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Article *in* Energy Procedia · December 2014

DOI: 10.1016/j.egypro.2014.11.534

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Energy Procedia 63 (2014) 5041 – 5050

Energy Procedia

GHGT-12

South West Hub CCS Project in Western Australia – Characterisation of a Greenfield Site.

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Abstract

The South West Hub Project (SWH) is undergoing pre-feasibility assessment through a stage-gated program of data acquisition, managed currently by the Western Australia Department of Mines and Petroleum (WA DMP). Undergoing assessment for potential to store commercial quantities of CO_2 is an area of approximately 150 km^2 north of the town of Harvey in south west Western Australia. The emissions hub of Collie (~ 70 km to the SE) is the home to some likely users of the pore space if the site proves up.

In contrast to many potential storage projects, the area under investigation had undergone only limited geological evaluation prior to this project's initiation in 2007. Therefore a program of data acquisition has had to be developed and undertaken to populate an essentially greenfield site, to provide sufficient information to make informed decisions prior to proceeding through each stage gate.

Activities to date have included:

- A 2D seismic survey (2011) along local roads, which enabled the placement of a stratigraphic well.
- The drilling of the Harvey-1 stratigraphic well (2012) to a depth of 2920.5 m TVDSS.
- Research projects have then been commissioned to utilise these new materials and provide additional site characterisation.
- A small scale 2D seismic survey (December, 2013) to aid in definition of acquisition parameters for a subsequent
- 3D seismic survey conducted, taking in 115 km^2 of the approximate 150 km^2 area (February – March, 2014).

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Peer-review under responsibility of the Organizing Committee of GHGT-12
doi:10.1016/j.egypro.2014.11.534

Results from these activities so far have not presented the project with any "show-stoppers". The key intervals of interest, the Yalgorup and Wonnerup members of the Triassic Lesueur Formation show suitable rock properties for purposes of carbon storage. Fault identification and their modeled transmissivity do not indicate extensive compartmentalization in the storage region. Whilst the key to this project is residual trapping (Wonnerup as the primary containment interval and Yalgorup as the secondary containment interval) there is improved evidence to suggest the presence of potential baffles and seals in the area to retain the CO_2.

As at mid-2014, the plan forward will include:

- 3D seismic processing, interpretation and the building of a new geological model (underway mid - 2014).
- Drilling of three shallow wells to better characterise the upper layers (2014 - 2015).
- Flow testing of one of those three wells to better assess the potential baffles (2015).
- Drilling of a deeper well(s) to characterise the reservoir properties off the Harvey Ridge Structure (late 2015).
- Related research activities using the new materials generated from the upcoming well drilling and testing program.

The recently acquired 3D seismic survey is already providing valuable information to constrain the main formations distribution and aiding in the location of the likely areas for further data acquisition. Complementary research projects are ongoing to facilitate the valuation of the site with the aim of reducing risk and uncertainty as the project proceeds to the next stage gate.

It is hoped that by using a stage-gate approach, the pre-feasibility data acquisition will be focused and provide a lower cost and more rapid approach to assessing sites in future.

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Keywords: South West Hub; SWH; CCS; carbon storage; assessment; Lesueur; Wonnerup; Yalgorup; Lesueur

1. Introduction

The South West Hub (SWH) is located within the southern part of the Perth Sedimentary Basin in the South West region of Western Australia, about 110 km south – southwest of the state capital Perth (Figure 1). The area marked "Lesueur" indicates the area originally designated for investigation at the commencement of the project. A number of previous studies have made preliminary assessments in the South West, summarised in Stalker et al, (2013)[1]. An appraisal of the geology around the town of Collie, a major emissions hub, by Varma et al, 2009)[2] showed no suitable storage locations proximal to Collie, and the study was geographically extended. The study then identified the current area (Lesueur; Figure 1) for investigation and work continues at present.

This area lies in the southern part of the Perth Basin, a northward trending sediment filled trough situated on the SW margin of the Australian continent. Note also that WA is host to the world's largest commercial scale CCS project with Chevron's Gorgon Project underway on Barrow Island in the north of the State with injection scheduled to commence in 2015-16 (Figure 1).

The main sequences of interest that require evaluation are the Yalgorup and Wonnerup Members of the Triassic age Lesueur Formation (Figure 2). There was little information on the geology of the area under investigation prior to the initiation of the SWH Project. Limited seismic data on the Western side of the project area was re-processed. Wells drilled previously in the area are sparse and completed between 40-50 years ago. Few wells have been cored, and well logs are basic and analogue. The consequence is that the limited data available did not encumber the project; rather the project was now regarded as a greenfield site with much new data required.

In order to plan and budget appropriately, the project developed a stage-gate approach to data acquisition to justify the components that made up each new phase of the evaluation campaign, with thorough review prior to moving through each new stage-gate. The process is discussed in detail in Sharma (this volume)[3], while results and new data are discussed here.

2. First Phase of New Data Acquisition

2.1. 2D Seismic Survey 2011

The first major phase of new data acquisition commenced with a 2D seismic survey conducted in 2011 where about 100 linear kilometers was shot along some of the major roads in the district (Figure 3). This exercise would provide the first detailed information on the structure (other than vintage data commencing from the 1960s). By sticking to the major roads in the area (Figure 3) impact on local landholders was kept to a minimum at the early evaluation stage. Social and community engagement activities have been put in context in the paper by Burke and Stalker (this volume)[4].

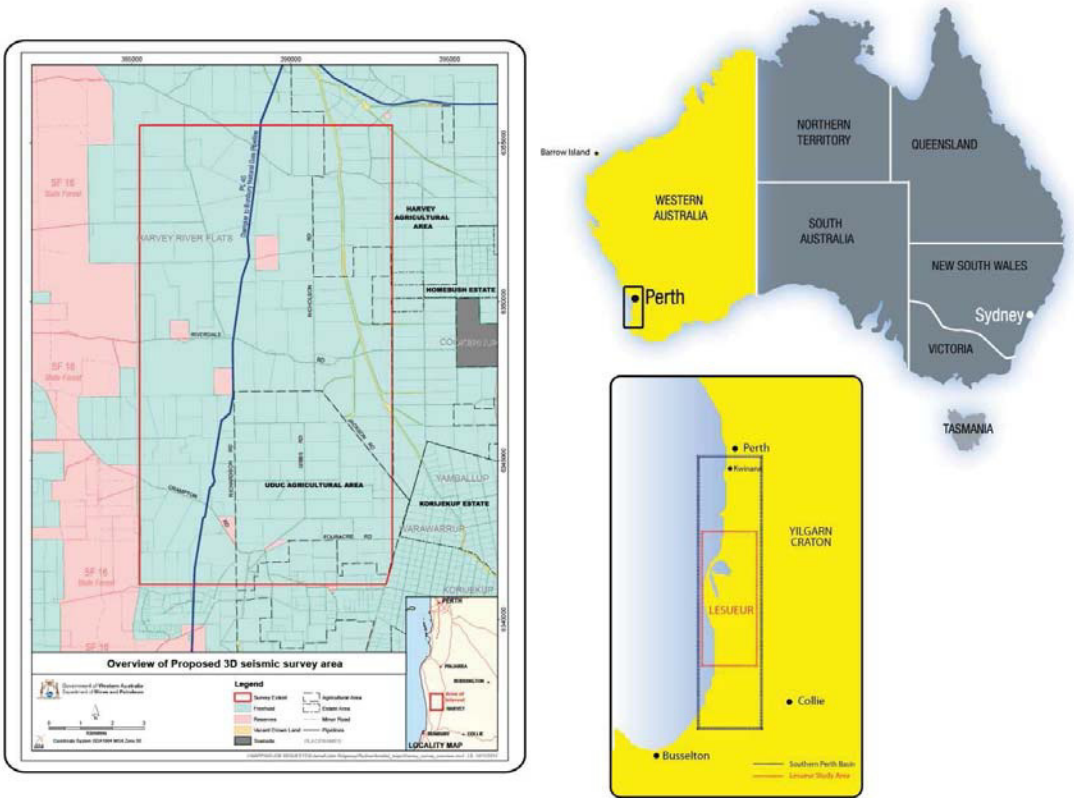

Figure 1 Location map of the area under investigation for the SWH Project in SW Western Australia.

The first pass geological model then provided some insight into the geometry of the Wonnerup Member of the Lesueur Formation i.e., the likely injection target. This model had no immediate depth control within the survey area, but instead had to rely on wells to the north (notably Lake Preston-1 and Pinjarra-1 some 25 km and 75 km away respectively). Data from the 2D Seismic Survey provided a geological model that showed that the area was cross cut by a number of faults. Some of these faults were sizable (Figure 4), for example the F10 fault to the east of the area may have up over 1000 m of throw[5].

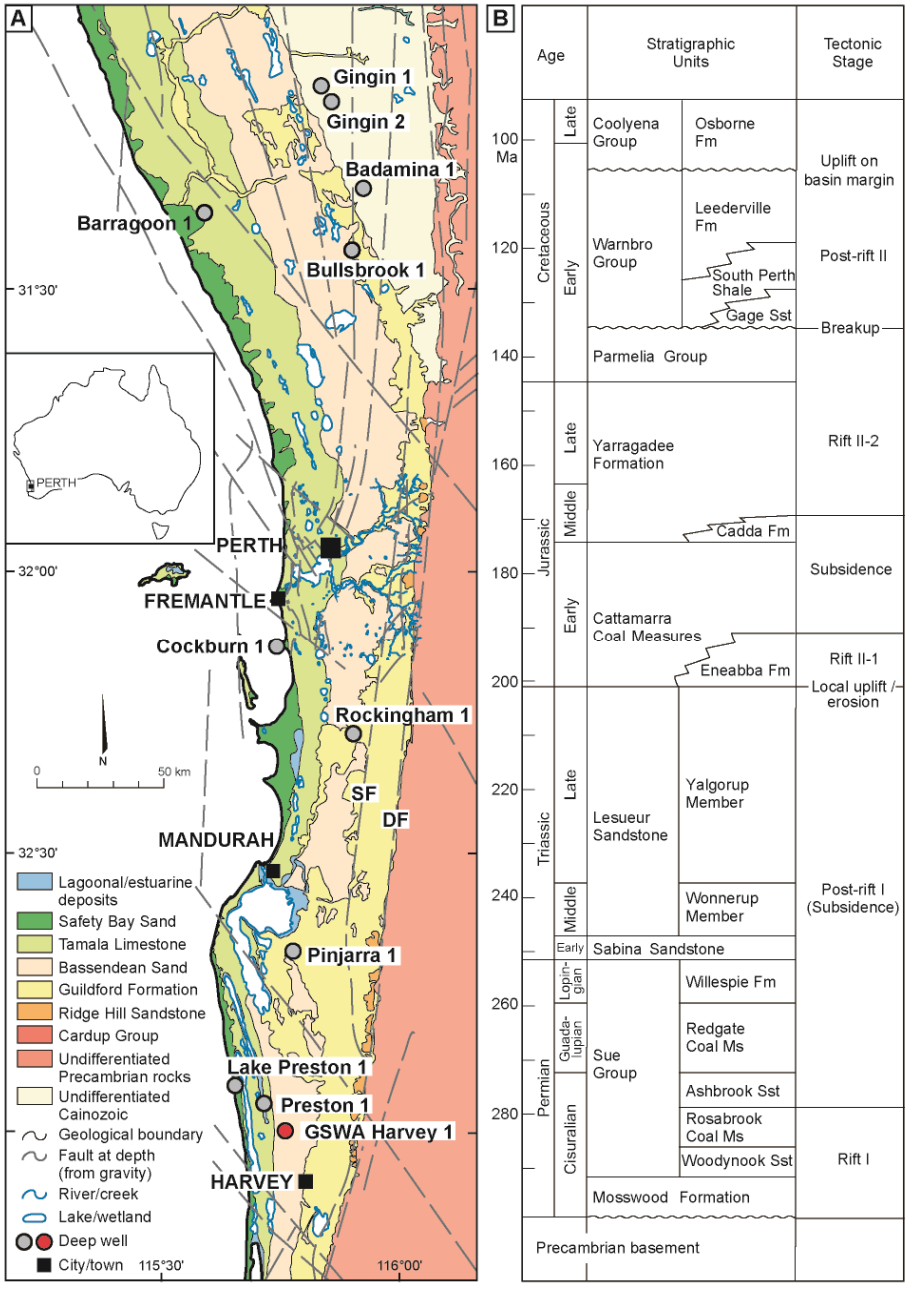

Figure 2 Location of the major wells and stratigraphy of the central and southern Perth Basin (from Olierook et al, 2014)[6]

The model also indicated that the best well location with which to intersect the entire Lesueur Formation to base of the Wonnerup Member would be near the top of the structural high in the area, geologically known as the Harvey Ridge (Figure 2).

2.2. Harvey-1 Well 2012

The well was drilled 100 m north of Riverdale Road (used in the 2D Survey) at 115°46'28.093"E and 32°59'30.730"S. In spite of the close proximity to the seismic line, the well prognosis was in error by between 135-154 m (Table 1) such that one target interval for coring, the Basal Eneabba Shale, was drilled through before it was recognised at 146 m shallower than anticipated.

The difference between prognosed and actual depth resulted from a poor velocity tie at this point (no other nearby wells; Figure 2). There was also a degree of uncertainty in the interpretation of the 2D seismic caused by the tortuosity and vertical elevation changes along the survey roads resulting in some challenges for the processing[7]. Finally the geometry of the location, using relatively distant wells on the other side of the ridge structure and the dip of the structure all contributed to the overestimation in depth to the top of the key formations (Table 1).

Table 1 Formation depth and thicknesses in the Harvey-1 well. Data from Millar and Reeve, 2014[8]

	Prognosed depths (m)		**Actual depths (m)**			
Formation	MDRT*	TVD SS	MDRT*	TVD SS	Thick	Difference
Guilford	5	19	5.38	19.1	47.6	
Leederville	31	-7	53	-28.5	203.6	***-22***
Eneabba	275	-251	249	-224.5	375	***26***
Basal Eneabba Shale	770	-746	624	-599.5	76	***146***
Lesueur	835	-811	700	-675.5	2195	***135***
Yalgorup	835	-811	700	-675.5	678	***135***
Wonnerup	1532	-1508	1378	-1353.5	1517	***154***
Sabina	2945	-2921	2895	-2870.5	+50	***+50***
Total Depth (TD)	2995	-2971	2945	-2920.5		

***Depths are reported as MDRT (measured depth from rotary table) and TVD SS (total vertical depth sub-sea)**
To correct MDRT to TVD SS take 24.48 m from the MDRT value.

The inaccurate well prognosis resulted in some of the shallower formations not being cored; formations that could act as potential baffles or seals (e.g., the Basal Eneabba Shale). This has informed some of the future data acquisition program (see Section 3 Future Activities).

In total 217 m core samples, two water samples and a suite of wireline log measurements were collected with a full description of the core prepared prior to an extensive sampling and analysis program. The data generated contributed to a series of studies summarised here:

- Facies based rock properties distribution along the Harvey 1 stratigraphic well[9].
- Geochemical characterisation of gases, fluids and rocks in the Harvey 1 data well[10].
- Advanced geophysical data analysis at Harvey 1: storage site characterisation and stability assessment[7].
- Fault seal first-order analysis – SW Hub[5].
- Stratigraphic forward modeling for South West Collie Hub Phase One – Static Model[11].

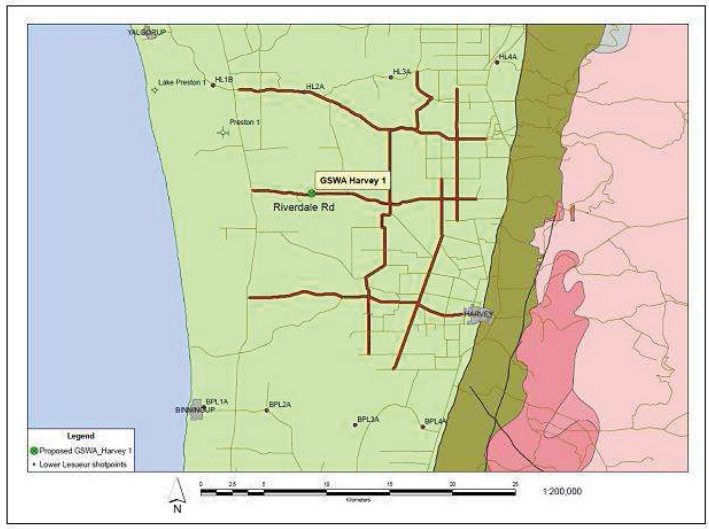

Figure 3 Map showing the roads used in the 2D seismic survey from 2011. The data were used to generate maps that aided the placement of Harvey-1 stratigraphic well drilled in 2012. To the west is the Swan Coastal Plain in the Shires of Harvey and Waroona (light green), and the eastern most part of the map shows the Darling Ranges (pinks). The central strip (brown) represents the Darling Scarp.

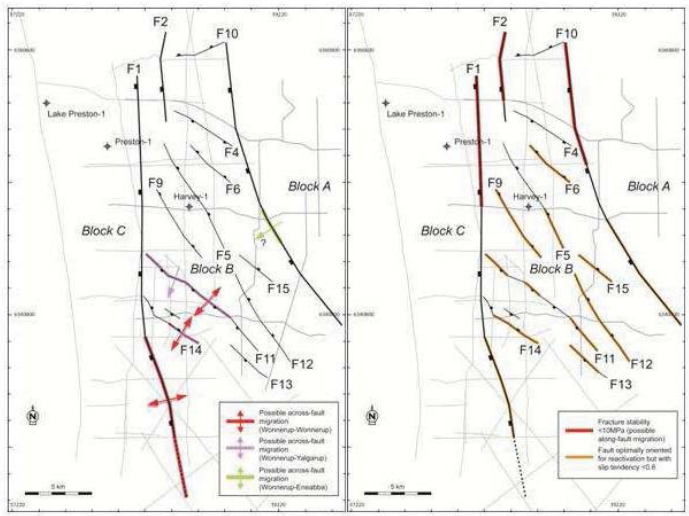

Figure 4 Summary of across-fault (left) and along fault (right) CO_2 migration potential for the SWH study area (from Langhi et al, 2013)[5].

2.3. Facies Analysis and Rock Properties

Most of the research focus in the early phase of activities has been on the Lesueur Formation, which is made up of two members; the Yalgorup (700 m – 1378 m MDRT) and Wonnerup (1378 – 2895 m MDRT)[8]. The Wonnerup is the anticipated injection target based on its large vertical thickness of clean, coarse-grained sandstone which possesses reasonable porosity and permeability values of 7 – 19 % and 0.01 – 580 mD respectively. Both Yalgorup and Wonnerup Members were deposited in a fluvial environment and, based on earlier work summarised by Olierook et al., (2014)[6], have developed a series of recognisable fluvial facies types through the Lesueur Formation. The facies distribution of porosity and permeability in a series of horizontal and vertical plugs illustrates the storage potential of the Wonnerup Member (Figure 5). The most common facies observed in the Wonnerup member was the Aii "high energy fluvial channel barforms" closely followed by Ai "high energy fluvial channel fill"[9].

While the Wonnerup is consolidated and easily tested for a series of rock properties, the Yalgorup Member was more difficult to assess due to difficulties with preserving and maintaining consolidation of the core. This was more likely due to the nature of the core than the preservation methods. The Yalgorup is much more variable lithologically than the Wonnerup (Figure 5). Porosity and permeability data are limited in potential seals or baffles due to the over representation of the more consolidated sandy layers being tested whereas the more shaley intervals were unable to be prepared for measurement. Notably in the Yalgorup was the appearance of a roughly 200 m thick interval of what appears to be a palaeosol (facies D - "floodplain palaeosols/vertisols"). This feature may prove quite laterally extensive (P. McCabe Pers. Comm.) and there is evidence to suggest it can be followed on some of the seismic survey data collected by Urosevic et al (2014)[12].

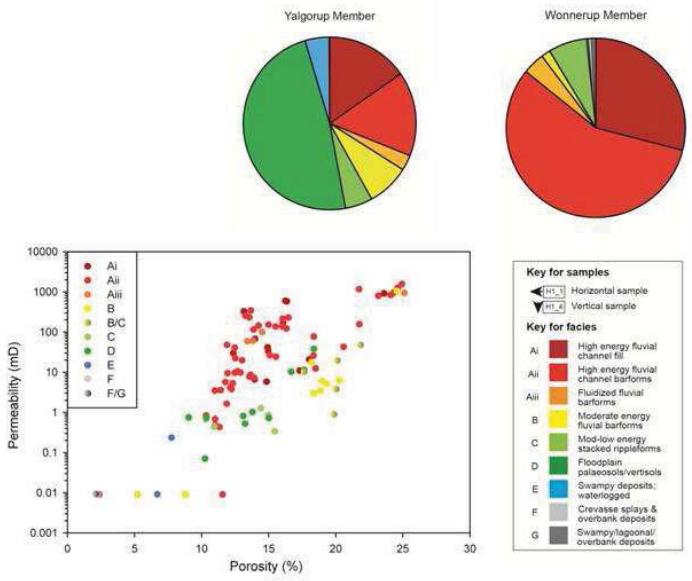

Figure 5 Facies distribution for the Yalgorup and Wonnerup members in Harvey-1. Images from Delle Piane et al (2013)[9].

2.4. Geochemical evaluation

A number of analyses were conducted on gas, core and fluids from the Harvey-1 well. In addition, gas samples from a fertilizer plant in the town of Kwinana to the north of the study area were analysed for gas composition and stable carbon isotopes. The purpose was to characterise the gas from this facility as it may be used in future for testing at the South West Hub site. The gas was found to be almost pure CO_2 with negligible amounts of other hydrocarbons, and had a very depleted carbon isotope signature of $\delta^{13}C$ -37.6 ± 0.28 ‰ VPDB, inherited from the source material, natural gas. This value is not typical of marine carbonates, atmospheric CO_2 or CO_2 generated from the maturation of organic matter and may prove a useful tracer if a similar gas stream is stored at a later date.

Several core plugs were taken and extracted to determine any presence of free hydrocarbons. Only small quantities were found (on average 38 mg/kg rock), with one slightly richer sample with 305 mg/kg rock in the uppermost sample taken from the Yalgorup at 913.94 m MDRT. Even this amount is not quantitatively significant with respect to potential resource conflicts[10]. A virtual absence of vitrinite throughout the Harvey -1 well and lack of source rocks suggests that there is no hydrocarbon potential in the immediate area, and to date there have been no commercial finds of hydrocarbons in the area under investigation.

A shallow water sample (~36 m) taken in an adjacent water well (within a few 10s of metres of Harvey-1) contained 458 mg/L total dissolved solids (TDS). One unconfined sample was taken in Harvey-1 at 856 m MDRT in the Yalgorup and contained 52,300 mg/L TDS. The latter was contaminated by drilling fluids and did not compare well with values calculated from the wireline logs, which suggested 40,000 mg/L NaCl equivalent for the Yalgorup Member and 30,000 mg/L NaCl equivalent for the Wonnerup Member[9,10].

One core sample from the Wonnerup at 1935.5 m was flooded with a 30,000 mg/L NaCl brine saturated with CO_2 and effluents collected and analysed (> 50 cation and anion species measured) to observe any potential mineral reactions and provide input to preliminary reaction transport [9,10].

These preliminary results suggest that the rocks have capacity to maintain circum-neutral conditions, until all albite is converted to dawsonite, with removal of dissolved Na. Once this stage is reached, pH drops to about 5, and CO_2 fugacity increases dramatically. However, pH is maintained above 4.5 by the acid-consuming conversion of feldspar to muscovite and quartz, with major release of K. While the results indicate some dissolution of mineral species[10], other tests gave evidence of fines migration during similar flooding experiments[9] and further work is planned to better understand the impact of CO_2 flow through the Wonnerup in particular. Residual Sc CO_2 saturation values were also measured and ranged from 22.9 to 42.7 % depending on the absolute permeability of each core sample[9].

2.5. Geophysical analysis and integration

The drilling of Harvey-1 enabled a review of the 2011 2D seismic survey to be conducted with the provision of some depth constraint on the formations. This has provided a better interpretation of the structure in the area and an evaluation of the fault locations and geometry of those faults. Work was also undertaken to improve imaging in zones where near-surface coastal limestones had impacted on data quality. The crooked nature of the 2D lines caused a significant degree of uncertainty in the interpretation which could be somewhat corrected with the well tie[7].

There was additional work conducted to better understand the stresses in the region through the wireline logging data. Stresses contributed to breakouts in the well and overbalancing of the drilling muds was a consequence of attempts to maintain wellbore integrity. These issues were particularly significant for the upper intervals, the Yalgorup in particular, and contributed to some of the poor quality of wireline data and the loss of the MDT tool towards the end of the operation.

Following on from the drilling of Harvey-1, subsequent seismic survey activities have been undertaken including a small (~ 9 km) 2D seismic survey conducted in 2013 along Riverdale Road near Harvey-1[12]. This survey using small vibroseis trucks was tuned to look at shallower intervals than the 2011 seismic survey (which focused on the Wonnerup Member as a potential storage interval) and has provided insight into defining parameters to obtain data for the subsequent 2014 3D seismic survey (approx 150 km^2 survey area with 110 km^2 data acquisition).

2.6. Fault analysis and integration with the SEDSIM geological model

The 2011 2D seismic survey and data from Harvey-1 have contributed to the development of several geological models. A sedimentary forward model (SEDSIM[11]) and other geological models have been used in a first pass fault seal analysis, undertaken to determine the extent of faulting and fault properties in the area. Use of various tools such as membrane fault seal capacity and Shale Gouge Ratio (SGR) have applied to determine the relative transmissivity of the faults mapped so far to evaluate the potential for significant compartmentalisation of the area[5,11].

The F10 fault to the north east of the study area (Figure 4) appears to have a significant throw of over 1000 m based on the 2011 2D seismic survey. Results (Figure 4) suggest that for some of faults evaluated, there is an average to low likelihood of across fault migration. Furthermore, some of these faults may be able to hold a CO_2 column of between 110-1100 m before breaching membrane seal. The main caveat on these results is that the faults are based on the limited 2D seismic survey mapping and the faults will be re-evaluated and assessed post receipt of the new geological model built from the recent 3D seismic survey acquired in March, 2014. Preliminary observations from this new data suggest that there is not a major increase in the number and distribution of the faults, rather they are more clearly defined and allow for a more rigorous assessment of fault properties going forward.

3. Future activities

Based on the outcomes of the research described above and additional work conducted by WA DMP and the Geological Survey of Western Australia, there are no barriers to proceeding to the next stage gate of data acquisition. This has enabled the large scale 3D seismic survey (acquired in February – March, 2014) to proceed over a large area with a significant number of landholders consulted[4]. The processing and interpretation of that data is ongoing and a new geological model is being built and will incorporate some of the research outcomes described above.

The next phase of activity for the project is the drilling of a series of new wells. Three shallow wells (1600 m or less) are planned within 2014 – 2015. Their primary focus is to better characterise the Yalgorup Member and shallower formations to better understand baffles and seals in the area. Previously, it was not expected that there would be a conventional regional seal in the area[1], however the observations made in Harvey-1 have suggested that there may be a number of baffles or containment intervals that warrant characterisation. The planned Harvey-2 well is likely to be drilled with a mineral rig (providing continuous core) and will be located to the east of the F10 fault (Figure 4). There is a degree of uncertainty regarding the geology on the eastern side of the fault based on the new 3D seismic data and this well will reduce that uncertainty. Harvey-3 will likely be a fully cored mineral well to the same depth to aid in the characterisation of the shallow intervals that may act as potential baffles or seals such as the Basal Eneabba Shale or Yalgorup palaeosol on the western margins of the study area. This will be located further south than Harvey-1 and will penetrate at least the top 50 m of the Wonnerup Member. This will enable coring across the unconformity between the Yalgorup and Wonnerup as well as obtaining some information on the rock properties of the Wonnerup further south of the Harvey Ridge. Harvey-4 will likely be drilled by a water rig and there are plans to conduct interval coring for key zones (Basal Eneabba Shale, Yalgorup palaeosol and unconformity). This well will subsequently be completed to conduct a series of flow tests to evaluate any of the potential baffles. All wells will only undergo temporary plugging so that they may be used if needed as monitoring wells at a later date rather than a full plug and abandonment operation at this stage.

The data from these wells will further inform the 3D seismic survey and increase confidence in the revised geological models for going forward. After a further evaluation, a deeper well, Harvey-5 will be drilled to assess the Wonnerup Member in a deeper section of the site to determine whether the storage capacity and injectivity potential remain favourable.

4. Conclusions

So far the stage gate approach to data acquisition at this site has proved valuable and has limited potential cost blow outs. The combination of a simple 2D seismic survey along local roads and the drilling, coring and subsequent plug and abandonment of Harvey-1 caused limited disruption to the local community while providing enough information to decide to invest in a large scale 3D seismic survey completed in 2014. The results of each phase of acquisition have allowed decisions to proceed through each stage gate in a transparent manner.

Results so far suggest that the target injection horizon, the Wonnerup Member of the Leusueur Formation has suitable porosity and permeability, and extends over a large area, both laterally and vertically, providing abundant storage capacity for a commercial operation. The drilling of Harvey-1 provided increased evidence of baffles and potential sealing units in the area not previously anticipated. Subsequent work, both of a seismic nature as well as a new drilling campaign will address the identification and characterisation of these intervals. Flow testing will contribute to understanding these baffles and assessing their potential for a commercial scale project. To date the project team and partners are confident to continue with the data acquisition program to move forward in assessing the South West Hub Project area for commercial scale carbon storage and see no geological impediments to continuing given the current understanding of the area.

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