



Government of **Western Australia**
Department of **Mines and Petroleum**

RECORD 2014/12

GSWA HARVEY 1 WELL COMPLETION AND PRELIMINARY INTERPRETATION REPORT, SOUTHERN PERTH BASIN

by
AS Millar and J Reeve



Geological Survey of Western Australia



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**compiled by
AS Millar and J Reeve***

*** Aztech Well Construction Pty Ltd, Colin Street, West Perth WA 6005**

Perth 2014



**Geological Survey of
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REFERENCE

The recommended reference for this publication is:

Millar, AS and Reeve, J (compilers) 2014, GSWA Harvey 1 well completion and preliminary interpretation report, southern Perth Basin:
Geological Survey of Western Australia, Record 2014/12, 17p.

National Library of Australia Card Number and ISBN 978-1-74168-593-0

Grid references in this publication refer to the Geocentric Datum of Australia 1994 (GDA94). Locations mentioned in the text are referenced using Map Grid Australia (MGA) coordinates, Zones 50. All locations are quoted to at least the nearest 100 m.

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Published 2014 by Geological Survey of Western Australia

This Record is published in digital format (PDF) and is available on USB and online at <www.dmp.wa.gov.au/GSWApublications>.

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* Can be found as separate attachments on the accompanying USB.

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1. Harvey 1 composite well log
2. Harvey 1 graphic core log

* Can be found as separate attachments on the accompanying USB.

GSWA Harvey 1 well completion and preliminary interpretation report, southern Perth Basin

by

AS Millar and J Reeve*

Abstract

GSWA Harvey 1 is a stratigraphic well drilled in early 2012 within the southern Perth Basin by the Geological Survey of Western Australia (GSWA). The well is located on a structural feature known as the Harvey Ridge, a poorly defined northwesterly–southeasterly trending basement high observed in seismic data and associated with a high gravity anomaly. The well was completed as part of the South West Hub Carbon Capture and Storage Project, a project jointly funded by the State and Commonwealth Governments, and industry. State funding was from the Royalties for Regions Exploration Incentive Scheme (EIS).

Based upon earlier assessments the area was interpreted to contain a significant thickness of a saline aquifer within the lower Lesueur Sandstone (Wonnerup Member), which could act as a reservoir for storing carbon dioxide. Regionally it is overlain by a potential baffle, the upper Lesueur Sandstone (Yalgorup Member, previously known as the Myalup Member). In turn, the upper Lesueur Sandstone is overlain by the Eneabba Formation, which may also include potential baffle and seal units. Importantly, the area does not contain the Yarragadee Formation, a significant fresh groundwater aquifer in the Perth Basin which might otherwise be at risk of contamination.

Results from the L198 Lower Lesueur Seismic Survey (2011), together with existing seismic data and limited nearby drilling data, were used to plan the location and design of the well to acquire the pre-competitive data needed to fill some of the identified knowledge gaps.

Harvey 1 was spudded on 7 February 2012 and the total depth of 2945 m measured depth below rotary table (MDRT) was reached on 8 March 2012. Following wireline logging, Harvey 1 was plugged with four cement plugs and the rig was released on 26 March 2012. Broadly the predicted stratigraphy was intersected; however, depths of formation boundaries were shallower than predicted by about 120–145 m.

A full mud logging program was completed with cuttings collected at 15 m intervals from 60 to 840 m, and 5 m intervals from 840 to 2945 m. A coring program designed to obtain representative rock samples for analysis was completed and recovered six 100 mm (4") diameter cores over four intervals for a total of 217 m of recovered core. Cored intervals were lithologically logged in detail and 90 representative horizontal and vertical plugs were obtained for analysis.

Standard porosity and permeability measurements were completed on core plugs, and plug trims were used for mercury injection capillary pressure (MICP) testing, X-ray diffraction (XRD) and petrological examination. Following longitudinal cutting, core was run through the GSWA HyLogger to obtain high-resolution photographs and spectral data for mineralogical studies. To assist with sediment provenance studies, a set of unwashed samples was collected for U–Pb detrital zircon geochronology.

Both logging while drilling and end of well wireline logging were used in the well formation evaluation. A single logging suite comprising five runs was completed for the 216 mm (8 ½") hole section at the completion of drilling.

Harvey 1 encountered the expected stratigraphic sequence for the Harvey Ridge area, although each formation was intersected at a shallower depth than predicted. Initial reservoir analysis has indicated that the Wonnerup Member may be suitable for the storage of CO₂.

KEYWORDS: Jurassic, Triassic, carbon capture and storage, coring, core analysis, geochronology, organic petrology, paleosols, palynology, petrology, reservoir data, spectral analysis, well logging

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Introduction

GSWA Harvey 1 (hereafter referred to as Harvey 1) was drilled as part of the South West Hub Carbon Capture and Storage (CCS) Project, Australia's first CCS Flagship project. The South West Hub CCS Project is a government and industry partnership to develop an economically and environmentally sustainable means of reducing carbon dioxide (CO₂) emissions in the southwest region of Western Australia.

The key stakeholders of the project are as follows:

- Commonwealth Government through the Department of Industry
- WA State Government through the Department of Mines and Petroleum (DMP)
- industry through a partnership with Griffin Energy, Verve Energy, BHP Billiton Worsley Alumina, Premier Coal, Perdaman Chemicals and Fertilisers, and Alcoa Australia
- the local community of southwestern Western Australia.

Additional information on Australian CSS projects may be obtained from the Geoscience Australia (GA) website <www.ga.gov.au/scientific-topics/energy/ghg> or, for Western Australian projects, from the DMP website <www.dmp.wa.gov.au/ccs>.

The geological structural unit known as the Harvey Ridge was identified in regional studies as having potential for CO₂ storage in saline aquifers (Varma et al., 2007, 2014). The area was interpreted to contain a significant thickness of a saline aquifer within the lower Lesueur Sandstone which could act as a reservoir; it is overlain by the upper Lesueur Sandstone which is a potential baffle. The latter is overlain by the Eneabba Formation, which may also include potential baffle and seal units. Importantly, the area does not contain the Yarragadee Formation, a significant fresh groundwater aquifer in the Perth Basin which might otherwise be at risk of contamination.

Early regional studies (Causebrook et al., 2006, Varma et al., 2007, 2014) highlighted the following gaps in available data:

- There was a lack of conclusive evidence of a regional seal formation.
- There was generally poor seismic and well coverage in the area.
- There was a paucity of modern petrophysical data to determine the reservoir characteristics of the Lesueur Sandstone.

In March 2011, the Geological Survey of Western Australia (GSWA), a division of DMP, in conjunction with GA, completed a 106 km 2D seismic survey along shire roads (Fig.1). Data from the survey is available from the GA website <www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=74810>.

The results from the 2011 seismic survey and existing seismic data were used to plan a stratigraphic well, Harvey 1, that would provide pre-competitive data. A seismic interpretation of the Harvey area is covered by Zhan (2014). The well was designed to assist in filling some of the identified knowledge gaps, and specifically it would:

- confirm the presence of the predicted stratigraphy
- test the presence of a lower 'shale unit' in the Eneabba Formation
- enable evaluation of the sealing capacity of the shale unit, if present
- provide fresh core samples of both the Eneabba Formation and Lesueur Sandstone for testing seal capacity, reservoir properties and injectivity capacity
- provide the opportunity to acquire a comprehensive suite of modern well evaluation logs
- enable calibration of the 2011 seismic data and integration into the 3D model for the area
- assist in the planning and development of future bore holes and seismic programs for further evaluation of the area.

Harvey 1 is located on private land (Lot 1326) off Riverdale Road, Cookernup (Fig.1). It is about 80 m north of shot point 2450 on the L198 Lower Lesueur Seismic Survey line 11GA_LL2 (Fig. 2).

The well was not expected to encounter hydrocarbons, but its planned depth (3000 m) and drilling program determined that a drilling rig with full provisions for hydrocarbon exploration drilling contingencies was required. Following a public tender, MB Century was awarded the contract to drill the well using Rig 7. Well design and drilling management was completed by Aztech Well Construction Pty Ltd in conjunction with GSWA.

Harvey 1 was spudded on 7 February 2012, reached a total depth of 2945 m on 9 March, and was plugged and abandoned on 23 March 2012 (Fig. 3). All depths related to the drilling are from the rotary table (MDRT) unless noted.

Research

The main objectives of the well were to acquire data and material to further assess the technical feasibility of storing, and permanently containing up to 6.5 Mt per annum over 40 years of CO₂ in a condition referred to as a 'super critical' phase. GSWA coordinated the collection of material and data from the well and its distribution to institutions and organizations awarded contracts to examine and report on the knowledge acquired from respective projects. These ongoing studies are being coordinated by DMP and Australian National Low Emissions Coal Research and Development (ANLEC

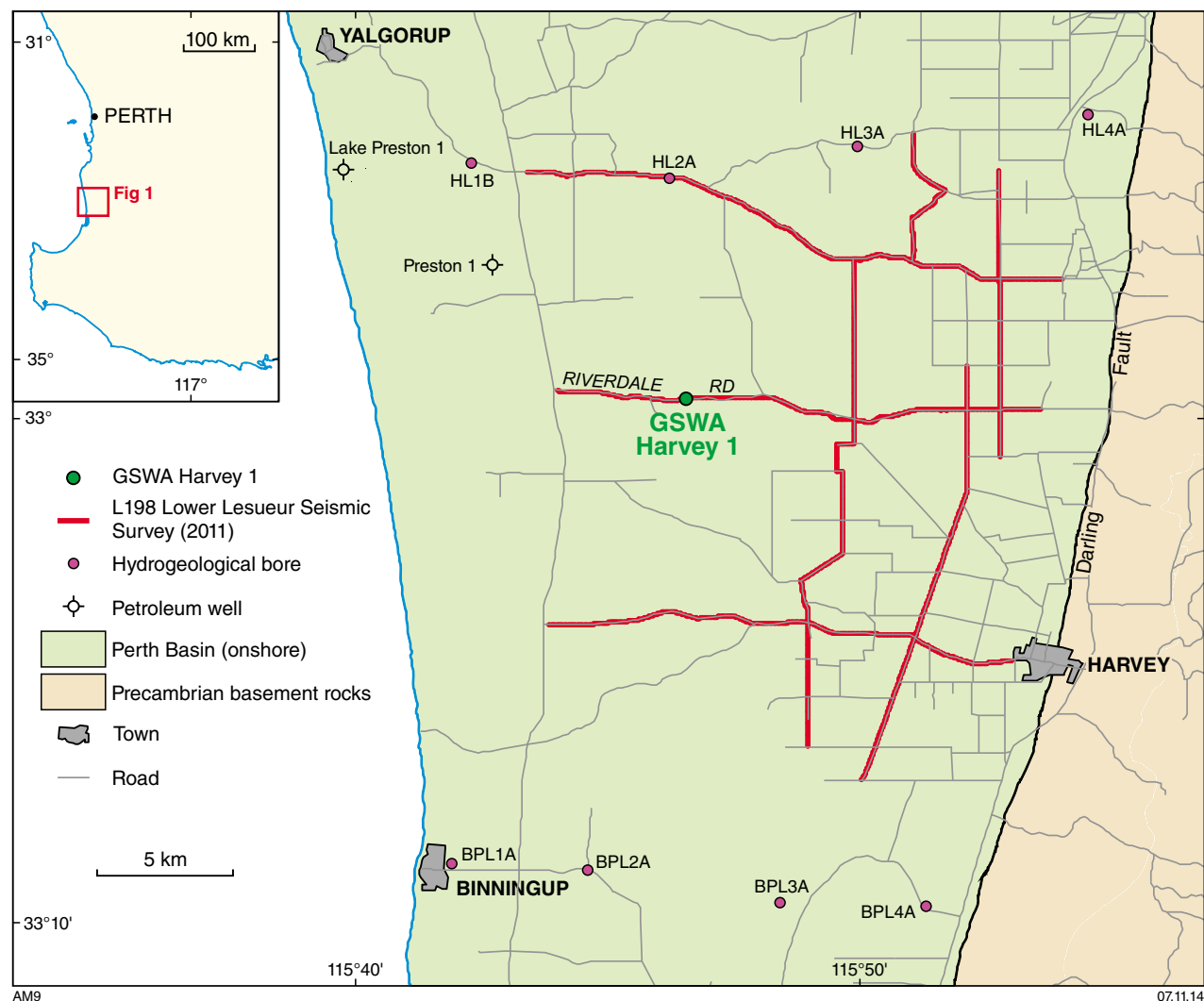


Figure 1. Location of GSWA Harvey 1, L198 Lower Lesueur Seismic Survey (2011) lines, existing petroleum wells, and hydrogeological bores

R&D), and carried out by scientists and engineers from CSIRO, Curtin University and The University of Western Australia. Projects were commissioned to evaluate the data under the following research topics:

1. Facies-based rock properties distribution
2. Geochemical characterization of gases, fluids and rocks
3. Fault seal first-order analysis
4. Advanced geophysical data analysis
5. Stratigraphic forward modelling
6. Static and dynamic reservoir modelling and simulations

Final reports on these projects are being published separately by ANLEC R&D <www.anlecrd.com.au/publications> and are also available via DMP's online database: Western Australian Petroleum and Geothermal Information Management System (WAPIMS). Results are not included within this report with the exception of

preliminary core descriptions, basic core and log analysis. Additional research projects using data from Harvey 1 are ongoing and these will be made available via WAPIMS as they are completed.

Follow-up work planned for the South West Hub CCS Project includes a 3D seismic survey (2014) and several additional wells (2014–15). The objective is to advance the storage assessment from a 'pre-competitive' phase to a point where commercial considerations and decisions are made possible, which would enable the project to become a viable business opportunity for industry.

Regional geology

Harvey 1 was drilled within the southern Perth Basin on the structural feature known as the Harvey Ridge, a poorly defined, northwesterly–southeasterly trending basement high observed in seismic data and associated with a high gravity anomaly (Iasky, 1993, Crostella and Backhouse,

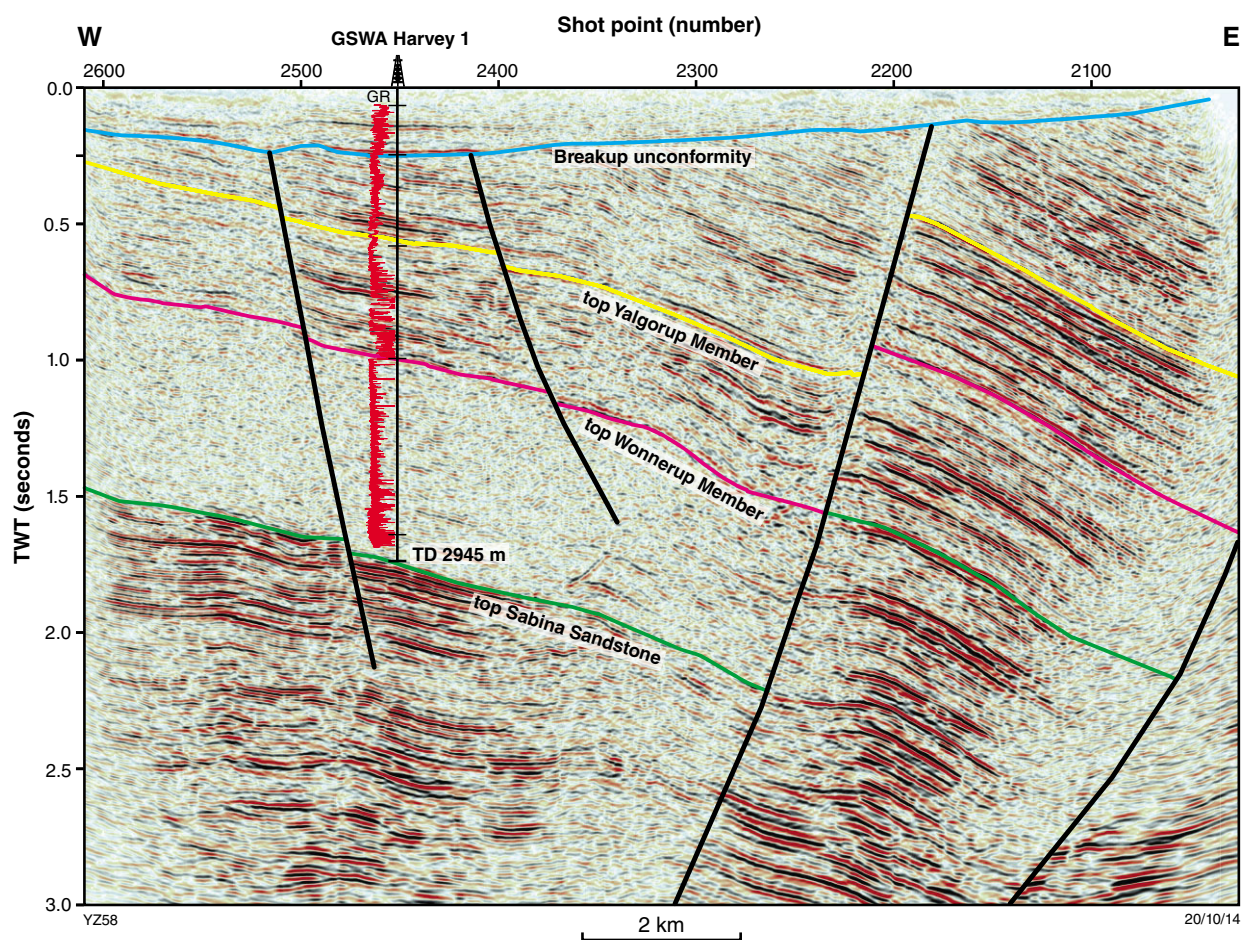


Figure 2. Interpreted seismic section (11GA_LL2) from the L198 Lower Lesueur Seismic Survey (2011) showing the position of Harvey 1, and the stratigraphic units it intersected, including the Wonnerup and Yalgorup Members of the Lesueur Sandstone. The seismic line is located along Riverdale Road (Fig. 1). (Zhan, 2014)



Figure 3. MB Century Rig 7 on-site at Harvey 1 (photo courtesy of Mark Mitchell)

2000). The ridge separates the Bunbury Trough to the south from the Mandurah Terrace/Dandaragan Trough to the north (Playford et al., 1976, Hocking 1994, Iasky and Lockwood, 2004).

Limited well control is available within the general area of Harvey 1. The relevant wells are: Lake Preston 1, about 13 km northwest (Young and Johanson, 1973); Pinjarra 1, about 35 km north (Jones and Nicholls, 1966); and Wonnerup 1, about 76 km south west (Union Oil Development Corporation, 1972). Two lines of deep water-bores, the Binningup Line (Deeney, 1989a) to the south and the Harvey Line (Deeney, 1989b) to the north were also used in the well planning (Fig. 1). As noted in the regional review of the area, the seismic coverage was considered poor, with limited time–depth control available, making depth estimates of formation boundaries uncertain. Biostratigraphic control is also poor with the majority of Jurassic sediments intersected in existing wells being generally highly oxidized and yielding poor palynological samples.

Harvey 1 was predicted to intersect approximately 250 m of Warnbro Group sediments (Leederville Formation) unconformably overlying Eneabba Formation. The base of the Eneabba Formation was predicted to be at about 830 m depth. Based upon Lake Preston 1 and Pinjarra 1, a shale unit at the base of the Eneabba Formation was prognosed between 770 and 830 m. The Lesueur Sandstone was interpreted to lie between 830 and 2940 m depth with Sabina Sandstone below. The generalized stratigraphic column for the Perth Basin is shown in Figure 4.

Based on intervals intersected in Lake Preston 1 and Wonnerup 1, Crostella and Backhouse (2000) divided the Lesueur Sandstone in the southern Perth Basin into upper and lower members, naming the upper unit the Myalup Member and the lower the Wonnerup Member. The name Myalup Sand, however, had been formally used (Semeniuk, 1995) prior to its use by Crostella and Backhouse (2000). It is therefore proposed to replace the name Myalup with Yalgorup for the upper unit of the Lesueur Sandstone. The Yalgorup Member was prognosed to occur at a depth between 830 and 1526 m and the Wonnerup Member between 1526 and 2940 m. The boundary between the Yalgorup and Wonnerup Members is generally clearly visible on seismic sections in the southern Perth Basin showing the contrast between the interbedded sandstones and finer clastic sediments of the Yalgorup Member and the clean homogeneous sandstone of the Wonnerup Member (Fig. 2).

Well design and drilling program summary

Well design was completed by Aztech Well Construction Pty Ltd and GSWA staff. A summary is presented as Figure 5 with the final drilling and formation evaluation program included as Appendix 1.

Well and camp site preparations were completed during December 2011 and early January 2012. A 340 mm

surface conductor (53.7 m) and a water supply bore (36 m) were completed by SmithDrill between 11 and 15 December 2011. Rig set-up commenced on 18 January 2012 and Harvey 1 was spudded at 00:00, 7 February 2012. Drilling total depth 2945 m (MDRT) was reached at 22:00, 8 March 2012. Following wireline logging and evaluation Harvey 1 was plugged with four cement plugs and MB Rig 7 was released at 06:30, 26 March 2012. Summary well details are shown in Table 1.

Actual versus predicted drilling-time curves are shown in Figure 6. The details of drilling operations are presented in Appendix 2; these include reports on the conductor drilling, daily drilling reports, drilling fluids report, the graphic drilling log plus an end of well drilling report prepared by Aztech Well Construction Pty Ltd.

Broadly the predicted stratigraphy was intersected; however, depths of formation boundaries were higher (shallower) than predicted by 120–145 m. The higher than predicted formation tops led to the basal Eneabba shale being drilled in the openhole section of the well from 625 to 705 m, and therefore not cored as was planned. This basal shale was thinner than that intersected in the nearest offset well Lake Preston 1 (Young and Johanson, 1973), and contains a sandstone interbed similar to the interval encountered in Pinjarra 1 (Jones and Nicholls, 1966). Mud logging (chip) samples indicate the unit contains multi-coloured mudstones and is oxidized in Harvey 1.

The Yalgorup Member contains both well-bedded, fine to coarse sandstones and interbedded sandstone–mudstone intervals. A variably oxidized interbedded mudstone–sandstone unit was intersected between about 1200 and 1378 m. The unit contains a number of sedimentary features such as slumped bedding and vertical sand dykes. The mudstones are typically multi-coloured and display features indicating they are paleosols.

The Wonnerup Member consists of massive and well-bedded sandstones with only minor finer grained intervals. Sandstones range from medium to coarse grained, becoming finer below about 2400 m. The boundary between the Lesueur Sandstone and the Sabina Sandstone is conformable and gradational in offset wells and has been tentatively placed at 2895 m based upon an overall increase in fine sandstone with minor mudstones and an increase in green colouration due to fine green mica below this depth. It is possible that the base of the well is still within the Lesueur Sandstone. Actual versus prognosed depths to formation tops, and their respective thicknesses, are listed in Table 2.

Plate 1 presents a composite well log for Harvey 1 that displays:

- the interpreted stratigraphy
- the caliper log between 841.3 and 2896 m
- the casing points and total depth
- merged logging while drilling (LWD) natural gamma logs between 60 and 2945 m
- LWD resistivity log between 60 and 830 m

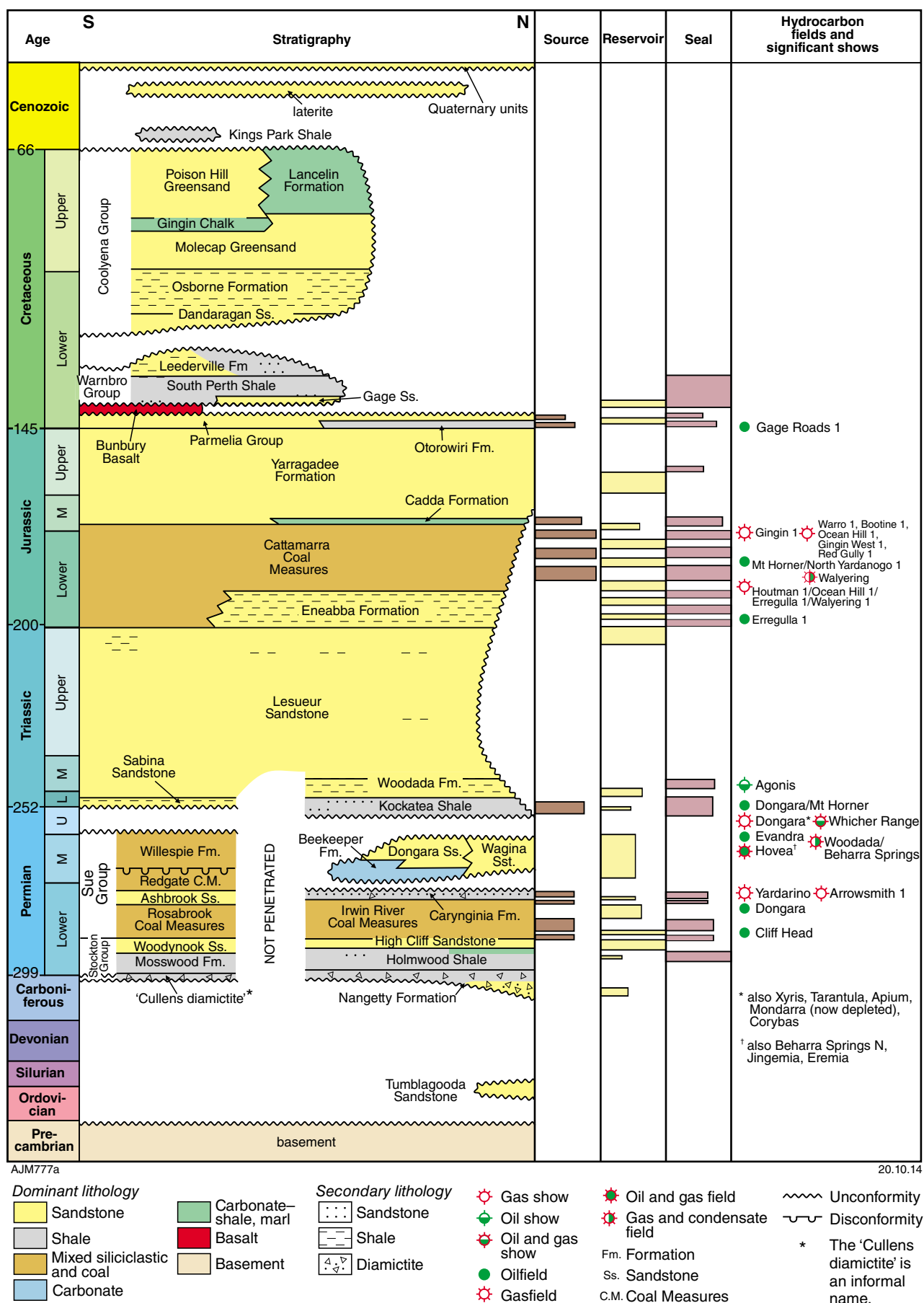


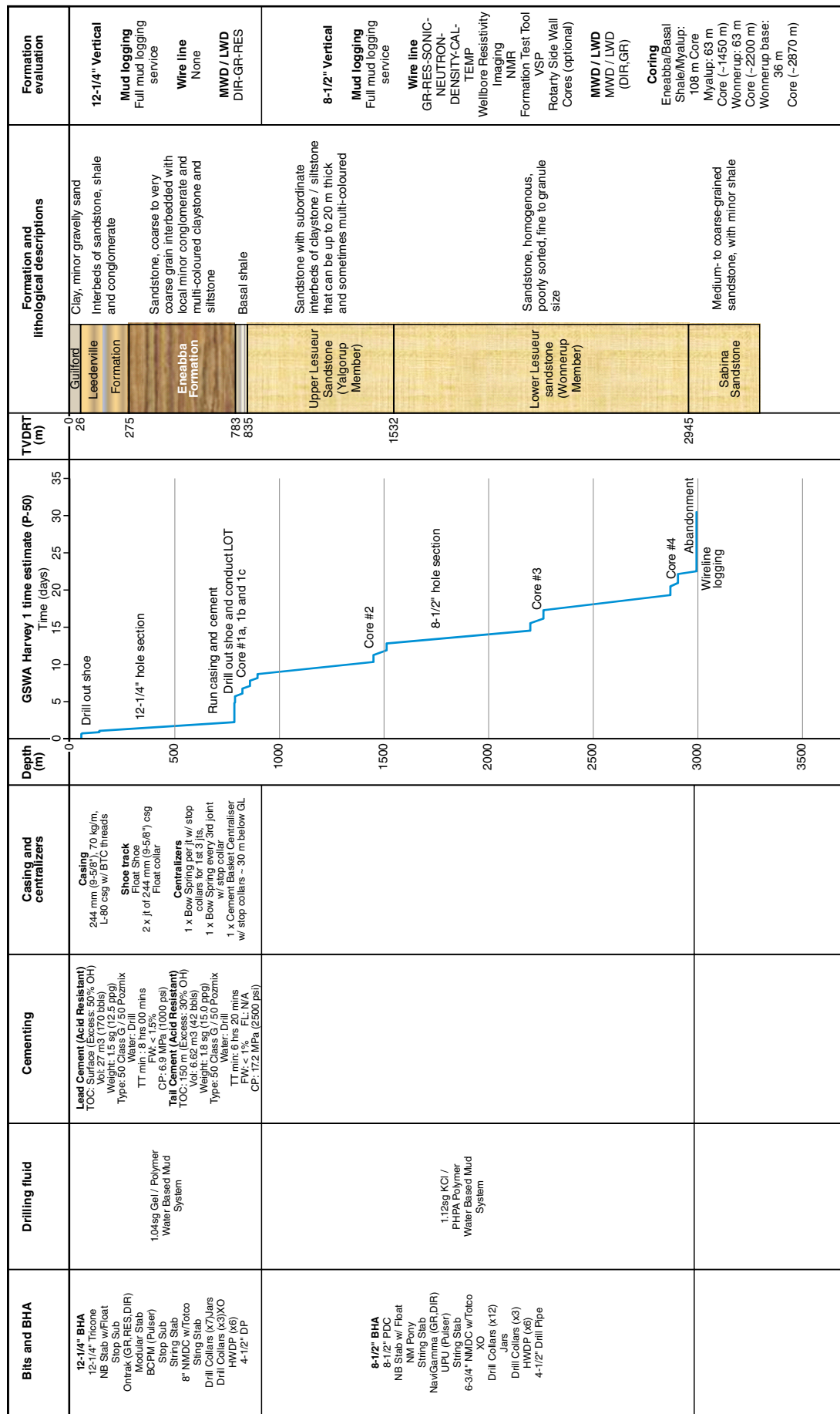
Figure 4. Generalized stratigraphic column for the Perth Basin

Table 1. Harvey 1 well data record

| Well: GSWA Harvey 1 | | | | | | | | | |
|-------------------------------------|--------------------|---|-------------------|--------------------|------------------|-------------------------------------|-----------------|-----------------|------------------|
| Well classification | | Stratigraphic | | Spud date | | 00:00, 7 February 2012 | | | |
| TD ^(a) date | | 22:00, 8 March 2012 | | Rig release date | | 06:30, 26 March 2012 | | | |
| Final TD (m): MDR1/TVDSS | | 2945.0 / 2913.8 | | Total rig days | | 48 | | | |
| Completion status | | Plugged and abandoned | | Permit/licence | | N/A | | | |
| Surface location coordinates | | Lat: 32°59' 30.730"S | | TD coordinates | | Lat: 32°59' 33.730"S | | | |
| | | Long: 115°46' 28.093"E | | | | Long: 115°46' 26.734"E | | | |
| Surface location coordinates | | 385502.044E | | TD coordinates | | 385467.77E | | | |
| | | 6348947.564N | | | | 6348860.13N | | | |
| Reference | | GDA94 / Zone 50 S | | Deviation at TD | | 16.03° | | | |
| Seismic location | | 80 m north of shot point 2450, 11GA-LL2 | | Projection | | MGA94 | | | |
| Permanent datum | | AHD | | RT to GL | | 5.38 m | | | |
| Ground Level (GL) to AHD | | 19.10 m | | RT to AHD | | 24.48 m | | | |
| Estimated final cost ^(b) | | \$9 085 000 | | Native Title claim | | N/A | | | |
| Location land owner | | Alcoa | | Nature reserve | | No | | | |
| Drilling contractor | | MB Century | | Drilling rig | | Century 7 | | | |
| Drilling mud contractor | | Rheochem | | Cementing services | | Halliburton | | | |
| Mud logging services | | Baker Hughes INTEQ | | Coring services | | Halliburton | | | |
| MWD/LWD | | Baker Hughes INTEQ | | Wireline logging | | Baker Hughes | | | |
| Wellsite geologists | | D Short and G Kjellgren | | | | | | | |
| Casing summary | | | | | | | | | |
| | 660 mm/26" hole | 508 mm/20" casing | 445 mm/17½" Hole | 340 mm/13¾" casing | 311 mm/12¼" hole | 244 mm/9¾" casing | 216 mm/8½" hole | 178 mm/7" liner | |
| MDRT (m) | - | - | 53.7 | 53.7 | 845.6 | 841.5 | 2945 | - | |
| TVDR1 (m) | - | - | 53.7 | 53.7 | 845.5 | 841.4 | 2938.3 | - | |
| PIT ^(c) | - | - | - | N/A | - | 2.46 SG EMW ^(d) at 848 m | | - | |
| Conventional coring summary | | | | | | | | | |
| Core number | Cored interval (m) | | Formation/Member: | | Bit/core size mm | | Metres cored | | Metres recovered |
| 1 | 895–931 | | Yalgopus Member | | 216/102 | | 36 | | 36.62 |
| 2 | 1266–1320 | | Yalgopus Member | | 216/102 | | 54 | | 53.16 |
| 3 | 1320–1336 | | Yalgopus Member | | 216/102 | | 16 | | 15.22 |
| 4 | 1336–1345 | | Yalgopus Member | | 216/102 | | 9 | | 7.76 |
| 2–4 | 1266–1345 | | Yalgopus Member | | 216/102 | | 79 | | 76.14 |
| 5 | 1896–1950 | | Wonnerup Member | | 216/102 | | 54 | | 51.64 |
| 6 | 2480–2534 | | Wonnerup Member | | 216/102 | | 54 | | 52.59 |

NOTES:

- (a) TD = total depth
 (b) Estimated final cost includes direct drilling costs and services, consumables, drilling camp, well site supervision, office support and HSE, insurances, site preparation and rehabilitation, geological and logging services and reporting, and laboratory costs.
 (c) PIT = Pressure integrity test
 (d) SG EMW = Specific gravity, equivalent mud weight



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Figure 5. Harvey 1 well design and drilling program summary

Table 2. Prognosed versus actual depth to top of stratigraphic units in Harvey 1

| Formation name | Prognosed depth to top of unit (m) | | | Actual depth to top of unit (m) | | | | |
|---|------------------------------------|----------------------|-----------|---------------------------------|----------|-------------------------|------------|-----------|
| | MDRT ^(a) | TVDSS ^(b) | Thickness | MDRT | TVDSS | High/low ^(c) | Difference | Thickness |
| Undifferentiated Quaternary | 5 | 19 | 26 | 5.38 | 19.1 | – | – | 47.6 |
| Leederville Formation | 31 | -7 | 244 | 53 | -28.5 | Low | -22 | 203.6 |
| Eneabba Formation | 275 | -251 | 495 | 249 | -224.5 | High | 26 | 375 |
| Eneabba Formation, 'basal shale' ^(d) | 770 | -746 | 65 | 624 | -599.5 | High | 146 | 76 |
| Lesueur Sandstone | 835 | -811 | 2 110 | 700 | -675.5 | High | 135 | 2 195 |
| Yalgorup Member | 835 | -811 | 697 | 700 | -675.5 | High | 135 | 678 |
| Wonnerup Member | 1 532 | -1 508 | 1 413 | 1 378 | -1 353.5 | High | 154 | 1 517 |
| Sabina Sandstone | 2 945 | -2 921 | 50 | 2 895 | -2 870.5 | High | 50 | 50 |
| Dry hole, total depth | 2 995 | -2 971 | – | 2 945 | -2 920.5 | – | – | – |

NOTES: (a) MDRT = measured depth rotary table
(b) TVDSS = true vertical depth subsea
(c) High/low = higher/lower than expected elevation
(d) The 'basal shale' is an informal unit of the Eneabba Formation

- natural gamma between 41 and 2882 m
- sonic (24") between 41 and 2871 m
- shallow and deep resistivity between 841.3 and 2886 m
- formation bulk density between 825 and 2864 m
- compensated neutron porosity between 796 and 2862 m
- spontaneous potential between 8 and 2596 m
- borehole temperature between 14 and 2855 m.

Alongside the wireline logs are displayed the cored intervals, biostratigraphy and vitrinite reflectance samples, a graphic mud log and a summary of abbreviated lithological descriptions directly from the mudlog.

The full wireline log suite is available to be downloaded from WAPIMS via DMP's web page and PDF versions of the logs are presented in Appendix 3. A graphic core log completed by the research group at Curtin University is included as Plate 2.

Daily reports

Daily reports for the rig move and drilling operations are contained in Appendix 2 and daily geological reports in Appendix 3.

Mud logging

A full mud logging program was completed by Baker Hughes INTEQ. Multiple sets of ditch cuttings were collected as outlined in the drilling and formation

evaluation program (Appendix 1) and the mud logging report (Appendix 3). Cuttings were collected at 15 m intervals from 60 to 840 m, and 5 m intervals from 840 to 2945 m. An additional set of samples was collected for geochronology analysis by GA. The full mud logging and drilling report can be found in Appendix 3 along with lithological descriptions completed by the wellsite geologists.

Conventional coring operations

The original design of the program was to cut four core intervals to obtain representative material for geological, reservoir and seal testing. The first core was planned to sample an interpreted fine-grained unit at the base of the Eneabba Formation, as intersected in Lake Preston 1 and Pinjarra 1, and include a section of the upper Lesueur Sandstone below about 788 m. The second core was planned within the upper Lesueur Sandstone at about 1450 m, the third within the lower Lesueur Sandstone at about 2200 m and the fourth towards the base of the lower Lesueur Sandstone at about 2870 m.

The interpreted basal shale of the Eneabba Formation was intersected in the openhole section of the well, between about 625 and 704 m, and therefore not cored. The coring program was subsequently modified to obtain representative rock samples for analysis from the remainder of the well. Six cores covering four intervals were cut and recovered from Harvey 1; the depths are listed in Table 1.

Halliburton completed all coring operations. Once the core was pulled to the surface, a standard set of handling procedures was followed for each core:

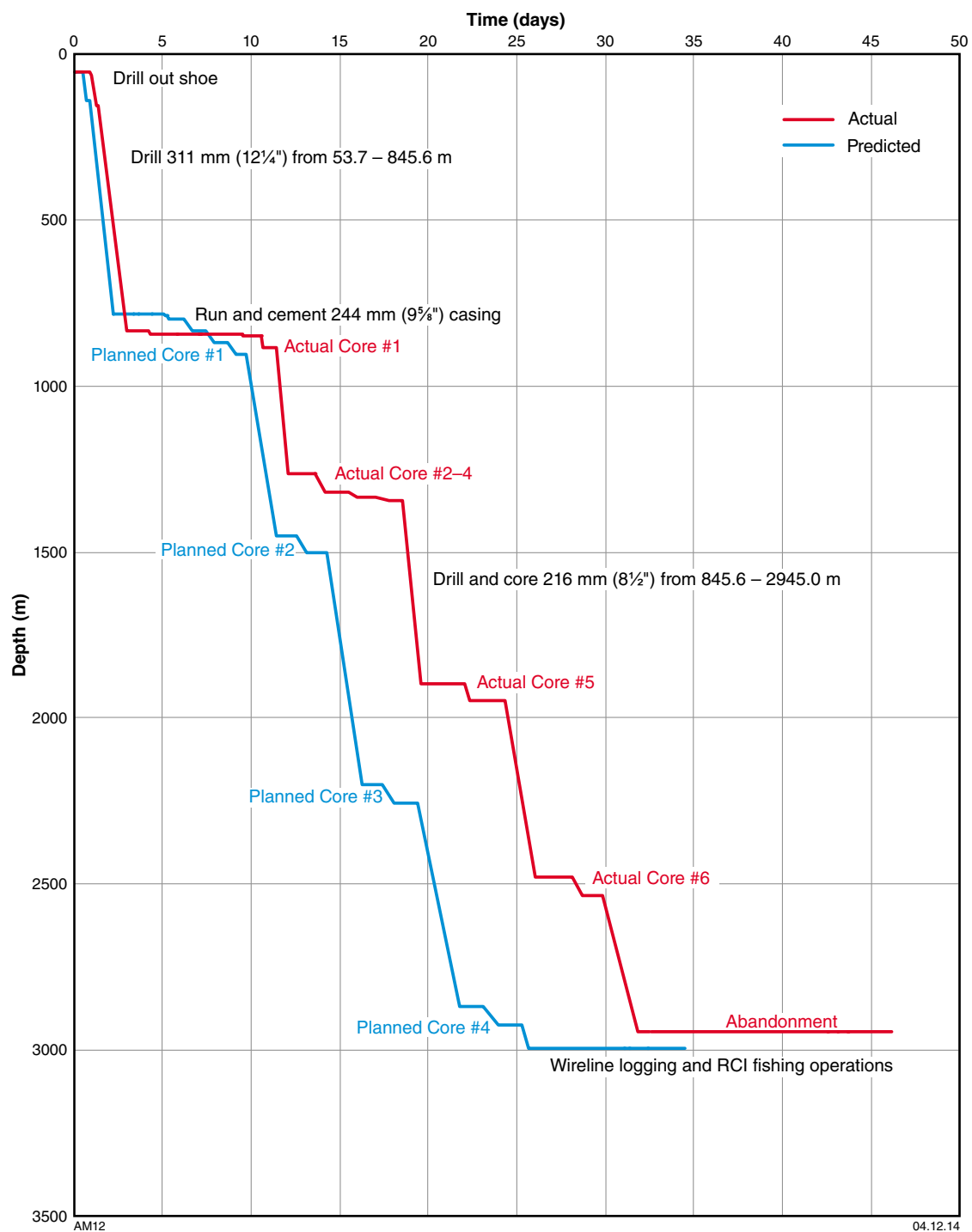


Figure 6. Harvey 1 drilling time curves: predicted versus actual

1. Remove the inner barrel from the outer barrel.
2. Lay out the 9 m inner barrels at the processing area.
3. Measure the recovered core and mark inner barrels.
4. Use gamma ray detectors to log the core while in the barrel.
5. Select 0.5 m 'shale' intervals for special core analysis.
6. Cap and fill the shale sections with mineral oil.
7. Cut the remaining sections into 3 m lengths, cap and inject each with foam resin.
8. Transport all core to the analytical laboratory in Perth.

Each core was drilled using equipment designed to minimize fluid invasion and reduce jamming. In addition, low-invasion, extended-shoe inner barrels were used; their fluted inner surfaces designed to reduce friction and jamming. Prior to cutting the core for transport, natural gamma readings were collected for each core to assist in identifying gross lithology (Appendix 4). To help prevent damage to the cores during transport, the annulus of each barrel was filled with a synthetic foam resin. Full details of the coring program can be found in the Halliburton Coring Report along with core drilling graphical plots (Appendix 4).

Cores 2, 3, and 4 contained intervals with mud rocks that may have the potential to form sealing or baffle units for CO₂ storage. Thirteen half-metre samples were selected, based on the core gamma readings at the wellsite, for special core analysis to be performed by CSIRO. After cutting each 0.5 m sample from the 9 m inner core barrel, the remaining mud was allowed to drain out of the annulus before capping one end and filling the empty annulus with deaerated mineral oil to prevent dehydration of the shale. Finally, the second cap was attached ready for shipment to Perth. Except for removal of the 0.5 m shale samples, the cores were left in 3 m sections for transport to Perth.

Wireline logging

The well formation evaluation was based on both LWD and end of well wireline logging data, with wireline logs being the primary evaluation method. Natural gamma ray and resistivity LWD data were collected in the 311 mm (12¼") openhole section to assist in identifying a competent casing shoe point. This was to be a critical pick as the shoe was designed to be set as deep as reasonably possible without drilling through the shale, interpreted to be at the base of the Eneabba Formation. No clearly identifiable signature could be recognized in the offset well logs, or in the Harvey 1 LWD log, above the basal shale. As the drilled sequence was about 140 m shallower than prognosed, the basal shale unit was drilled in the

openhole section. Gamma LWD data were collected in the remainder of the openhole section of the well.

At the completion of drilling, a single logging suite comprising five runs was completed for the 216 mm (8½") hole section:

- Run 1: Super combo (GR-RES-SON-DEN-NEUT-CAL-TEMP)
- Run 2: Resistivity and sonic imaging
- Run 3: Nuclear magnetic resonance (NMR)
- Run 4: Formation pressure test tool (RCI)
- Run 5: Vertical seismic profile (VSP)

Selected log traces are displayed on the composite well log (Plate 1) and individual logs are presented in Appendix 5. The full log suite can be downloaded from the WAPIMS database <www.dmp.wa.gov.au/wapims>.

RCI tool loss and fishing operations

At 21:30 on 11 March 2012, while attempting to collect formation water samples at 2504 m with the Reservoir Characterization Instrument (RCI) tool, the logging cable became differentially stuck against the wall of the well at an estimated depth between 1300 and 1500 m. While attempting to pull free, the wireline cable unexpectedly parted inside the casing at approximately 684 m leaving an estimated 1780 m of cable and the RCI tool in the openhole section of the well. Overpull applied to the cable was within the specified 50% limits of allowable tensions. Various fishing runs recovered about 450 m of the cable (in sections) before operations were abandoned. Recovery of the tool was unsuccessful due to the deteriorating hole conditions between 1125 to 1378 m. Details of fishing operations are included within the drilling operations daily reports (Appendix 2).

Further logging below 1400 m was not possible due to the wireline fish remaining in the hole. Two cement plugs were set from 1460 m and top cement tagged at 1338 m prior to completing logging operations above that depth.

Plugging and completion

As noted above, two cement plugs were set from 1460 m and top cement tagged at 1338 m following the tool loss and fishing operation. Following the completion of the remaining wireline program, cement plugs were set at 871 m and tagged at 781 m and from 25 m to surface. Details of the plug and abandonment are contained in the drilling end of well report (Appendix 2).

Core analyses

Core preparation

The 3 m core tubes were transported in core cages to the Intertek Geotech laboratory in Welshpool. At the laboratory the inner tubes were opened and a preliminary descriptive log (Plate 2) was completed by geologists from CSIRO, Curtin University and GSWA. Representative plugs were selected following the logging and details of the core plugs extracted are contained in Appendix 6. Each plug description contains information on its depth, core run, sample type (horizontal or vertical), lithological description and facies type, and its allocated GSWA sample number. The GSWA sample number is used in DMP's sample storage system and also provides the depth correlations for samples used in other studies.

Removal of the inner barrel from the fine-grained material intersected in Cores 2–4 proved difficult. The semiconsolidated sandy mudstones and muddy sandstones commonly disintegrated upon opening. Obtaining useable plugs from this interval, even from the separately sampled and preserved 0.5 m sections, was unsuccessful.

Following the initial logging and extraction of core plugs, the 100 mm core was cut longitudinally into $\frac{3}{4}$ and $\frac{1}{4}$ slabs, placed into 1 m core trays and forwarded to the GSWA core storage facility at Carlisle. Core is available for viewing as per normal GSWA core library procedures available via the DMP website <www.dmp.wa.gov.au/corelibrary>.

X-ray diffraction

Core plug trims were used for X-ray diffraction (XRD) and petrological examination. A total of 28 samples was submitted to Intertek Geotech for quantitative XRD analysis. The plug offcut samples were pulverized to a fine powder and prepared as unoriented powder mounts. A report on the XRD analysis is attached as Appendix 7.

Petrographics

Thin sections were made from 62 of the plug offcuts and full descriptions of the 56 slides suitable for examination are contained in the petrographic report by Dr Andrew Glikson in Appendix 8. A summary of this report follows.

The sequence is dominated by five poorly sorted rock types: light-green clay matrix-supported arkoses, feldspathic arenites, diamictites, gritstones and micro-conglomerates. Grains are dominantly angular, although some samples contain rounded to semirounded quartz grains. Many samples display extreme comminution of matrix quartz, typical of glacially ground material.

The sediments display weak low-temperature alteration, which includes sericite and saussurite clouding, and alteration of biotite to chlorite; these alterations are likely to have occurred in the source-rock terrain. Most arenites have an irregular, non-oriented texture whereas

some display sedimentary banding and flow textures. The sediments contain fresh little-altered mineral and rock fragments, including garnet, perthite and microcline, which suggest derivation from a high-grade garnet gneiss provenance. Samples below 1930 m contained little or no garnet. The appearance of carbonate cement and recrystallized muscovite below this level represents hydrous and low-temperature hydrothermal effects.

Porosity and permeability

Porosity and permeability measurements on core material were performed by Intertek Geotech.

Plugs were first cleaned to remove any reservoir fluids and residual salts, and then dried. Porosity was measured by injecting core samples with helium, while permeability measurements were performed with air as the flowing medium. Both sets of measurements were performed at ambient temperature, at both 5520 kPa and 29 650 kPa (measured at 800 psi and 4300 psi, respectively). Results are presented in Table 3 and Appendix 9.

End trims (6.35 mm, or $\frac{1}{4}$ " long) were taken from 28 plugs for mercury injection capillary pressure measurements (MICP). The end trims were placed in a Micromeritics Autopore IV porosimeter, under a 50 micron vacuum, and injected with mercury. Capillary pressure was increased over 120 steps until ~413 700 kPa (60 000 psi) was achieved. Table 4 provides a summary of the results and a full report is presented as Appendix 9.

Geochronology

To assist with sediment provenance studies in the Perth Basin and with GA provenance studies on the North West Shelf, a separate set of unwashed samples was collected over selected intervals for U–Pb detrital zircon geochronology. Preliminary results from five samples covering the intersected sequence are summarized below. Following the preliminary results, the processing of additional samples commenced; however, results for these samples have not been received. A final report with interpretations will be published separately and results made available via WAPIMS.

The deepest sample (GA 2132434), from near the base of the Lesueur Sandstone or top of the Sabina Sandstone (2900 m depth), yields dates between 3323 and 538 Ma. Two significant age components were identified: the oldest, and dominant component is Mesoproterozoic (1324–1027 Ma), and the younger component is Neoproterozoic–Cambrian (572–538 Ma). The remaining results are dispersed and do not form significant age components.

The lower Lesueur Sandstone sample (GA2132433), from 2200 m depth, yields dates between 3308 and 514 Ma, again with two age components identified; the older is Mesoproterozoic–Neoproterozoic (1237–832 Ma) and the younger is Neoproterozoic–Cambrian (609–534 Ma). Analyses yielding dates >1300 Ma are dispersed and do not form significant age components.

Table 3. Summary of porosity and permeability analyses for Harvey 1

| <i>Plug number and type^(a)</i> | <i>Depth (m)</i> | <i>Grain density (g/cc)</i> | <i>Porosity 800 (%)^(b)</i> | <i>Permeability 800 (mD)^(b)</i> | <i>Porosity 4300 (%)^(b)</i> | <i>Permeability 4300 (mD)^(b)</i> | <i>Comment</i> | <i>GSWA sample numbers</i> |
|---|------------------|-----------------------------|---------------------------------------|--|--|---|-----------------------------|----------------------------|
| 1H | 897.63 | 2.65 | 23.60 | 918.17 | — | — | Friable sample | 206601 |
| 2H | 898.47 | 2.65 | 25.12 | 937.69 | — | — | Friable sample | 206602 |
| 3H | 903.62 | 2.65 | 17.64 | 10.26 | 17.01 | 9.02 | — | 206603 |
| 4V | 904.00 | 2.65 | 21.85 | 47.68 | 21.12 | 40.03 | — | 206604 |
| 5H | 905.71 | 2.65 | 24.56 | 1 047.82 | 23.91 | 936.55 | — | 206605 |
| 6H | 906.93 | 2.67 | 20.03 | 3.77 | 19.86 | 3.25 | — | 206606 |
| 7V | 907.00 | 2.68 | 19.87 | 0.89 | 18.65 | 0.77 | — | 206607 |
| 8H | 909.17 | 2.64 | 20.59 | 42.75 | 20.11 | 36.55 | — | 206608 |
| 9H | 911.53 | 2.64 | 25.66 | — | — | — | Friable sample | 206609 |
| 10H | 913.83 | 2.64 | 24.87 | — | — | — | Friable sample | 206610 |
| 12H | 915.45 | 2.67 | 20.12 | 19.45 | 19.69 | 17.71 | — | 206612 |
| 13H | 917.57 | 2.64 | 21.74 | 1 164.54 | — | — | Friable sample | 206613 |
| 14H | 919.16 | 2.66 | 24.62 | 1 253.55 | 23.55 | 912.54 | — | 206614 |
| 15V | 920.00 | 2.66 | 20.29 | 6.29 | 19.54 | 4.43 | — | 206615 |
| 16H | 920.56 | 2.66 | 19.33 | 5.15 | 18.89 | 4.67 | — | 206616 |
| 17H | 922.42 | 2.65 | 18.19 | 17.56 | 17.80 | 16.15 | — | 206617 |
| 18V | 923.00 | 2.65 | 24.55 | 1 037.89 | — | — | Friable sample | 206618 |
| 19H | 923.23 | 2.66 | 23.17 | 798.66 | 22.66 | 751.01 | — | 206619 |
| 20H | 925.84 | 2.66 | 21.76 | 156.33 | 21.02 | 132.05 | — | 206620 |
| 21H | 926.00 | 2.65 | 24.09 | 837.20 | — | — | Friable sample | 206621 |
| 22H | 927.61 | 2.65 | 24.33 | 964.14 | 22.24 | 789.52 | — | 206622 |
| 23H | 929.30 | 2.65 | 24.93 | 1 573.23 | — | — | Friable sample | 206623 |
| 24H | 930.71 | 2.65 | 18.37 | 2.99 | 17.18 | 2.66 | — | 206624 |
| 25V | 930.84 | 2.65 | 18.87 | 3.45 | 18.12 | 3.03 | — | 206625 |
| 26H | 1 266.21 | 2.65 | 17.65 | 11.40 | 17.04 | 8.16 | — | 206626 |
| 27H | 1 271.95 | 2.65 | 24.66 | — | — | — | Friable sample | 206627 |
| 28H | 1 273.89 | 2.65 | 15.01 | 0.72 | 14.39 | 0.41 | — | 206628 |
| 34H | 1 323.53 | 2.63 | — | — | — | — | Irregular plug not suitable | 206634 |
| 35H | 1 323.93 | 2.65 | 18.50 | 12.40 | 17.77 | 8.63 | — | 206635 |
| 36V | 1 324.00 | 2.65 | 18.34 | 25.83 | 17.04 | 17.52 | — | 206636 |
| 37H | 1 325.83 | 2.66 | 18.37 | 38.19 | 17.40 | 34.50 | — | 206637 |
| 38H | 1 329.94 | 2.75 | 6.70 | < 0.01 | 6.57 | < 0.01 | — | 206638 |
| 40H | 1 331.05 | 2.66 | 13.95 | 6.62 | 12.87 | 4.95 | — | 206640 |
| 41H | 1 331.55 | 2.65 | 18.37 | 77.19 | 17.78 | 66.32 | — | 206641 |
| 42H | 1 337.41 | 2.68 | 10.25 | 0.07 | 9.93 | < 0.01 | — | 206642 |
| 43H | 1 342.60 | 2.65 | — | — | — | — | Irregular plug not suitable | 206643 |
| 44H | 1 343.61 | 2.68 | 13.24 | 0.52 | 12.62 | 0.07 | — | 206644 |
| 45H | 1 897.66 | 2.65 | 15.51 | 136.82 | 15.07 | 128.58 | — | 206645 |
| 46V | 1 897.91 | 2.65 | 16.05 | 215.01 | 15.34 | 194.35 | — | 206646 |
| 47H | 1 901.61 | 2.65 | 16.35 | 578.67 | 15.86 | 527.89 | — | 206647 |

Table 3. continued

| Plug number and type ^(a) | Depth (m) | Grain density (g/cc) | Porosity 800 (%) ^(b) | Permeability 800 (mD) ^(b) | Porosity 4300 (%) ^(b) | Permeability 4300 (mD) ^(b) | Comment | GSWA sample numbers |
|-------------------------------------|-----------|----------------------|---------------------------------|--------------------------------------|----------------------------------|---------------------------------------|---------|---------------------|
| 48V | 1902.92 | 2.65 | 13.92 | 7.28 | 13.37 | 5.89 | — | 206648 |
| 49H | 1904.70 | 2.65 | 14.92 | 41.62 | 14.53 | 37.44 | — | 206649 |
| 50H | 1908.71 | 2.64 | 13.56 | 7.77 | 13.17 | 6.75 | — | 206650 |
| 51V | 1908.92 | 2.65 | 18.37 | 77.24 | 17.66 | 68.13 | — | 206651 |
| 52V | 1915.00 | 2.65 | 14.84 | 5.81 | 14.18 | 4.55 | — | 206652 |
| 53H | 1916.38 | 2.67 | 10.94 | 0.44 | 10.23 | < 0.01 | — | 206653 |
| 54H | 1919.30 | 2.65 | 15.54 | 24.37 | 15.35 | 21.86 | — | 206654 |
| 55H | 1927.20 | 2.67 | 15.08 | 26.65 | 14.62 | 25.54 | — | 206655 |
| 56H | 1929.40 | 2.66 | 14.52 | 100.39 | 14.11 | 93.60 | — | 206656 |
| 58V | 1930.00 | 2.81 | 11.56 | < 0.01 | 11.13 | < 0.01 | — | 206658 |
| 59V | 1931.00 | 2.67 | 16.07 | 170.12 | 15.67 | 156.12 | — | 206659 |
| 60H | 1935.50 | 2.65 | 16.33 | 122.38 | 15.97 | 111.49 | — | 206660 |
| 61V | 1940.00 | 2.72 | 14.42 | 1.27 | 13.65 | 0.13 | — | 206661 |
| 62H | 1940.58 | 2.68 | 15.46 | 0.34 | 14.22 | 0.07 | — | 206662 |
| 63H | 2480.66 | 2.67 | 12.90 | 9.76 | 12.37 | 8.73 | — | 206663 |
| 64V | 2480.91 | 2.65 | 11.01 | 0.68 | 10.57 | 0.12 | — | 206664 |
| 65H | 2485.53 | 2.65 | 12.36 | 29.98 | 11.96 | 26.92 | — | 206665 |
| 66V | 2488.00 | 2.66 | 8.80 | < 0.01 | 8.37 | < 0.01 | — | 206666 |
| 67H | 2488.14 | 2.69 | 5.24 | < 0.01 | 5.04 | < 0.01 | — | 206667 |
| 68H | 2491.22 | 2.65 | 13.02 | 19.78 | 12.57 | 18.17 | — | 206668 |
| 69H | 2491.56 | 2.65 | 13.67 | 343.66 | 13.13 | 322.90 | — | 206669 |
| 70H | 2492.34 | 2.81 | 2.12 | < 0.01 | 2.01 | < 0.01 | — | 206670 |
| 71V | 2495.93 | 2.66 | 11.33 | 0.43 | 10.58 | 0.01 | — | 206671 |
| 72H | 2496.22 | 2.65 | 12.47 | 40.83 | 12.10 | 38.13 | — | 206672 |
| 73H | 2501.29 | 2.65 | 12.51 | 22.37 | 12.16 | 20.14 | — | 206673 |
| 74V | 2503.00 | 2.65 | 12.13 | 4.13 | 11.66 | 3.17 | — | 206674 |
| 75H | 2503.46 | 2.65 | 13.56 | 231.44 | 13.30 | 216.08 | — | 206675 |
| 76H | 2506.55 | 2.73 | 11.01 | 0.48 | 10.66 | 0.21 | — | 206676 |
| 77H | 2508.29 | 2.65 | 14.96 | 33.67 | 14.47 | 30.37 | — | 206677 |
| 78H | 2509.42 | 2.78 | 2.25 | < 0.01 | 2.08 | < 0.01 | — | 206678 |
| 79V | 2510.00 | 2.66 | 11.87 | 1.65 | 11.65 | 1.29 | — | 206679 |
| 80H | 2510.29 | 2.67 | 14.24 | 145.09 | 13.86 | 134.35 | — | 206680 |
| 81H | 2513.34 | 2.67 | 11.42 | 3.59 | 11.02 | 3.03 | — | 206681 |
| 82H | 2513.53 | 2.67 | 12.48 | 9.70 | 11.86 | 7.78 | — | 206682 |
| 83V | 2516.00 | 2.67 | 13.83 | 60.40 | 13.59 | 55.73 | — | 206683 |
| 84V | 2520.00 | 2.66 | 10.99 | 3.48 | 10.70 | 2.37 | — | 206684 |
| 85H | 2520.44 | 2.65 | 13.87 | 115.64 | 13.63 | 107.99 | — | 206685 |
| 86H | 2523.34 | 2.71 | 2.36 | < 0.01 | 2.08 | < 0.01 | — | 206686 |
| 87B V | 2525.00 | 2.65 | 12.23 | 3.79 | 11.78 | 2.97 | — | 206687 |
| 88H | 2525.83 | 2.65 | 12.33 | 5.32 | 11.86 | 4.68 | — | 206688 |
| 89H | 2527.38 | 2.65 | 11.94 | 9.44 | 11.49 | 7.51 | — | 206689 |
| 90H | 2529.29 | 2.65 | 13.98 | 67.70 | 13.30 | 61.64 | — | 206690 |

NOTES: (a) H = horizontal plug, V = vertical plug
(b) Samples without values were not suitable for determining porosity and permeability

Table 4. Summary result of MICP tests for Harvey 1

| Sample number ^(a) | Depth (m) | Corrected Mercury porosity (%) | Mercury/air displacement pressure (psi) | Pore throat distribution | | | Swanson method | |
|------------------------------|-----------|--------------------------------|---|---|----------------------------------|------------------------------|-------------------------|-----------------------|
| | | | | Micropores < 0.1 micron (% PV) ^(b) | Intermediate 0.1-3 micron (% PV) | Macropores > 3 micron (% PV) | Brine permeability (mD) | Air permeability (mD) |
| 1H | 897.63 | 22.613 | 1.993 | 13.623 | 37.348 | 49.030 | 554.154 | 580.881 |
| 3H | 903.62 | 20.280 | 20.300 | 26.192 | 69.260 | 4.547 | 2.352 | 5.799 |
| 9H | 911.53 | 24.414 | 1.364 | 13.901 | 33.007 | 53.091 | 762.102 | 759.971 |
| 16H | 920.56 | 18.440 | 51.014 | 40.431 | 59.569 | 0.000 | 0.391 | 1.277 |
| 22H | 927.61 | 24.927 | 2.192 | 14.290 | 38.202 | 47.508 | 313.794 | 359.568 |
| 26H | 1266.21 | 15.657 | 45.287 | 23.132 | 76.868 | 0.000 | 2.755 | 6.627 |
| 27H | 1271.95 | 21.097 | 3.880 | 6.915 | 25.043 | 68.042 | 229.585 | 276.269 |
| 28H | 1273.89 | 16.023 | 43.234 | 31.090 | 68.910 | 0.000 | 0.466 | 1.482 |
| 35H | 1323.93 | 16.434 | 10.248 | 2.273 | 78.337 | 19.390 | 5.882 | 12.565 |
| 36H | 1324.00 | 20.431 | 10.245 | 10.538 | 45.466 | 43.997 | 33.794 | 54.897 |
| 38H | 1329.94 | 13.163 | 92.283 | 51.886 | 48.114 | 0.000 | 0.098 | 0.396 |
| 42H | 1337.41 | 14.230 | 50.107 | 46.052 | 53.948 | 0.000 | 0.178 | 0.657 |
| 43H | 1342.60 | 11.693 | 44.358 | 62.858 | 37.142 | 0.000 | 0.080 | 0.336 |
| 44H | 1343.61 | 16.475 | 45.122 | 27.873 | 72.127 | 0.000 | 0.762 | 2.241 |
| 45H | 1897.66 | 13.618 | 11.294 | 17.199 | 50.684 | 32.117 | 8.982 | 17.955 |
| 46H | 1897.91 | 13.279 | 1.129 | 13.772 | 43.204 | 43.023 | 50.650 | 77.225 |
| 47H | 1901.61 | 16.733 | 2.916 | 9.205 | 39.426 | 51.370 | 172.229 | 216.793 |
| 48H | 1902.92 | 2.206 | 41.385 | 31.992 | 68.008 | 0.000 | 0.011 | 0.063 |
| 53H | 1916.38 | 9.965 | 84.829 | 40.249 | 59.751 | 0.000 | 0.056 | 0.249 |
| 60H | 1935.50 | 16.383 | 5.717 | 12.056 | 54.123 | 33.821 | 15.136 | 27.883 |
| 62H | 1940.58 | 11.725 | 62.203 | 36.559 | 63.441 | 0.000 | 0.150 | 0.568 |
| 63H | 2480.66 | 11.230 | 41.279 | 21.334 | 78.666 | 0.000 | 0.367 | 1.210 |
| 64H | 2480.91 | 10.384 | 14.699 | 24.734 | 68.521 | 6.745 | 0.380 | 1.245 |
| 69H | 2491.56 | 12.536 | 5.190 | 11.139 | 48.126 | 40.735 | 29.068 | 48.347 |
| 72H | 2496.22 | 11.815 | 6.943 | 26.754 | 61.608 | 11.638 | 0.897 | 2.571 |
| 75H | 2503.46 | 12.336 | 3.881 | 8.682 | 38.776 | 52.542 | 59.481 | 88.436 |
| 83H | 2516.00 | 14.210 | 6.301 | 15.068 | 35.483 | 49.448 | 32.197 | 52.700 |
| 88H | 2525.83 | 9.885 | 49.901 | 31.745 | 68.255 | 0.000 | 0.216 | 0.773 |

NOTES: (a) H = horizontal plug
(b) PV = pore volume

The upper Lesueur Sandstone sample (GA 2132432), at 1000 m depth, yields dates between 3262 and 511 Ma. Three age components have been identified; the oldest is Mesoproterozoic (1272–1067 Ma), the second is Mesoproterozoic–Neoproterozoic (1011–866 Ma), and the younger cluster is Neoproterozoic (604–511 Ma). Analyses yielding dates >1300 Ma are dispersed and do not form significant age components.

The Eneabba Formation sample (GA 2132431), at 450 m depth, yields dates between 2681 and 515 Ma. The data define two age components; the older is Archean (2681–2636 Ma) and the younger is Mesoproterozoic (1223–1080 Ma). The remaining results are dispersed

(between 2636 and 1223 Ma, and <1080 Ma) and do not form significant age components.

The shallowest sample analysed was from the Leederville Formation (GA 2132430), at 100 m depth. Data are dispersed between 3358 Ma and 134 Ma, with two dominant and, arguably, two subordinate age components. The oldest dominant component is Archean (2763–2571 Ma) and the younger dominant component is Mesoproterozoic (1232–1061 Ma). The older subordinate component is Paleoproterozoic–Mesoproterozoic (1763–1595 Ma) and the younger is Neoproterozoic (727–683 Ma). The remaining results are dispersed and do not form significant age components.

HyLogger

Both $\frac{3}{4}$ and $\frac{1}{4}$ core portions of core were scanned using the GSWA HyLogger, capturing high-resolution digital photographs and three electromagnetic spectrum from visible and near-infrared wavelengths (380–1000 nm) to shortwave-infrared wavelengths (1000–2500 nm) and thermal-infrared wavelengths (6000–14500 nm). Data were analysed using The Spectral Geologist (TSG) interpretation software. Core photographs and summary spectral interpretation data are presented in Appendix 10.

Palynology

A total of 16 samples was submitted for palynological examination by Backhouse Biostrat Pty Ltd; full results are presented in Appendix 11. Two samples, one of selected drill chips and the other a mud sample collected from the openhole interval 795–825 m, were examined during the well-drilling operation in an attempt to define the stratigraphic position close to the casing shoe. The chip samples were considered barren and the few palynomorphs recovered from the mud samples were not definitively identified.

The remaining samples were selected from drillcore with only three yielding identifiable palynomorphs, at 901.75, 903.6 and 2514.4 m. The upper two samples from Core 1 (901.75 and 903.6 m) have been allocated to the *S. speciosus* Zone, probably the lower part, which is currently considered to be early Carnian to ?latest Ladinian. The deepest sample (2514.4 m, Core 6) produced a number of identifiable specimens; however, most are not well preserved and there appears to be some latent oxidation of the original material. The best estimate is that this sample is from the *S. quadrifidus* Zone, currently considered to be Ladinian.

Vitrinite reflectance

Two selected samples were submitted to GeoGAS for organic petrography and vitrinite reflectance determination. The report is attached as Appendix 12. The upper sample from Core 1 (916.42 m) was dominantly a vitrinite-rich coal with a R_v max of 0.40%. The second sample, from Core 6 (2514.45 m), contained inertodetrinite in a silty claystone with no vitrinite. This sample returned an inertinite reflectance value of 1.52%. Inertinite reflectance together with the fluorescence colours of liptinite macerals and mineral matter suggest a maturation level of this sample is about 0.7 – 0.8% vitrinite reflectance equivalent.

Contributions to geological knowledge

Harvey 1 is a stratigraphic well drilled on the Harvey Ridge, a structural high in the southern Perth Basin. The well was drilled to obtain data to assist with the assessment of the potential of the area for geological storage of CO₂ within the Lesueur Sandstone.

A standard suite of mud logging, modern wireline logging, selected coring and an extensive sample analysis program has provided a large dataset to allow a decision to move to the next stage of the assessment project. A total of 217 m of 100 mm-diameter drillcore was recovered over four intervals from the upper and lower members of the Triassic Lesueur Sandstone.

The well confirmed the general stratigraphic sequence although the intersected sequence was shallower than predicted. This meant the fine-grained unit interpreted at the base of the Eneabba Formation was not cored as planned. However, samples recovered from openhole drilling through this unit indicate that the material is oxidized and similar to the interpreted pedogenic units intersected in core in the Yalgorup Member below. This unit at the base of the Eneabba Formation is unlikely to act as a conventional seal formation, at least at this location.

The presence of oxidized multi-coloured mudstone, claystone and sandstone representing paleosols was more extensive than predicted; several intervals were encountered in each of the Yalgorup Member of the Lesueur Sandstone and the overlying Eneabba Formation.

Plugs taken from the drillcore allowed the measurement of reservoir properties including mineralogy, porosity, permeability and mechanical strength. Initial reservoir analysis has indicated that the Wonnerup Member may be suitable for the storage of CO₂. Palynological sampling was limited due largely to the scarcity of suitable material in core. The limited results obtained along with uncertainties with existing age data indicate that a review of the stratigraphic interpretation of the southern Perth Basin is needed.

The modern suite of well logs has contributed significant data on the stratigraphic sequence and the properties of the rocks intersected. The completion of a vertical seismic profile log has allowed for an improved time–depth calibration allowing for better estimation of formation depths in future drilling programs.

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