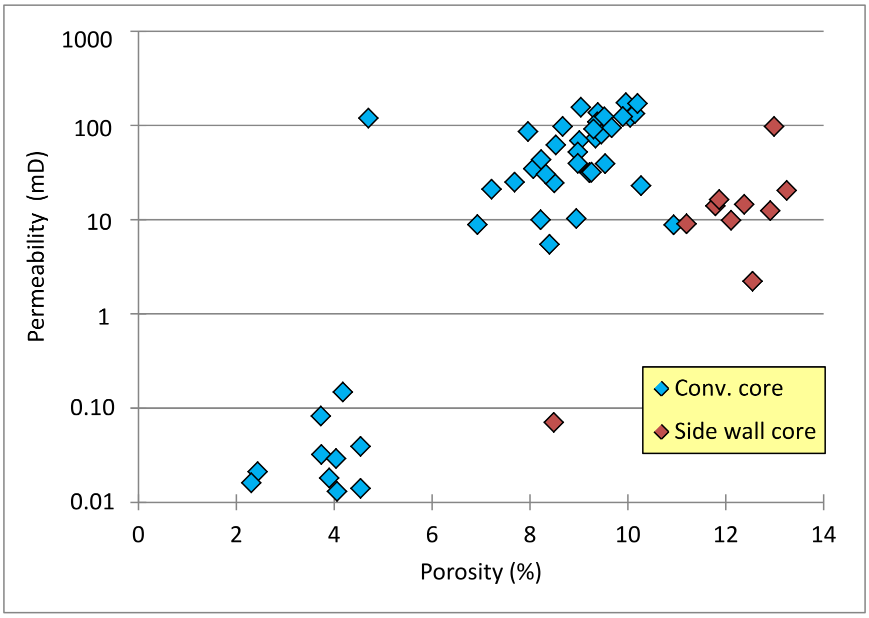


**Figure 14. Cross plot of porosity and permeability (Kinf) of Mena Murtee-1 cores.**

During coring activities at the well, the bottom 2/3rd of Core No. 1 was dropped and broken whilst being retrieved at the rotary table. To mitigate future risk, the core handlers underwent refresher training and no further incidents occurred. The incident caused varying degrees of damage to the lower section of this core; however there were no obvious effects on the porosity and permeability results from RCA with core data from the dropped interval plotting in a similar pattern to the remainder of the data from this core (Figure 15).

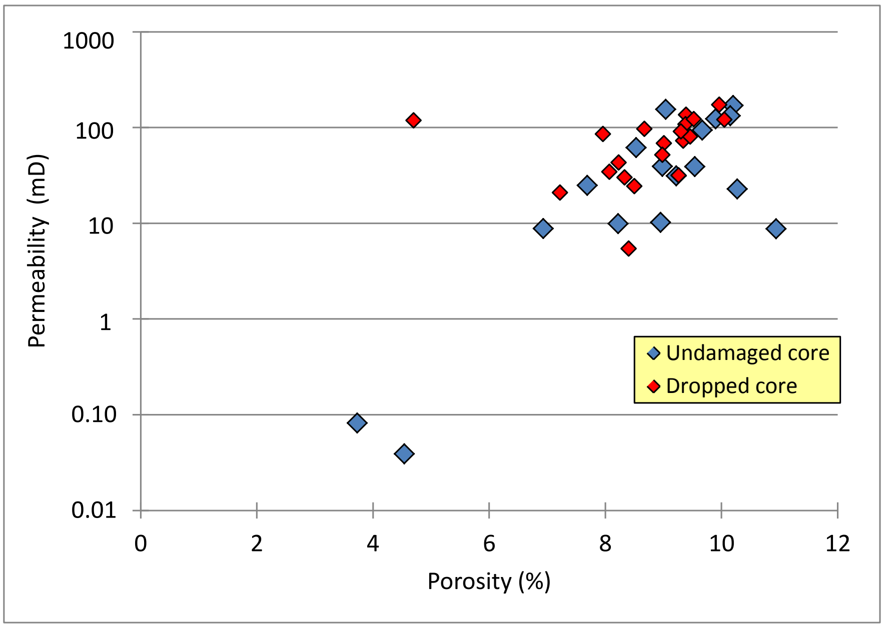


**Figure 15. Cross plot of porosity and permeability values from Mena Murtee-1 conventional undamaged and dropped cores cut between 1598 and 1631 m.**

The relative permeability results for the four sandstone samples taken from depths between 1603 and 1631 m are presented in Table 15. The porosity, permeability, and grain size results from this work by Core Laboratories closely matched the RCA data from Intertek Geotech for samples of corresponding depths (Table 14 and Table 15), thereby providing confidence that the results from the two labs are compatible. The relative permeability results were favourable for $CO_2$ storage. An average of 45.4% of the pore space in the samples was filled with gas (i.e. gas saturation) and hence 54.6% of the reservoir fluid was retained (i.e. the irreducible water saturation or Swr). The relative permeability of the samples (i.e. gas endpoint relative permeability or Kg) averaged 47.13 mD. This mean increases to 62.77 mD when the low permeability sample from 1621 m (Sample 29) is excluded; a sample specifically included in the analysis to gain an understanding of the relative permeability of the tighter sandstones within this unit.

**Table 15. Summary of the Mena Murtee-1 unsteady-state gas ($N_2$) – water relative permeability analysis results (at 2050 psi Net Overburden Pressure).** Mean[2] excludes Sample 29 data. Refer to text above for an explanation of terminal condition terms.

| Sample No. | Depth (m) | Kinf (md) | Kair (md) | Porosity (%) | Grain Density (g/cc) | Kw (100% Sw) at NOBP (Md) | TERMINAL CONDITIONS | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Gas Saturation (frac pv) | Swr (frac pv) | Kg at Swr (md) | Krg at Swr (md) |
| 10 | 1603.17 | 170 | 172 | 10.2 | 2.64 | 131 | 0.547 | 0.453 | 94.3 | 0.720 |
| 21 | 1615.00 | 90.9 | 91.9 | 9.3 | 2.65 | 60.0 | 0.388 | 0.612 | 48.8 | 0.814 |
| 29 | 1621.54 | 5.44 | 5.99 | 8.4 | 2.96 | 0.409 | 0.426 | 0.574 | 0.218 | 0.534 |
| 39 | 1631.28 | 123 | 127 | 9.9 | 2.64 | 62.0 | 0.456 | 0.544 | 45.2 | 0.729 |
| | | | | | | **Mean** | **0.454** | **0.546** | **47.13** | **0.699** |
| | | | | | | **Mean[2]** | **0.464** | **0.536** | **62.77** | **0.754** |

Understanding the diagenetic and metamorphic processes that have affected a potential storage area is helped by microscopic examination. A thin section was produced from each sample sent for RCA and examined. The porosity and permeability of the samples has been affected by diagenetic and metamorphic processes during formation and subsequent deformation but not to the extent of Tiltagoonah-1. The tested sandstone samples are very fine to fine grained and moderately to well sorted. Minor differences exist in the cementing process. The granular framework of the sandstones is moderately well compacted which results in sutured contact, deformation of ductile grains and decreased porosity. The grain assemblage of the sandstones is described as mature and predominantly composed of monocrystalline quartz with few polycrystalline quartz grains and plagioclase heavily altered to sericite, kaolinite and other clays. Diagenetic cementation is dominated by quartz overgrowth development as well as intergranular clay formation. Overgrowth crystals are common and fill the intergranular areas classifying many of the samples as very mature sandstones. Porosity is generally visible except in samples with heavier compaction.

Figure 16 through to Figure 21 are photomicrographs of the samples with highest porosity and permeability values from Mena Murtee-1. The blue sections illustrate where porosity exists and show good porosity over a series of samples from 1490.80–1612.93 m. The porosity differences between Tiltagoonah-1 and Mena Murtee-1 are easily visible using thin sections. The siltstones that were examined do not exhibit much visible porosity, but may have micropores in the matrix.

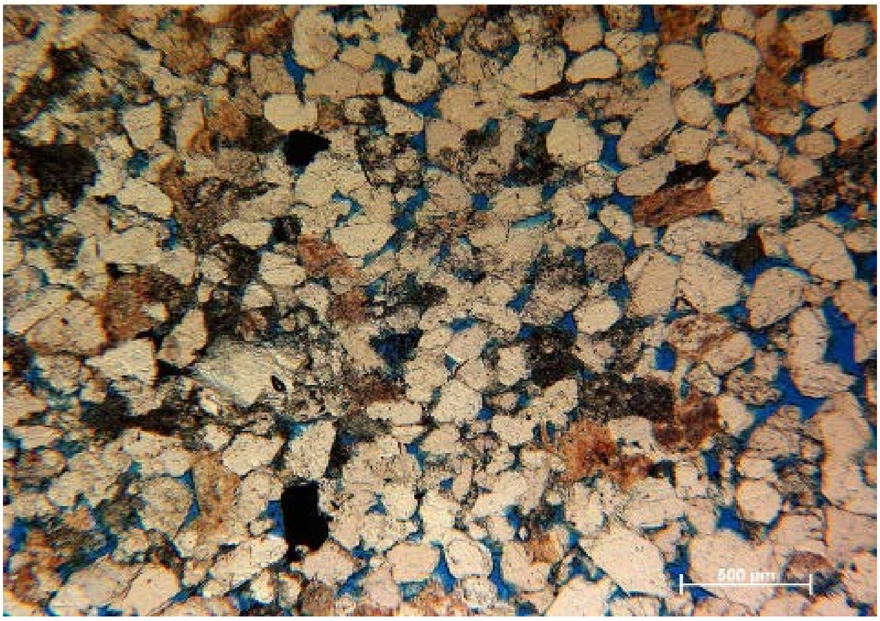


**Figure 16. Sample MM1-37 (40x magnification).**

Well rounded, well sorted, fine grained quartz exhibits overgrowth cementation. Porosity (blue) is good and mostly primary intergranular pores with a few secondary dissolution pores. Pore spaces are generally filled with clays.

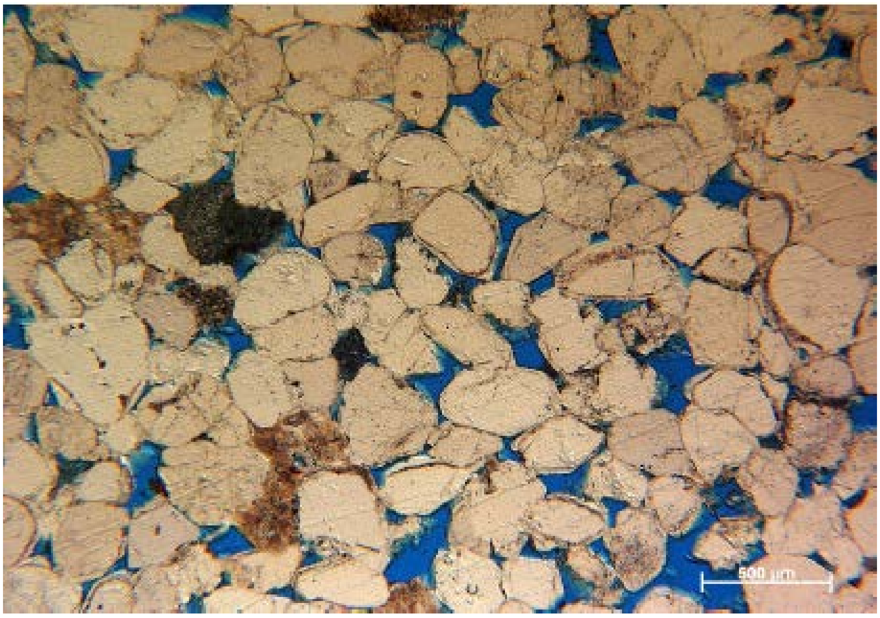


**Figure 17. Sample MM1-40 (40x magnification).**

Well rounded, well sorted, fine grained quartz exhibits overgrowth cementation. Porosity (blue) is good as mostly primary intergranular pores with a few secondary dissolution pores. Pore spaces are generally filled with clays.

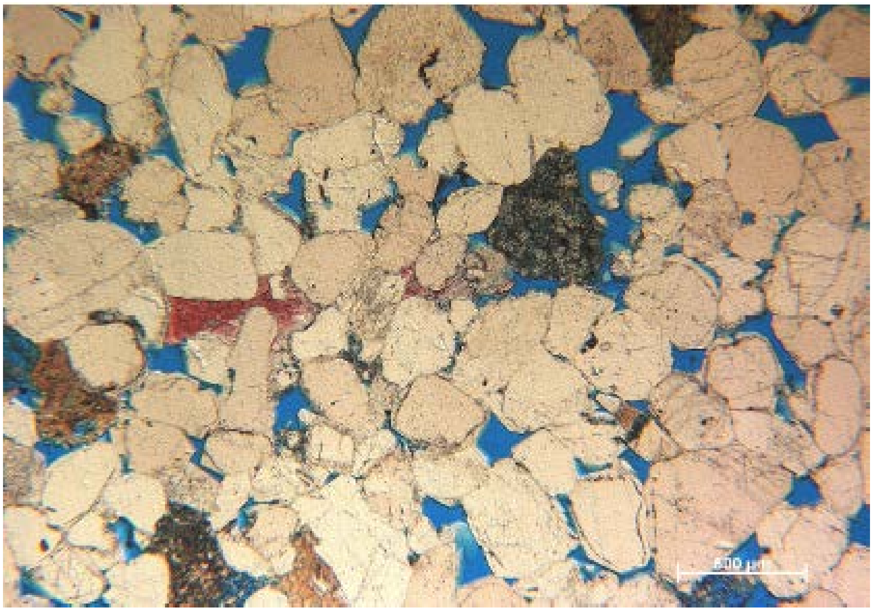

**Figure 18. Sample MM1-19 (40x magnification).**
Well rounded, well sorted, fine grained quartz exhibits overgrowth cementation. Porosity is good as mostly primary intergranular pores with a few secondary dissolution pores. Pore spaces are generally filled with clays.

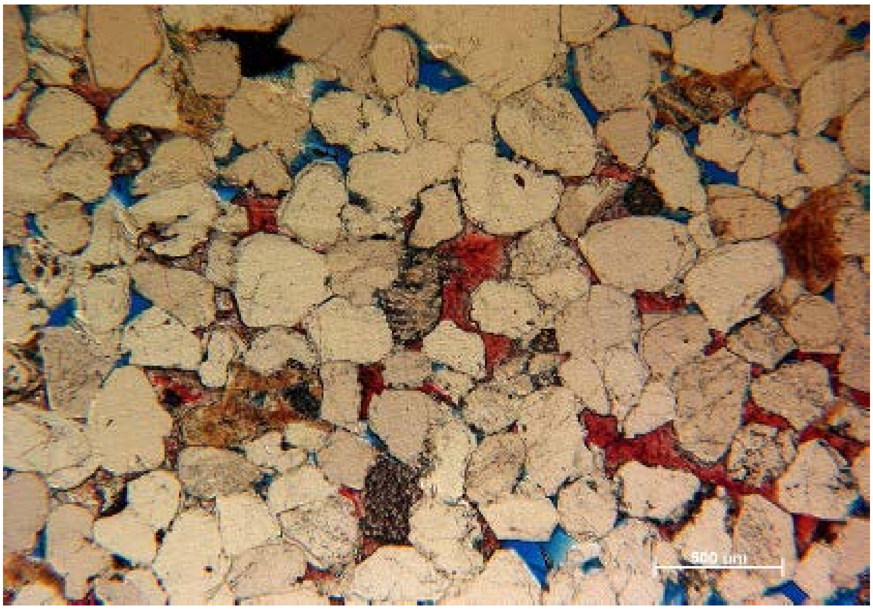

**Figure 19. Sample MM1-20 (40x magnification).**
Well rounded, well sorted, fine grained quartz exhibits overgrowth cementation. Rare mosaic calcite (red) forms between grains locally. Porosity is good as mostly primary intergranular pores with a few secondary dissolution pores. Pore spaces are generally filled with clays or calcite.

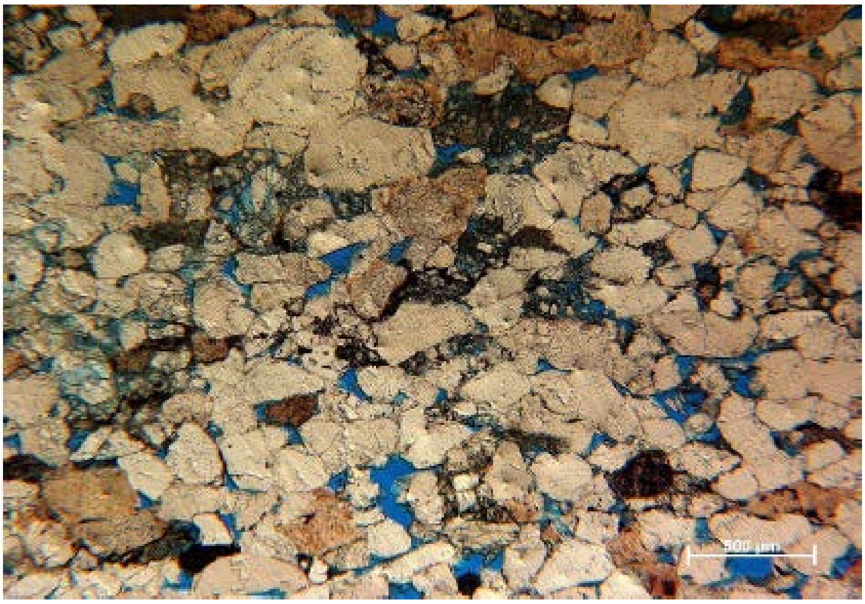

**Figure 20. SWC 2.9 (40x magnification).**
Well rounded, well sorted, fine grained quartz exhibits overgrowth development. Porosity is good as mostly primary intergranular pores with a few secondary dissolution pores. Pore spaces are generally filled with clays.

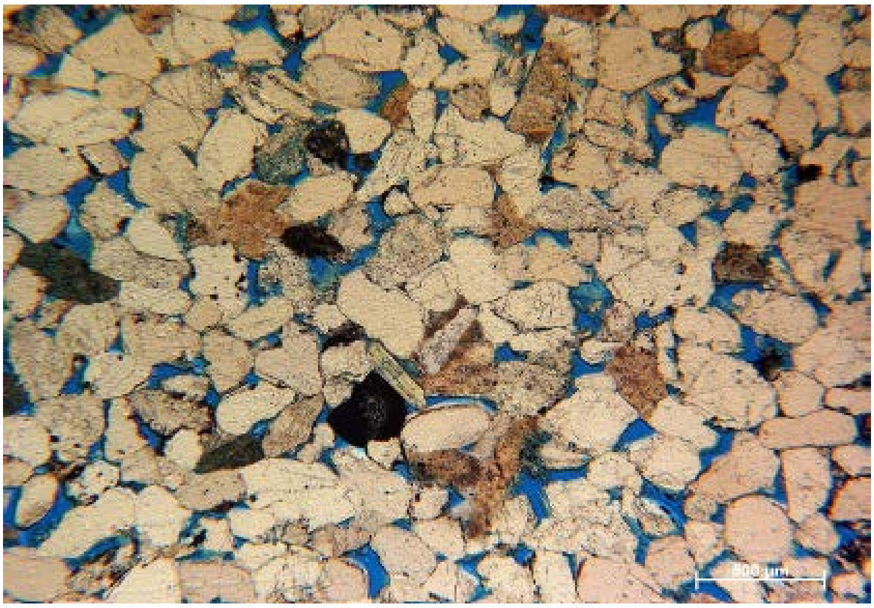

**Figure 21. SWC 2.10 (40x magnification).**
Well rounded, well sorted, fine grained quartz exhibits overgrowth development. Porosity (blue) is good as mostly primary intergranular pores with a few secondary dissolution pores. Pore spaces are generally filled with clays.

*XRD Analysis*
X-Ray powder Diffraction (XRD) analysis was conducted on 64 samples and measured the bulk composition of each sample and separately the clay composition. XRD testing provides a mineral composition by weight% for each sample and is especially good for identifying fine grained minerals. XRD also determines which form of a mineral is present which is useful in understanding metamorphic processes. The XRD data were used in the collaborative research projects.

*MICP Analysis*

MICP analysis was undertaken of the cores cut from the interbedded claystones within Unit 5 between 1426 and 1547 m to test their suitability as seals for the prospective sandstone units. $CO_2$ column heights (i.e. CO2 containment heights) calculated as part of the CO2CRC collaborative research project ranged between a maximum of 52 and 417 m using a contact angle of 0 degrees, and a minimum of between 26 and 208 m using a contact angle of 60 degrees (Appendix 2). Thus, in the majority of cases the seals were determined to have a column height capacity significantly larger than the underlying reservoir’s thickness. The many thinner claystone stringers observed within the Mena Murtee-1 stratigraphy may also serve to slow the vertical migration and increase the lateral sweep of injected $CO_2$. Analysis of drill cuttings from the overlying claystone Unit 4 at 755 m also gave favourable results with column heights ranging from 84 to 169 m for contact angles of 60 and 0 degrees, respectively. Testing of cores from below Unit 5 also indicated very competent sealing units (Appendix 2).

*HyLogger$^{TM}$ Analysis*

Core from Mena Murtee-1 underwent HyLogger analysis at the W. B. Clark Geoscience Building, Londonderry, NSW. The HyLogger analysis provided semi-quantitative information on the mineralogical composition of the core which was used to identify areas of interest not visible by macroscopic examination or from log data (Figure 22). These areas were targeted for additional testing, including for inclusion in collaborative work. Information on diagenesis and metamorphism can also be gained from the HyLogger data. The data was compared with well log data and changes in mineral abundances correlated to changes in well log data. Additional to the mineralogical composition data is high quality imaging of the core which is of benefit when looking at depositional environment conditions, boundaries and intrusives. The HyLogger data also assisted in selecting core samples for analysis and was used extensively by collaborative researchers.

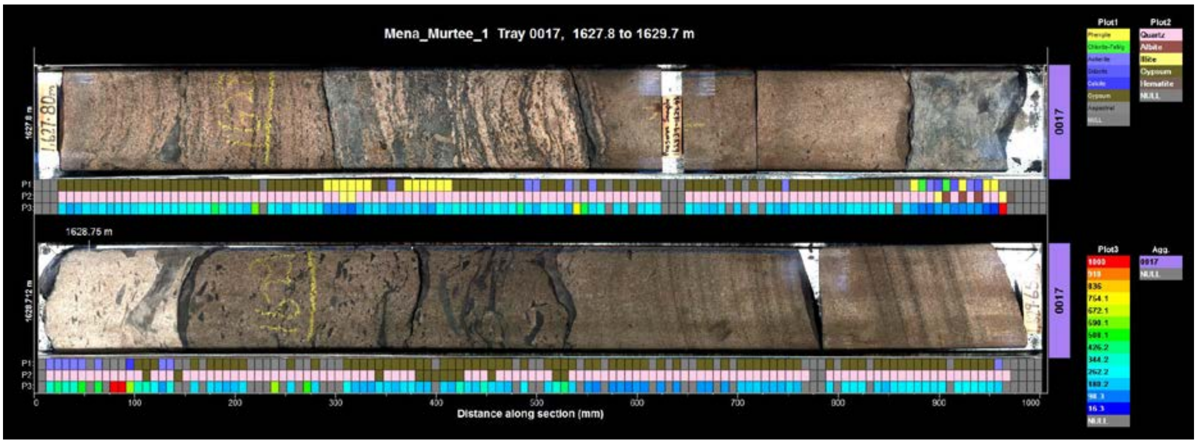


**Figure 22. Example of Mena Murtee-1 HyLogger imaging.** Included is the compositional analysis and mineral concentrations.

### 3.2.6. Conclusion

Overall the rocks encountered at Mena Murtee-1 were not as tenacious and dense as those encountered at Tiltagoonah-1. Three prospective sandstone reservoirs with good permeability were identified at a suitable depth for geosequestration, that were overlaid by competent intraformational and regional seals. This work highlights the prospectivity of the Pondie Range Trough as a storage site for $CO_2$, and further work is warranted to further characterise this sub-basin. The age of the intersected units remains unclear with palynology work commenced in an attempt to date or at least provide constraints on deposition to determine where within the stratigraphy the deeper Pondie Range Trough rocks sit. The drilling of Mena Murtee-1 has greatly increased the amount of data for the sub-basin and will be available for continued research by government authorities, academia and industry.

## *3.3. Summary of the CO2CRC Collaborative Research Project*

The CO2CRC project, developed to complement the data acquisition program, was essential in understanding the evolution of the sub-basins and the properties that can affect the region if $CO_2$ storage was to progress. The four work packages provided a first pass assessment of the areas proximal to the well locations and also extend further to also include the sub-basins. The executive summary and recommendations from the CO2CRC report are reproduced below and the full report is provided in Appendix 2.

### 3.3.1. Geological Characterisation and Modelling

A basic Tiltagoonah-1 well data interpretation, consistent with drilling observations, indicated that intergranular cementation has occluded most of the original pore space in the geological formations, rendering the entire section as non-prospective for $CO_2$ storage. Given the units intersected, further characterisation and modelling work within the Nelyambo Trough was not undertaken.

Core and well log analysis was undertaken to characterise the geological system of the prospective Pondie Range Trough storage region. This included an interpretation of local depositional environments, development of a calibrated facies classification scheme, top and/or intraformational seals containment analysis, and geological modelling.

The Mena Murtee-1 well data interpretation found several sand-rich intervals between 1290 and 1640m mD. Key porous intervals include mD ranges: 1386-1418; 1488-1498; 1526-1535; 1552-1641. 1552.5-1641 m mD in particular is an exceptionally thick sand interval interbedded with 1-2 m thick shale beds. Key features of these intervals are: low clay matrix; effective porosities of 5-12%; and permeabilities in the order of 10s – 100s mD. The thick interbedded sand-shale section presents long-term injection potential with shale interbeds providing vertical migration barriers and enhanced lateral sweep. The cleaner sandstone intervals, in particular those at 1488-1498 and 1526-1535 m MD, individually offer smaller-scale $CO_2$ injection potential. Based on the positive identification of porous units, a static geological model of the Pondie Range trough was constructed.

A stratigraphic prognosis was achieved for the Mena Murtee-1 location, using the Pondie Range-1 well (28km SW of Mena Murtee-1) and a few 2D seismic survey lines. The prospective storage interval was correlated to the Late Devonian Ravendale Interval of the Mulga Downs Group. The porous sandstone intervals are likely to be fluvial channels, bound by interfluve or lacustrine muds.

The Pondie Range Trough static geological model was developed by adopting existing seismic horizon markers into the stratigraphic framework, depth converting the 2D seismic lines using the Mena Murtee-1 interval velocity model, applying a 10-class facies scheme constrained by the stratigraphy, and populating the petrophysical properties with porosity and permeability data from Pondie Range-1 and Mena Murtee-1. Three geological realisations were generated from the static model. These were a base case model realisation, an axial geobody orientation realisation using the ‘raw’ permeability log, and a second axial geobody realisation with permeability increased by a factor of ~8.25. The stratigraphic framework and modelling layering underpinning all realisations were used to underpin the $CO_2$ Injection & Plume Migration Modelling work package.

Seals and intraformational barriers were analysed from both Tiltagoonah-1 and Mena Murtee-1. MICP analysis on samples showed a $CO_2$ containment height from 124 m to 985 m (Tiltagoonah -1) and 52 m to 417 m for Mena Murtee-1, when using a contact angle of 0 degrees in the calculation of column height retention. Using a 60 degrees contact angle in the sensitivity analysis decreased the minimum column heights to a range of 62 to 493 m (Tiltagoonah-1) and 26 to 208 m (Mena Murtee-1).

The multiple, sufficiently high quality reservoir units with suitable top seals interpreted in the Mena Murtee-1, and modelled across the Pondie Range Trough, provide an initial positive indicator for storage prospectivity for this structure within the Darling Basin. With this geological understanding, the Pondie Range Trough static geological model was utilised for the investigation of $CO_2$ injectivity and capacity.

### 3.3.2. $CO_2$ Injection & Plume Migration Modelling

Analytical models using CO2CRC’s software MonteCarbon and 2D radial numerical flow simulations using TOUGH2 reservoir simulator software computed the injectivity and storage capacity at the Mena Murtee-1 location and of the broader Pondie Range Trough. Due to data uncertainty and a lack of geological and hydraulic information away from Mena Murtee-1 detailed 3D simulations were not considered appropriate for this study. As the contiguity of the various reservoir intervals is not clear, it is uncertain whether to assume open or closed reservoir conditions, the latter resulting in approximately 50% less injectivity as indicated by the statistic of a wide range of Monte Carlo simulations.

Based on the data at hand and the model assumptions, the modelling results indicate sufficient single well injectivity at 1440-1640 m MD at Mena Murtee-1 for a pilot-scale $CO_2$ injection operation (i.e. 100 ktpa for 2 years) with pressure change <<1 MPa and plume radius on the order of 100 m. An injection rate of 1 Mtpa for 25 years is feasible with injection pressures well below the fracture pressure of the reservoir and a plume radius less than 2.5 km. A maximum single well injectivity of 4 Mtpa is possible without approaching the fracture pressure, assuming the entire 200 m reservoir interval is perforated, but due to well equipment technical limits would in practice likely require more than one well in this location. These numbers are contingent on additional wells to determine the lateral extent of potential reservoir units. Additional injectivity could be achieved by also completing thinner reservoir units between 1288 m and 1419 m depth, which are less well constrained by core and DST data, and/or by using horizontal well completions.

Theoretical Pondie Range Trough $CO_2$ storage capacity, based on the basin volumetrics, ranges between 48 and 1730 Mt, with a mean capacity of ~650 Mt over 25 years. Considering the permeability of the potential injection horizons and their areal distribution, the simulations found that up to 12 Mtpa with up to 10 injectors is a realistic measure of the trough’s injectivity.

These numbers do justify further appraisal of the Pondie Range Trough as a potential future $CO_2$ storage site. It is important to reiterate that the injectivity and storage capacities are based on limited data. There is significant uncertainty related to the actual properties and distribution of reservoir and seal units and their geometries; factors that may impact capacity, injectivity and containment security. To reduce this uncertainty, it is recommended in particular that more wells and seismic are acquired to confirm lateral contiguity of reservoir-quality intervals; long-term drill stem tests to determine pressure continuity in reservoirs beyond the immediate well bore; core tests to assess $CO_2$ drainage and imbibition; well tests for characterising relative permeability and irreducible saturation; and further modelling of scenarios to test parameter sensitivities.

### 3.3.3. Geomechanical Evaluation

Data from the Tiltagoonah-1 and Mena Murtee-1 wells were analysed to characterise the in situ stress field, fracture gradient and the relative stability of faults in the zones of interest in the Darling Basin. An analysis of the in situ stress determined a reverse to reverse/strike-slip faulting regime, with the maximum horizontal stress direction E-W, roughly consistent with surrounding basins. The fracture gradient for the two wells ranged from 24.5 MPa/km for Mena Murtee-1 to 26.7 MPa/km for Tiltagoonah-1.

Fault orientations at highest risk of reactivation would be both low angle faults striking approximately N-S and high angle faults striking WNW and ENE. All geomechanically modelled faults were capable of safely supporting significant increase in pore fluid pressure. A 5 MPa increase in pore pressure was interpreted as a threshold before risking fault reactivation. This threshold was derived for faults with poor orientation, low fault friction and cohesion and using the higher SHmax magnitude for the Pondie Range Trough. It is therefore considered at the low end of a likely fault reactivation pressure. Injection model outputs, with the maximum 4 Mtpa scenario, increased pressure up to 4.5 MPa, which was safely below the interpreted reactivation threshold.

It is important to note that the data presented represents a first step to sufficiently understanding the geomechanical framework of the Darling Basin. To gain higher certainty in the interpreted stress regime and develop a detailed 3D geomechanical model for appraising geological integrity, further in situ stress data and mechanical laboratory tests on key reservoir and seal samples is recommended.

### 3.3.4. Geochemical Analysis & Modelling

Formation water composition, mineral trapping capacity, and changes to porosity under $CO_2$ storage conditions over time, for the Mena Murtee-1 well were assessed, as well as a mineralogical analysis of Tiltagoonah-1, as a part of this work package. Core samples were characterised using various petrological techniques, including XRD, QEMSCAN and HyLogger to identify the mineralogy within different lithologies represented. In particular the quartz-rich sandstone sequence cored between 1598 and 1631 m was characterised with core derived permeability of up to 176 mD and porosity up to 12%.

Representative water chemistry for the prospective storage intervals was not possible to determine, due to significant drill mud contamination of the pore fluids sampled. The composition of shallow wellbore water at Mena Murtee-1, assumed to be representative for the Darling Basin, was used instead for the geochemical modelling. Similar fluid composition from the nearby Mount Jack-1 well at 1085 m depth supports this assumption.

Geochemical modelling identified the solubility of $CO_2$ under the conditions of the prospective reservoir unit from 1552 to 1641 m. These fluids, saturated with $CO_2$ led to an initial decrease in fluid pH from approximately 8.1 to 4.5. Subsequent mineral dissolution was modelled over 10,000 years. Dissolution of primarily albite increased pH to ~5.5. Minor clays were almost completely dissolved and kaolinite, quartz and some K-feldspar precipitated. Calcite was completely dissolved, however dolomite precipitated as a secondary carbonate mineral with a net precipitation of around 5.5 moles of carbonate from the equivalent of 1 kg of formation water over the 10,000 year reaction period. Overall, no significant storage risk was determined in the likely $CO_2$ – water – rock interactions for the Pondie Range Trough, and some minor mineralisation of the injected CO2 enhances storage security time.

### 3.3.5. Darling Basin $CO_2$ Storage Prospectivity

The geological characterisation of the Mena Murtee-1 and existing well and seismic data identified several porous, permeable sandstone units paired with suitable seals for the containment of supercritical $CO_2$ within the Pondie Range Trough. This stratigraphy, along with reasonably low risk of adverse storage-related geochemical and geomechanical effects, and reasonable injectivity and capacity suggests that the Pondie Range Trough of the Darling Basin is potentially viable for $CO_2$ geological storage. A caveat is that this initial assessment of the Pondie Range Trough is based on limited exploration data, and hence holds a high degree of uncertainty.

Analysis and interpretations of the initial Darling Basin Drilling Program data by the CO2CRC has determined potential for $CO_2$ storage within the range of 48 – 1730 Mt. This storage potential is sufficient to warrant further pre-competitive appraisal both of the Pondie Range Trough, refining the storage estimate. In addition, it is recommended that storage characterisation is expanded to other underexplored structures of the Darling Basin, to possibly increase the $CO_2$ geological storage resource for NSW and offer further sinks for managing the state's GHG emissions.

### 3.3.6. Recommendations

The geological characterisation and modelling of injectivity and capacity for the Pondie Range Trough has provided some positive indications for large scale storage of $CO_2$ within the Darling Basin. The prospective intervals encountered in Mena Murtee-1 were demonstrated through low resolution injectivity and capacity modelling to be a viable storage target for large scale $CO_2$ storage. This prospectivity in one of the Darling Basin troughs provides reasonable justification for the expansion of an exploration program to other underexplored structures in the region.

While modelling showed the Pondie Range Trough to have positive storage prospectivity, there are many areas where further work needs be undertaken to constrain the interpretations presented here and to reduce the identified uncertainties. Some of these recommendations are documented below. This set of activities is a recommendation for part of a continuing pre-competitive assessment of the Darling Basin:

1. The existing seismic lines across the Pondie Range Trough are inadequate for constraining models over the large region with a consistent level of uncertainty. A minimum of four new 2D seismic lines in the western half of the Pondie Range Trough is recommended, along with reprocessing of existing seismic, to provide greater geographic balance to the dataset currently used to inform the Pondie Range Trough Model (PRTM). Incorporating interpretations of additional survey lines postdating the seismic interpretation study of Willcox et al. (2003) would tighten control on modelled seismic horizons in the eastern

half. Extension of these lines into the neighbouring Poopelloe Lake Trough would assist in understanding the long term migration pathway of future large scale $CO_2$ injection.

2. The current scarcity and large distance between wells (2 wells, 28km apart) in the Pondie Range Trough creates a very large uncertainty in the prediction of petrophysical properties in the PRTM. It is recommended that a new delineation well be drilled within the NW quadrant of the Pondie Range Trough. The well placement would be refined after the seismic acquisition recommended above. This new well will provide additional high resolution data in this sparse data region, and importantly, complete a triangle of well data points within the Pondie Range Trough so facies and petrophysical property trends can be modelled in two dimensions. This would provide further insights into the Devonian palaeoenvironment and the distribution of potential $CO_2$ storage system components.

3. The structural and geomechanical controls on full field $CO_2$ needs to be resolved by developing a fault framework model. The current PRTM needs to delineate pressure compartments within the modelled stratigraphy for more accurate injection pressure build-up simulations, and to produce probability maps of potential formation damage and reservoir degradation. The acquisition of seismic (recommendation 1); specific well tests in the new well (recommendation 2); and a comprehensive structural and stratigraphic interpretation of the existing FMI data could be undertaken to assist in the population of this fault model and assess the risk of structural compartmentalisation within the trough.

4. A key uncertainty in the assessment of this region for $CO_2$ storage is the behaviour of the $CO_2$ in the near well environment, which strongly controls injectivity (permeability) and capacity. Drilling a new well for initial well testing, potentially linked to the execution of the 100 ktpa scenario, is recommended, allowing a better understanding of bulk permeability and residual trapping potential, important parameters for reducing the existing uncertainty in reservoir simulation models.

5. Given that formation water intersected at Mena Murtee-1 at the prospective interval is calculated as fresh, it is important to evaluate any possible resource use overlap or environmental implications associated with development of the $CO_2$ storage in the Pondie Range Trough. With the challenges of deriving water chemistry from the Mena Murtee-1 well, and the need to understand the groundwater system, it is recommended that a detailed hydrodynamic study of the Darling Basin’s Pondie Range Trough is undertaken. With new drilling (recommendation 2), it would be important that a new deep well should be configured for water production as a means to flush out contaminated and sample pristine water. Well testing (recommendation 4) would be able to provide the necessary pristine water sample.

# 4. Workplace Health and Safety

## *4.1. Planning*

Trade & Investment Secretary (as title holders) nominated Aztech as 'Operator' of the mine under the *Mine Health & Safety Act 2004* (MHS Act). Therefore, Aztech was recognised as the 'principal contractor' under the *Work Health and Safety Act 2011* (WHS Act) and as the 'mine operator' under the MHS Act.

The Department remained as the 'person conducting a business or undertaking' (PCBU) under the WHS Act and that Act imposes a general duty of care upon the PCBU, such as – *to ensure, so far as is reasonably practicable, the health and safety of workers engaged, or caused to be engaged by the PCBU*. The WHS also imposes obligations upon the Department's Secretary as an 'officer' of a public authority and head of the PCBU. Accordingly the Secretary must exercise 'due diligence' to ensure that the Department complies with its obligations under the Act.

The MHS Act imposed further obligations upon the project and nominated operator by requesting *the preparation of a Mine Safety Management Plan (MSMP) stating how the occupational health and safety of all persons will be protected*. Further, *no work is to be carried out on site unless the MSMP and Emergency Plan is implemented and complied with on site, including contractors*. Because of the size of the operation, being an exploration drilling rig and camp site, it was deemed appropriate that the project act in accordance with the 'Safety Management Kit for small-scale mines, quarries and extractive industry operations' (with self assessment toolkit) as developed by the NSW DRE.

Expert independent legal advice was sought from Henry Davis York, lawyers, (HDY) as to the obligations of the Department and Secretary to safety during the drilling program. Prior to receiving that legal advice from HDY, the NSW DRE had commenced an extensive safety / risk evaluation and planning program.

In summary, the list of actions below highlights steps taken by the Department and Aztech, to manage site safety:

- Risks were identified in consultation with all sub-contractors, three meetings were conducted with an independent facilitator. The final workshop involved a DWOP (drilling well on paper) and Hazard Identification (HAZID) program.
- A risk register with mitigation options treating each identified risk.
- Aztech (in consultation with drilling rig and camp contractors) developed the sites' MSMP including:
  - Safety Management Plan (SMP)
  - Emergency response Plan (ERP)
  - Spill Contingency Response (SCR)
  - Environment Management Plan (EMP)
- The NSW DRE developed a 'Crisis Management Plan'.
- MSMPs were peer reviewed and revised where necessary.
- A comprehensive reporting structure was devised
- A commitment to ongoing updating and improvement of all systems took place as a matter of course during the program.

Aztech engaged Petroleum Specialized Inspection Corp (PSI), an international rig inspection group, to inspect the Enerdrill rig prior to mobilisation. The scope of their work included visual inspection, review of all service records, checking of NDT (non destructive testing) records, reviewing of equipment certification, Preventative Maintenance System (PMS) evaluation, review of contractual requirements for compliance, safety management systems and emergency response plans. Where applicable, all items were inspected in line with recognised standards, guidelines and contractual requirements. Any outstanding matters were verified as corrected by Aztech prior to Aztech accepting the Rig on site prior to the commencement of drilling.

The NSW DRE engaged An Mea, a risk-based HSE Management Systems & Auditing consultant, within the petroleum and mining industries, to 'peer review' Aztech MSMPs for the project. They noted "*The system demonstrated by the SMP, EMP and ERP provide appropriate policy, planning, resourcing, identification of roles and responsibilities, and deliver sufficient management processes (investigation, audit, etc.) to provide a solid basis for implementation of the system at the site to meet the letter and intent of the applicable HSE legislation in NSW."* They did however raise specific minor comments which Aztech addressed and appendixed to the appropriate plans.

The An Mea report concluded *"the system of Enerdrill conforms to NSW Workplace Health and Safety Regulations 2011 with respect to delivering the required content of safe work method statements and deliver them in a manner that is fit-for-purpose for the activities planned."*

A final part of An Mea's commissioned work for the NSW DRE was unannounced site visits to audit the implementation of the MSMP to verify compliance. An Mea visited Tiltagoonah site on the 13 March 2014 to audit the implementation of the safety management plans and concluded *"On the basis of the gap analysis completed prior to the site visit contained in the report of 5 March 2014 (SWMS Gap Analysis 5Feb14.pdf) and the findings of the site audit identified above, it is the opinion of the Lead Auditor that the Enerdrill HSE management system in theory and practice meets the letter and intent of the legislation with regard to the content and implementation of a safe system of work."*

A similar audit inspection of the Mena Murtee site was also conducted on 14 April at the Mena Murtee site. "*The rig continues to demonstrate a very good safety culture, from the Rig Manager to the Leasehands, with a spirit of cooperation, problem solving and communication in evidence"*.

All sub-contractors arriving to site conformed to the MSMP and worked under the directions of the site drilling supervisor. All sub-contractors had to provide proof of compliance with respect to equipment certification, staff training and safety prior to commencement of work.

The NSW DRE had also worked closely with the Bureau of Meteorology (BoM) to understand the climate conditions for the area and the possibility of flooding, both from the Darling River (after extensive rain upstream) or localised flooding due to localised storms. The BoM provided a detailed report and websites for daily monitoring of weather, which assisted in the development of a Flood Response Plan for the drilling program. Another risk factor was heat stress due to day (and night) temperatures. This risk was mitigated by providing on-site air conditioned facilities and ice making (significant capacity) facilities.

Close working relationships were built with the local SES and Rural Fire Services. Each drill site had a fire cart on site for any emergency and ample water from the site's water storage system.

## 4.2. Results

Due to the extensive planning into WHS the following excellent results were achieved:

- Very good participation from all crews on site in Safety Management Program.
- Total of 47,376 man hours worked on site with no Lost-Time Injuries (LTIs).
- A 'stop card system' or work observation card system was implemented on site (Figure 23).

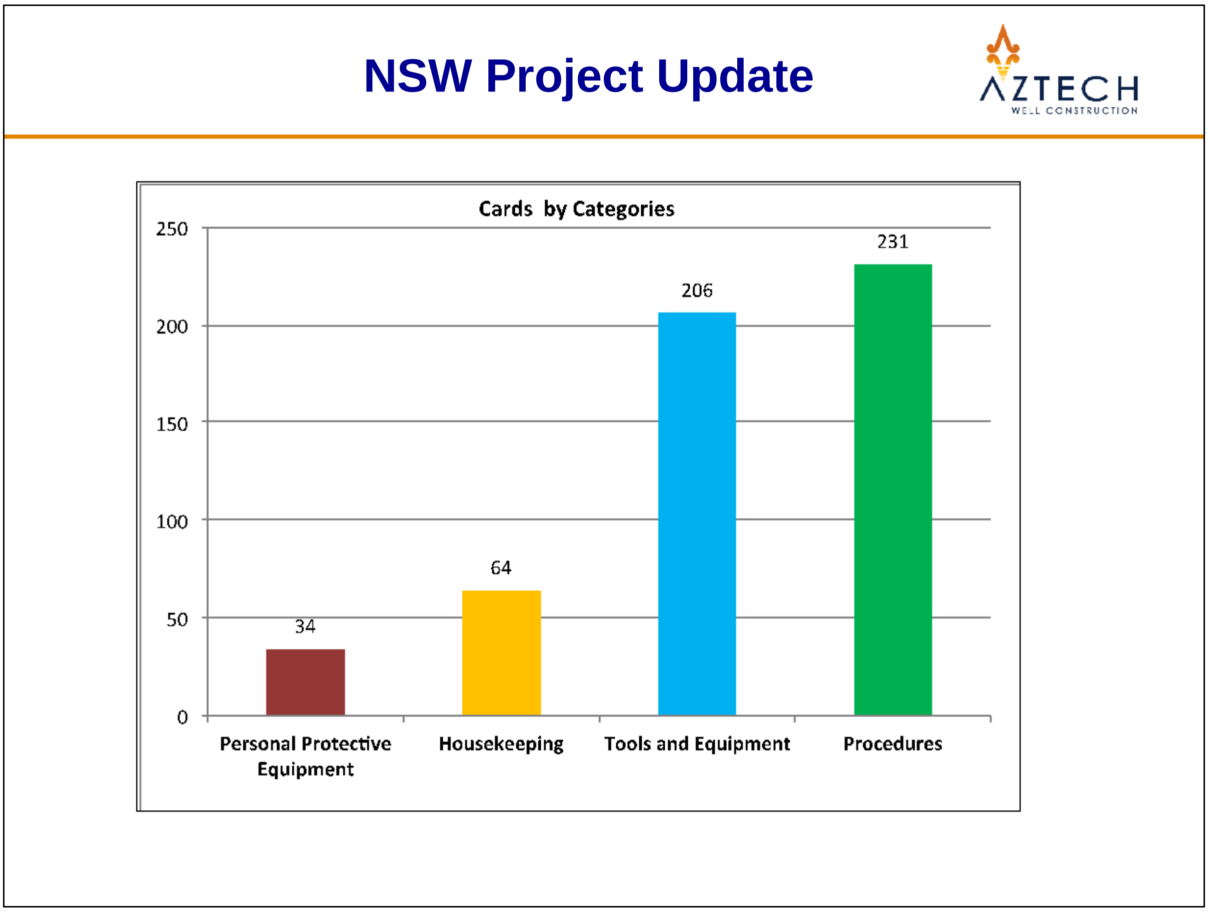


**Figure 23. Number of stop cards issued on the drill sites grouped into broad categories.**

Lead indicators were developed from meetings and 'stop cards' system and their frequency of issue on the drill sites is depicted in Figure 24 below.

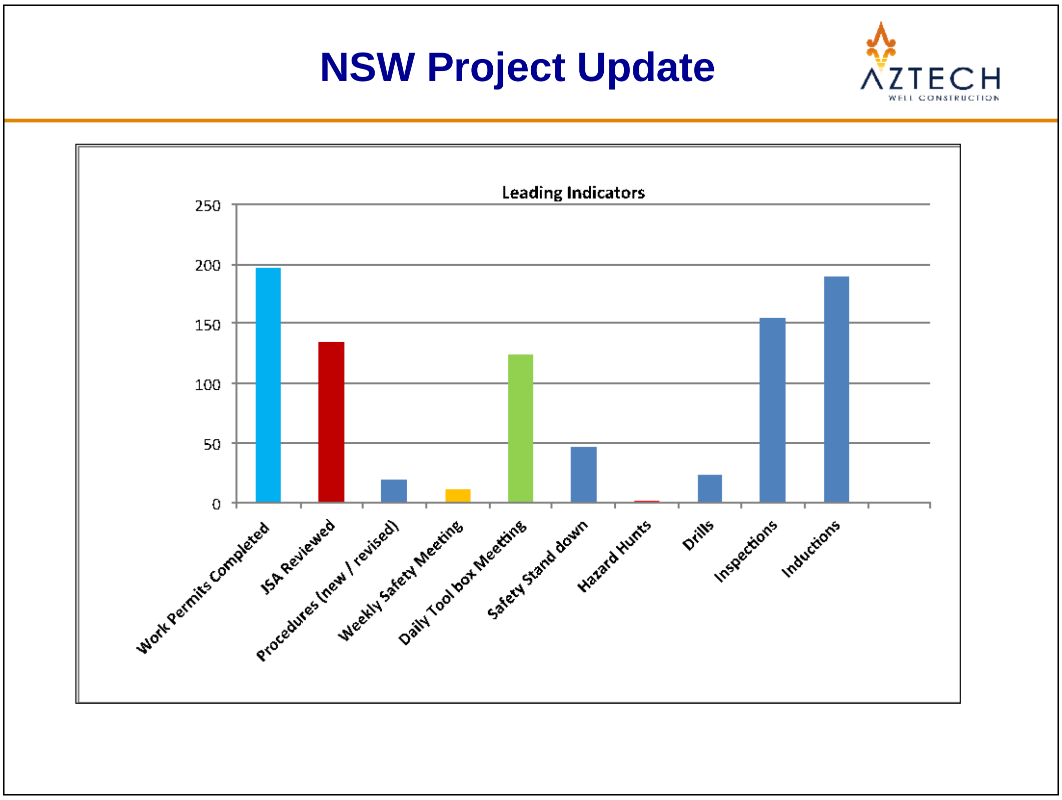


**Figure 24. Number of stop cards issued on the drill sites grouped by leading indicators.**

A number of incidences that involved minor injuries or near misses were however recorded on the drill sites (Figure 25), although none were classified as requiring notification to an appropriate authority. Near misses were mainly to do with mechanical matters and were treated as an early warning or free lesson for the future.

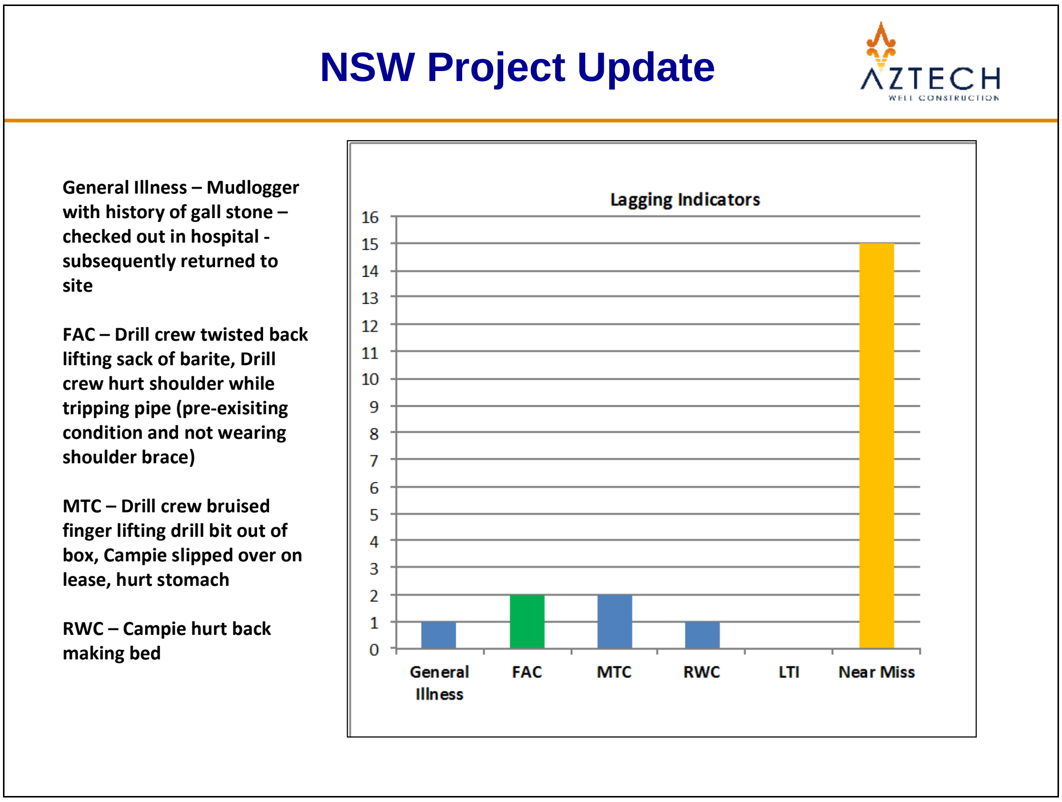


**Figure 25. Number of minor incidents and near misses recorded on the drill sites.**

# 5. Budget / Expenditure

The funding partners established funding commitments at the signing of the Agreements, and variations as advised and agreed at Steering Committee meetings, as follows:

**Table 16. Contributions by each funding partner to Stage 1 of the NSW $CO_2$ Storage Assessment Program.**

| Sponsor | Stage 1A contributions | Expended during Stage 1A | Stage 1B contributions | Budget for 1B drilling | Total contributions |
|---|---|---|---|---|---|
| Commonwealth | $ 2,500,000 | | $ 7,200,000 | $ 9,700,000 | $9,700,000 |
| ACALET | $ 300,000 | | $ 8,000,000 | $ 8,300,000 | $ 8,300,000 |
| Coal Innovation NSW | $7,550,000 | $7,550,000 | $ 2,200,000 | $ 2,200,000 | $ 9,755,000 |
| Total | | | | | |

The original budgets established by the Steering Committee for the drilling:

**Table 17. Original budgets established for the Stage 1B drilling program.**

| Well | Budget | Contingency | Total |
|---|---|---|---|
| Tiltagoonah-1 | $ 8,855,515 | $ 1,244,485 | $10,100,000 |
| Mena Murtee-1 | $ 9,644,862 | $ 455,138 | $10,100,000 |
| total | $ 18,500,377 | $ 1,699,62 | $ 20,200,000 |

With the completion of Tiltagoonah coming in under budget, approximately $500,000 budget and $1,000,000 contingency was moved to the Mena Murtee overall budget.

Below is an overview of the drilling program on expenditure

**Table 18. Overview of Stage 1B budget against expenditure.**

| **Budget** | **$ 20,200,000** |
|---|---|
| | |
| Expenditure to end September | $ 19,241,873 |
| Anticipated to end of project (rehabilitation) | $ 511,119 |
| **Total Expenditure** | **$ 19,752,992** |
| | |
| **Surplus** | **$ 447,007** |
| | |

The following is an audited extract of the expenditure up to the 30 September 2014.

**Table 19. Extract from Audited Report of the Stage 1B expenditure up to the 30/11/14.**

**CO2 STORAGE ASSESSMENT PROGRAM**

**STAGE 1(B) – DARLING BASIN**

**WHOLE OF PROJECT SPECIAL PURPOSE FINANCIAL REPORT**

| | Notes | Contributions and Revenues Received up to 30/9/14 $ | Expenses to 30/9/14 $ | Available Funds yet to be Received and Anticipated Expenditure 1/10/14 to Project completion $ | Whole of project projected income and expenditure $ |
|---|---|---|---|---|---|
| **Contributions** | | | | | |
| DTIRIS | | 2,200,000.00 | | | 2,200,000.00 |
| Commonwealth Government | | 9,700,000.00 | | | 9,700,000.00 |
| ACALET | | 7,990,011.10 | | 309,988.90 | 8,300.000.00 |
| **Total Contributions** | 3 | **19,890,011.10** | | **309,988.90** | **20,200,000.00** |
| Revenues from 3rd parties | 4 | 507,995.68 | | | 507,995.68 |
| **Total Contributions and Revenues** | | **20,398,006.78** | | **309,988.90** | **20,707,995.68** |
| **Expenditure** | | | | | |
| Contractors | 5(a) | | 18,910,179.67 | 511,119.42 | 19,421,299.09 |
| Vehicle, fuel and oil | 5(b) | | 428,443.05 | | 428,443.05 |
| Consultancy Fees | 5(c) | | 153,470.72 | | 153,470.72 |
| General insurance expenses | 5(d) | | 68,327.94 | | 68,327.94 |
| Grants Paid | | | 54,019.00 | | 54,019.00 |
| Travel | | | 51,661.22 | | 51,661.22 |
| Motor Vehicle Expenses | | | 39,471.72 | | 39,471.72 |
| Legal fees | | | 22,287.90 | | 22,287.90 |
| Professional fees | | | 11,397.00 | | 11,397.00 |
| Internal expenses | | | 5,230.39 | | 5,230.39 |
| Other Maintenance Costs | | | 3,405.61 | | 3,405.61 |
| Other expenditures | | | 3,259.41 | | 3,259.41 |
| Consumables and Stores | | | 1,936.73 | | 1,936.73 |
| Membership | | | 1,906.70 | | 1,906.70 |
| Advertising-Employment | | | 1,646.78 | | 1,646.78 |
| Administration fees | | | 1,572.62 | | 1,572.62 |
| Operating lease rentals-motor vehicles | | | 1,346.08 | | 1,346.08 |
| Freight and Carriage | | | 1,306.55 | | 1,306.55 |
| Expenses relating to another stage | | | -11,000.00 | | -11,000.00 |
| **Total Expenditure** | | | 19,749,869.09 | 511,119.42 | 20,260,988.51 |
| **Excess of Contributions over Expenditure** | | | | | **447,007.17** |

3

# 6. Knowledge Gained and Lessons Learnt

Stage 1B of the NSW $CO_2$ Storage Assessment Program was undertaken with the aims of increasing geological knowledge of the Darling Basin, filling data gaps, identifying potential $CO_2$ storage reservoirs and furthering the understanding of geothermal potential within NSW.

Prior to commencement of the project the prospectivity of suitable seals and reservoir units for the storage of $CO_2$ in the sub-basins was unknown. The lack of prospectivity at Tiltagoonah-1 site is a significant finding in understanding the $CO_2$ storage potential of the NSW sedimentary basins, and future dating and diagenetic studies are required to assist in understanding why this location has such low porosity. The discovery of reservoir/ seal units in Mena Murtee-1 that may serve as large-scale storage sites is encouraging, and further exploration is warranted to better understand the prospectivity of the Pondie Range Trough. Work is continuing on age dating the recovered core and determining where the units intersected at each well sit in relation to the regional stratigraphy.

A total of 114.39 m of core was obtained and a significant volume of data was produced from the drilling and testing programs undertaken at the two wells. These new data have already been used as part of collaborative research programs with the CO2CRC, CSIRO, and ANLEC R&D. All new data will be available to governments, academia and industry to further enhance the understanding of basin development and NSW geology.

A number of lessons learnt from the Stage 1B drilling program are outlined below.

Stage 1B was completed within budget and with no lost time injuries. The drilling and coring program required modification during Tiltagoonah-1 due to the unexpected highly abrasive, high compressive strength, dense rocks encountered and the shortcomings of the NOV drilling and coring system in these types of conditions. The total depth was reduced to 1434 m and NOV was released from contract. Instead, a conventional 4” coring system was sourced from Halliburton for Mena Murtee-1. Although additional time is required to trip out and change the drill head for coring it was agreed that overall drilling speed should be greater in rocks with high compressive strength with a conventional drilling and coring assembly. The management decisions taken to shorten Tiltagoonah-1 were prudent and beneficial to the overall project, as it allowed unspent financial resources to be reallocated to the more prospective second well. The change to conventional coring for Mena Murtee-1 and easier drilling conditions proved beneficial and TD was called at 2270 m, only 130 m short of proposed TD. The additional funding for Mena Murtee-1 was utilised to gather more data essential to better understanding the properties of the reservoir and to aid in modelling and collaborative work.

Tiltagoonah-1 was effectively a wildcat well, with the well prognosis generated primarily from a seismic model, outcrop data, and limited data from offset wells. As drilling progressed it became clear that the seismic model had limited predictive ability, with little correlation between the rocks intersected and the well prognosis. Thus, decisions on core points in Mena Murtee-1 relied mostly on drill cuttings and drilling breaks.

Aztech Well Construction displayed a high-level of expertise and professionalism during operations at both wells, particularly at Tiltagoonah-1, which turned out to be a very difficult well to drill. Receiving geological and financial information in real time by Aztech also greatly assisted in effectively managing the well within budget. This gave a high degree of confidence leading into operations at the second well.

The difficult drilling conditions experienced during the Stage 1B drilling program have provided fresh insights into the choice of drilling rigs to use in future exploration activities in the Darling Basin. As part of the Stage 1B procurement strategy, the tender documents send out to procure well site project management services included three drilling rig options: a heavy conventional drilling rig, a light conventional drilling rig, and a mineral drilling rig. Analysis of the submissions identified technical limitations for both the mineral rig, and light conventional rigs which would have prevented coring at the full depth specified (2,400 m), thereby eliminating these rigs from complying with the tender requirements. A total of four submissions for heavy conventional rigs and alternate heavy rigs were therefore accepted for consideration and ranking, with a mid-sized conventional rig selected for the program. However, the knowledge gained from Stage 1B indicates that future wells may not need to drill and core beyond 1,800 – 2,000 m, and thus a mineral rig equipped with diamond drill bits may more efficiently cut through the tenacious rocks in a shallower well and allow a larger volume of core to be acquired. This option should be examined carefully in future exploration programs.

The presence of limestones and the tenacity of the sandstones intersected in Tiltagoonah-1 are not considered typical of the late Devonian rocks intersected in offset wells in the Darling Basin, thereby raising the possibility that the rocks may have been much older than originally thought. Hence, the dates of the rocks intersected at Tiltagoonah-1 are being investigated; as are those at Mena Murtee-1 in order to better identify the stratigraphy. A detailed diagenetic study of the Tiltagoonah-1 cores is also required as part of any future program, aimed at understanding the timing of the digenetic phases and how they affect the cementation as well as the potential to produce secondary porosity and permeability. This work will allow comparison with adjacent sub-basins, and ultimately aid in understanding the evolution of the Nelyambo and Pondie Range trough and the greater Darling Basin.

The data acquisition program developed for Stage 1B provided substantial data and sample sets sufficient to meet the needs of an initial geological interpretation of the near well lithology, principally the identification of reservoir/seal pairs as prospective intervals for $CO_2$ geological storage. The testing program, whilst still needing to operate within budget and time constraints and at the mercy of the hole conditions, has proved to be a solid foundation, with all of the collaborative work programs having heavily utilised the new data. The reservoir modelling, while based on a single hole, has provided an excellent first-pass assessment of plume migration with an improved level of confidence from Stage 1A. Fault reactivation work is a first for the Darling Basin and is essential to any $CO_2$ storage project. The assessment of depositional environments will assist in future analysis of the evolution of the north east Darling Basin and fluid analysis has aided in the understanding of potential interactions between the reservoir rock, reservoir fluids and the $CO_2$ brine. This work provides the foundation for further investigation as part of Stage 2 of the NSW $CO_2$ Storage Assessment Program.

# 7. Conclusions

The mixed results achieved by Stage 1B of the NSW $CO_2$ Storage Assessment Program highlight the underexplored nature of areas being assessed. Effectively a wildcat well and proving unexpectedly difficult to drill, Tiltagoonah-1 has enabled sufficient data capture to determine that this site is unsuitable for $CO_2$ storage. Much was learned from the drilling which was used in the final planning and decision making processes for Mena Murtee-1. These learnings were of significant value to the project during the drilling of Mena Murtee-1, contributing to monetary savings and an increase in data acquisition.

The results from Mena Murtee-1 indicate that there is potential for large-scale storage of $CO_2$ in the Pondie Range Trough of the Darling Basin. The discovery of potential storage and excellent seal units highlight the storage potential of the Darling Basin and begin to confirm previous (limited data) Basin studies.

Work is continuing on studying the lithologies intersected and geothermal potential of the Nelyambo and Pondie Range Troughs, adding to the data generated as part of the project but also leading to greater understanding of the state’s geological resources.

The experience gained by the DRE team involved in Stages 1A and 1B has proved invaluable. The skills of the group were called upon throughout the project from project inception, planning, procurement and project management in the office to on-site based activities such as the ‘real-time’ design of well velocity survey, side wall coring, and wireline formation test programs. The enhanced knowledge base within the Departmental team will aid greatly in the development and implementation of future exploration programs.

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# 10. Appendices

***Appendix 1 - Stage 1B Well Completion Reports***

- **Tiltagoonah-1**
- **Mena Murtee-1**

## *Appendix 2 – CO2CRC Collaborative Research Report*

## *Appendix 3 – Drill bits used in the 8 1/2 " section of Tiltagoonah-1*.

Photos courtesy of Antonio Ribeiro.