Harvey-4 Final Well Report

South West Hub Carbon Capture and Storage Project

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HARVEY-4 FINAL WELL REPORT

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

HARVEY-4 FINAL WELL REPORT

1. Introduction

In late 2014, DDH1 Drilling Pty Ltd (DDH1), in conjunction with Drilling Contractors Australia (DCA) and Rockwater Pty Ltd (Rockwater), were awarded a contract by the WA Department of Mines (DMP) to drill and geologically log three wells in the Harvey area of the Perth Basin, approximately 150km south of Perth. The three vertical wells, Harvey-2, -3, and -4, were to be drilled as a part of ongoing investigations in the South West Hub Carbon Capture and Storage (CCS) Project – a joint endeavour by the Federal and WA State Governments, various research institutions and private industry.

DDH1 was appointed as lead contractor with overall site responsibility together with direct responsibility for drilling wells Harvey-2 and Harvey-3, both of which were to be continuously cored to estimated total depths of 1350 and 1550m respectively. DDH1's brief also included mud-rotary drilling an additional shallow (52m) monitoring hole adjacent to the Harvey-4 site.

DCA was subcontracted to drill Harvey-4 to an estimated total depth of 1800m, the bulk of which was to be drilled open hole with limited core runs in zones of specific interest. Rockwater was subcontracted to provide on-site hydro-geological logging services and supervision for all three holes and DDH1 engaged the Australian Mud Company to provide mud engineering services for the entire program.

Local field investigations and earlier drilling at Harvey-1 (Millar and Reeve, 2014) had determined that the strata were highly unlikely to be over-pressured or to yield hydrocarbon flows. However, as a precautionary measure, the drilling programs were undertaken using appropriate well control and mud systems.

This report summarises operational and technical aspects of the drilling program undertaken by DCA as a subcontractor to DDH1 Drilling to complete Harvey-4. In particular, the report captures all drilling intervals and documents the drilling practise and mud engineering responses to the various issues encountered whilst drilling the well.

2. Specifications and Well Design

Well design for Harvey 4 was undertaken by DDH1 in consultation with DMP staff taking account of:

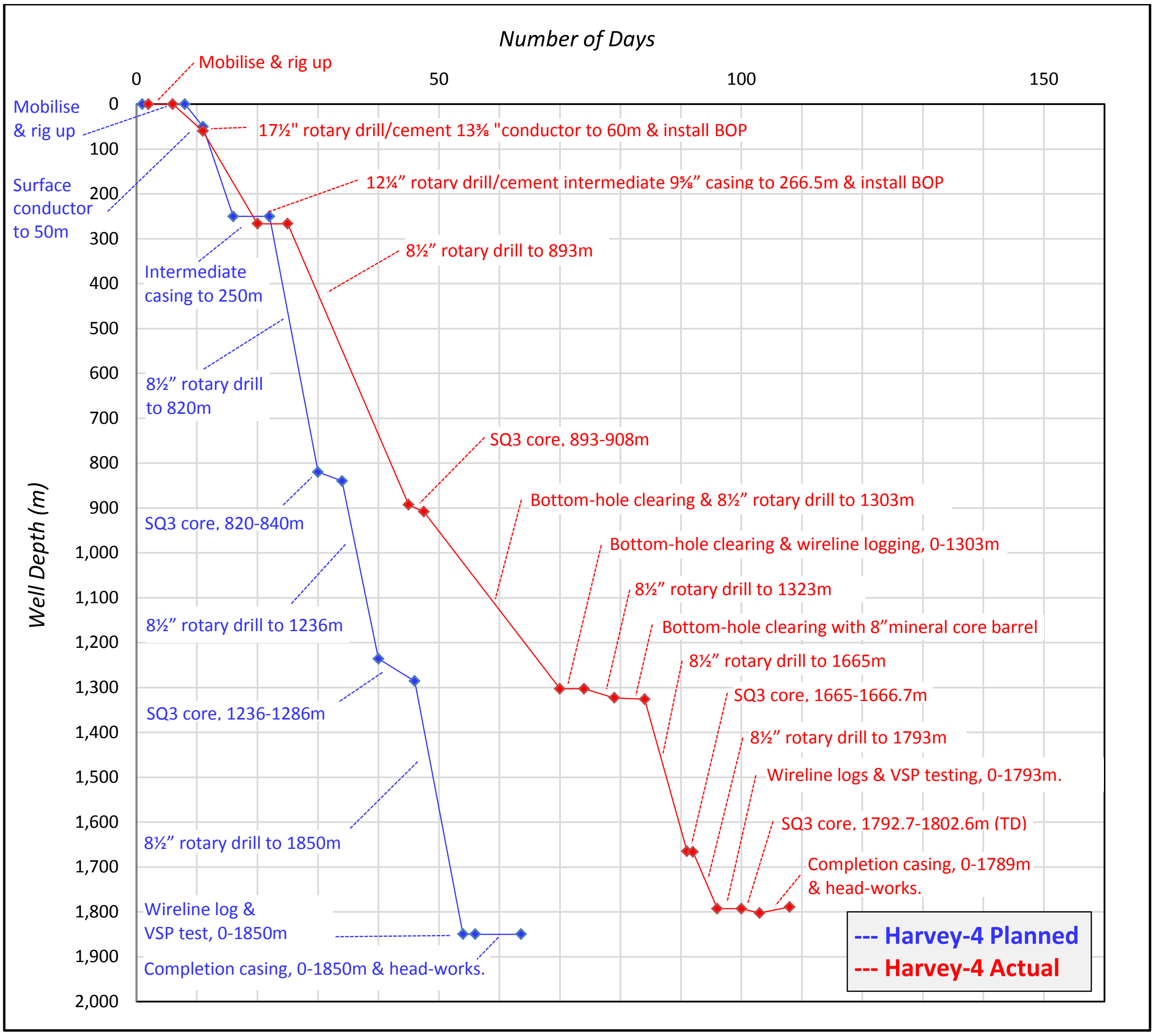
- the project's technical objectives and budgetary constraints,
- prior drilling experience at Harvey-1 (including a review of all drill reports, geophysical logs and inspection of core and drill cuttings),
- environmental and safety considerations,
- original well specifications (DMP Tender 120214 and subsequent negotiated revisions).

Well specifications are shown in Table 1 and the planned *vs* actual well design and timeline is shown diagrammatically in Figure 1.

Table 1: Harvey-4 Well Specifications

Specification	Original (DMP Tender & revisions)	Final (on completion)
Dip:	-90°	-90°
Azimuth:	000°	000°
Total Depth:	1400 – 1500m – 1850m	1800m
Drilling Technique	Rotary Mud (with 2 core intervals)	Rotary Mud (with 3 core intervals)
Minimum core size	100mm	102mm
Hole Orientation	Not required.	Not undertaken
Wireline Logging	To EOH	To 1793m (beginning of last core run)
Casing	5½" carbon steel to end of hole (EOH)	5½" carbon steel to 1463m; 5½" high chrome steel, 1463-1789m; cemented to surface
Completion	Plugged at base of casing and head-works	Plugged at base of casing and head-works

*Figure 1: Harvey 4 Well Design and Timeline (Planned vs Actual)**



**Note: Actual time taken in days does not take account of single shifts worked and off-site crew breaks*

3. Personnel and Equipment

Details of on-site equipment and personnel utilised in drilling Harvey-4 are shown in Table 2.

Table 2: Harvey-4 Site Equipment and Rig Personnel

Item	Detail
Rig	DCA Rig (ADS 1500 with 200,000lb pullback)
Mud System	(25,000L above-ground mud tank incorporating shakers, de-sanders, de-silters and mixers)
Mud Auxiliary	8,000L mud storage and mixing tank
Site Power Supply	300 KVA generator
Water Source	Mains supply
Water Storage	2 x 10,000L tanks
Well Control	11.0"annular diverter, closing unit and 30m flare line
Pumps	2 x Skytop Brewster (230-545 GPM max 2500 PSI)
Site Infrastructure	DCA rig office caravan Geology office Site mess and storage unit and site ablutions unit (pump-out) Security fencing and signage
Infrastructure power supply	300 KVA generator
Rig Lighting	Intrinsically safe rig lighting
Transport / Lifting	2 x 7 ton BHB mobile cranes 2x 45' trailers & prime-mover 1 x 30,000L vacuum tanker 1 x LV for crew transport
Site shifts	2 x 12-hour shifts (6.00 – 6.00) per day
Personnel	2 x Senior Drillers/Supervisors (1 per shift) 6 x Drilling Offsiders (3 per shift) 1 x Rockwater Geologist (per shift) Safety Officer (regular on-site visits) 1 x Australian Mud Company Mud Engineer (on-site support as required) Mechanic (on-site support as required)

4. Daily Drilling Reports

Copies of the Harvey-4 Daily Drilling Reports are provided digitally in Appendix 1. Information from the reports and the site geologist daily log has been utilised in preparation of the drilling summaries provided below.

5. Summary of Pre-Spud and Rig-Up Procedures (December 2-5 & 11-12, 2014)

The DCA rig and crew arrived on the Harvey-4 site between December 2 and 4, 2014 and underwent site inductions and a review of safe-work procedures on December 5. The final Harvey-4 site access preparations were delayed by wet weather and rigging-up did not commence until December 11.

6. Summary of Drilling Operations (December 13, 2014–April 27, 2015)

Surface Casing (TCI Tricone 17½'' hole, 0 to 60m):

The Harvey-4 conductor drilling commenced on December 13, 2014. It was drilled during a single shift with a 17½'' Tungsten Carbide Insert (TCI) tricone bit using a bentonite base mud and reached the planned conductor depth of 60m on December 15. The drill-pipe was pulled and 58m of 13⅜" buttress casing was subsequently installed with a float shoe and centralizers. The casing was then cemented with 4,700L of 1.6 SG cement and cement returns were sighted at surface. After completing a small annulus top-up the DCA staff left site for the Christmas break on December 17.

Intermediate Casing (Mud rotary, 12¼" hole, 60 to 266.5m):

Drilling recommenced single shift on January 15, 2015 and moved to double shift on January 20. The 12¼" section was drilled with a TCI tricone bit through clay, sand and silicified formations to 266.5m on January 22. The mud weight during this interval was relatively constant at approximately 8.5ppg. Retracting the gear from the hole on January 23 required significant over-pull and the bottom-hole assembly (BHA) had to be reamed back from bottom into the surface casing. The drill pipe and BHA were laid out on surface in preparation for running the casing.

Subsequently 259.5m of 9⅝'' BTC casing was run with a float shoe and centralizers to 259.5m and cemented with 9,000L of 1.6sg cement with full returns sighted at surface. While waiting for the cement to set, the cellar and well control blow-out prevention (BOP) equipment was installed and function tested. An 8½" BHA was prepared and mud was mixed for the next phase of drilling.

8½" Rotary (266.5 to 893m):

Drilling-out of the cement plug commenced on January 29 and a successful Leak-Off Test (LOT) was conducted at 267m to 214psi. Drilling continued slowly using three separate PDC bits until 655m. The formation was difficult to penetrate and was reported by the drillers as sand, sandstone, siltstone and mudstone with some intensely silicified sections. At 661m, in order to achieve an increased rate of progress (ROP), a TCI tricone bit was run. However this proved unsuccessful: down-hole torque increased and penetration actually decreased. After 9 hours on bottom for only 1m of progress, the TCI tricone was changed to a milltooth bit and the stabilizer was removed. It is possible that the near-bit stabilizer that was removed may have had insufficient clearance in the hole resulting in high torque and slow penetration.

Progress generally improved for the interval drilled with the latter bit from 662 to 810m. The worn milltooth was replaced with a PDC bit at 810m. However, after drilling only 5m in 8 hours, the bit face became blocked with cuttings. It was exchanged for another milltooth bit at 815m and drilling progressed steadily to the first coring interval which was reached on February 17 at 893m.

Eight separate drill bits were run over the entire 627m interval for an average bit life of 78m (refer Table 3) and the overall penetration rate was slow. Despite the formation being assessed as hard and silicified, the use of PDC and TCI tricone drill bits specifically designed for such conditions proved less effective than using standard milltooth bits. The milltooth bits progressed faster and lasted longer than the other bits.

At bit changes, the new bits often required reaming to the bottom of the hole as the formation was squeezing and reducing the drilled hole diameter. The mud weight throughout this section was progressively increased by the addition of KCl to approximately 9ppg with an approximate viscosity of 45 second-mud.

Planned SQ3 Coring Run 1 (893 to 908m):

Commencing on February 18, two core runs were conducted with DDH1's 9.9m SQ core barrel. In total 15m of SQ3 (102mm diameter) core was recovered from 893 to 908m. During the first core run a sliding stabilizer was used to centralize the 6'' core barrel within the 8½" rotary hole. Coring operations were finished and the core barrel was removed on day-shift, February 20. However, prior to commencing reaming of the cored interval, a slips retaining pin fell into the hole.

Bottom-Hole Clearing / 8½" Rotary (908 to 921m):

On the night shift of February 20, reaming was completed, but after 4m of drilling ahead from 908m, the TCI bit rollers became jammed with metal and it was pulled and replaced by a PDC bit which ground away for a further 9m on the remaining junk in the hole.

8½" Rotary (921 to 1303m):

Once the metal had been cleared, the worn PDC bit was replaced with a mill-tooth bit which went on to drill from 921 to 1121m - one of the best performing bits throughout Harvey-4. The mill-tooth was replaced on February 23 by a reasonably well-performing TCI bit which drilled ahead to reach 1303m by March 10, but was found to have damaged rollers and badly chipped tungsten inserts on recovery.

Although progress was reasonable over this interval, it was apparent that hole conditions were still deteriorating and that the formation was continuing to squeeze into the hole. This had become particularly evident at 1222m when, to allow for rig maintenance, the drill-pipe had been pulled back 45m off bottom and remained stationary in the hole for 2 hours. On recommencement of drilling, significant over-pull had been required to free the stationary drill pipe. These difficulties were attributed to differential sticking due to the rotary gear being stationary. Concern about the down-hole formation swelling led to a decision to again progressively increase the mud weight by the addition of KCl. A mud weight of approximately 10.2ppg was achieved by 1250m and the weight was maintained in the 10.2-10.4ppg range until the end of the interval.

On March 13 due to a lack of replacement staff, the DCA crew left site for a seven-day break.

Bottom-Hole Clearing (1303m):

Upon return on March 20, it was decided to run a 7⅞" oilfield coring fishing basket (sourced from Tasman Oil Tools) to clear any junk from hole potentially remaining from the previously damaged roller bit. Running the basket was slow as the hole had squeezed over almost the entire uncased section. The coring junk basket was drilled for its entire 0.70 m length and after recovery was sent off-site for the supplier to extract consolidated core and replace the coring basket's damaged tungsten shoe bit which had been drilling on loose metal.

Wireline Logging (0 to 1303m):

Ongoing concerns about down-hole deterioration led to the DMP's decision to wireline log the hole. Halliburton arrived on site during the day-shift of March 23 and completed electrical logging to 1303m by the end of the night-shift.

Consideration was also given at this time to the possible need to run an additional string of 7''casing with a view to protecting the exposed down-hole formation and ensuring completion to the total revised TD of 1800m. However, after the successful wireline logging run, the costly casing decision was deferred in favour of trialling the effectiveness of increased mud weight in stabilising down-hole conditions.

8½''Rotary (1303 to 1323m):

On March 24, 2015, rotary drilling recommenced with a new TCI Tricone bit and barite was gradually added to the drilling fluid to lift the mud weight to 11ppg. The mud viscosity was also increased to 54 seconds to keep the heavier mix in suspension. Progress was very slow and the bit was pulled at 1305m to again observe severely worn rollers with broken tungsten inserts. A magnetic fishing tool was run to recover the loose metal in the bottom of the well. Despite down-hole washing and movement on bottom to disturb any debris, the magnet was pulled without having recovered any significant metal.

A new hard-formation TCI Tricone bit was then used to drill-on very slowly but was pulled after 30 hours on bottom at 1323m and was found to be in poor condition due to running on broken tungsten inserts from previous bits.

Bottom-Hole Clearing with 8'' Mineral Core Barrel (1323 to 1326m):

On March 31, an 8'' OD / 6'' ID, 1.5m-long mineral core barrel was run to more effectively clear the hole of junk. Utilising an impregnated diamond coring bit, the mineral barrel was drilled through the residual junk and 1.5m of core was recovered. To ensure that the hole was completely cleared, the barrel was run a second time and recovered more tungsten inserts and additional core that was kept as part of the geological sampling program.

8½'' Rotary (1326 to 1665m):

On April 4, after almost continuous reaming to return the BHA to bottom, drilling recommenced with a four-wing double-row PCD hard-formation bit and progressed to 1665m, at an average of 40 metres per shift. Throughout this interval barite and loss circulation material (LCM) were added to the KCl Pac mix to achieve an 11-11.3ppg mix and viscosity was increased to 60-63 second mud in order to reduce losses and to ensure that the barite stayed in suspension. Notable mud loss occurred around 1660.6m but the zone was successfully sealed-off[1] as drilling progressed towards the next coring interval at 1665m.

Planned SQ3 Coring Run 2 (1665 to 1666.7m):

On April 11 at a depth of 1665m, a planned core run within the Wonnerup Member was conducted by DCA using DDH1's SQ assembly. During the core run the drilling crew interpreted surface indications to mean that the 9.9m SQ3 core barrel was full of fall-back. However, after pulling the barrel it was found to contain only 1.65m of core. The core run was not repeated due to DMP concerns about instability and the ability to complete the well, and mounting costs.

8.1/2'' Rotary (1666.7 to 1793m):

After frequent reaming while returning the BHA to bottom, drilling of the Wonnerup Member recommenced on April 12 with the same 4-wing PCD bit used over the 1326- to 1665m interval. The drilled fluid mix was continued to be maintained at approximately 11-11.3ppg weight and 60-second viscosity until the final planned coring point at 1793m was reached on April 15. Prior to pulling the BHA out of the hole a 200m off-bottom wiper trip was conducted in preparation for wireline logging.

Wireline Logging and VSP Testing (0 to 1793m):

Because of the poor down-hole conditions it was decided to complete the final pass of wireline logging prior to the final Harvey-4 core run and thereby avoid prolonged open-hole exposure during coring operations. Halliburton commenced logging towards the end on day shift on April 16 and successfully completed logging and vertical seismic profiling (VSP) of Harvey-4 to 1793m on April 18.

Planned SQ3 Coring Run 3 (1792.7 to 1802.6m):

To ensure that the hole was fully clear of fall-back, another wiper trip was completed on April 19 prior to commencing final coring. The SQ3 core barrel was run under DDH1 supervision and the 9.9m core barrel was filled to capacity. This represents the world's deepest application of the SQ3 Geobar core barrel to date. Drilling was completed on April 22 when Harvey-4 reached its planned total depth of 1802.6m.

Completion Casing (Surface to 1789m):

The drill floor was cleared of drill pipe in preparation for running the 5½" completion casing. The BOP was removed and a well-head incorporating a 5½" casing hanger and a 3000psi valve was attached to the top of the 9⅝" intermediate casing string.

The completion casing string included 326m of high chrome steel casing at the base with 1463m of overlying VAM oilfield carbon steel casing. Commencing on April 22 night shift, the string was run complete with centralisers and a 6⅛" OD cement float shoe and the shoe was set 3.7m above the final SQ cored interval to allow for cement circulation and to ensure that the casing did not jam in the 6'' core hole. The casing was successfully cemented with 55,000L of 1.6sg cement. Cement returns were sighted at the surface by the

[1] Similarly the cored holes (Harvey 2 and Harvey 3) experienced fluctuating losses and these also tended to seal with LCM and drill cuttings. With building mud weight it is considered that the higher weight may have shattered the formation at top of Wonnerup Member. Viscosity was progressively increased as was the use of LCM. Mud losses could also have been associated with fractured horizons within the formation.

supervising geologist and the casing was left suspended and undisturbed throughout the setting process. Rigging-down commenced while the casing cement set and Harvey-4 was completed on April 27, 2015.

7. Demobilisation

DCA demobilised from the Harvey-4 site to Perth over approximately 6 days intermittently spread between April 28 and May 14, 2015. The site was left in a clean and tidy condition.

8. Mud Program

As mentioned previously, AMC was contracted to provide product and mud engineering services for the entire Harvey drilling program including:

- Pre-drill test work on historic samples from drill hole Harvey-1 with a view to designing and costing the most appropriate drilling fluids for the current program.
- Ongoing monitoring and technical support during drilling activities at Harvey-2, -3 and -4.
- A review of the effectiveness of the various mud programs with the aim of informing future drilling in the Harvey sequestration project.

AMC's Harvey-4 Drilling Fluid Summary Report is included herein as Appendix 2 and summary comments drawn from it and from DCA's logs are listed below:

- At Harvey-4, the extended drilling timetable added considerably to drilling fluid costs. The additional time was due to some work that was conducted on single- rather than double-shift, an extended Christmas break, shortage of personal requiring rig shutdown to allow for crew R&R and difficulty in achieving reasonable rates of progress through harder-than-anticipated silicified formations.
- Fluid shear stress and polymer break down is proportional to total circulation time and the extended drilling timetable required additional product to ensure fluid properties were maintained to specification.
- The initial program recommended a KCl PAC R based mud which proved suitable, however greater-than planned KCl concentrations were required to maintain adequate mud weight and inhibition.
- Formation squeezing was apparent in Harvey-4 from an early stage and caused high torque while drilling, over-pull when pulling drill-pipe and excessive reaming when changing bits. Increased concentrations of KCl PAC R combined with the introduction of barite earlier in the hole may have reduced formation squeezing into the open drilled hole. A further increase in mud weight may have also provided increased formation stability.

- The length of time over which the susceptible formations in Harvey-4 were exposed to drilling fluids was clearly an issue in deteriorating down-hole conditions. Whilst ultimately the increased mud weights and viscosities were successful in allowing completion to planned TD, the exposure issues, particularly in the more fragile top-hole section, could have been minimised if the intermediate casing had been run to significantly greater depth (say 500 – 700m). This may have allowed for better matching of the circulating fluid hydrostatic head to the formation at depth, rather than attempting to balance these components over the entire exposed well length.

- Relative to Harvey-2 and -3, circulation losses in Harvey-4 were minimal. This may be due to the greater annulus and lower annular dynamic pressures inherent in rotary drilling. The decision to increase viscosity to 60 seconds and the amount of LCM added to seal any fractures caused by the hydrostatic head of 11ppg drilling fluid may have also reduced losses below 1300m.

9. Bit Record

A summary of bit usage throughout the hole is provided in Table 3 and aspects of bit performance have already been addressed in Section 6. In attempting to determine the optimal bits for drilling progress and bit life, change-outs were relatively frequent. A total of 17 rotary bits and 3 coring bits were used.

Despite the trialling of various bit designs, the overall penetration rate was still very slow and at times progress was less than 1m per hour when drilling silicified bands. The ground was assessed as hard and silicified from a relatively early stage but the use of tungsten carbide insert bits specifically designed for these types of conditions seemed to provide no real advantage compared with mill-tooth bits. However, on occasion, junk in the hole may have made objective comparative assessment difficult.

Optimum performance was achieved from a four-blade hard-formation PDC bit which completed a total of 465m in the Wonnerup Member at the fastest progress rates achieved (up to 40m per shift) throughout Harvey-4.

Most rotary bits were totally worn out at the end of their runs and metal left in the hole from the latter bits exacerbated subsequent bit wear. Scheduled in-hole bit life should be shortened in any future drilling campaign.

Table 3: Harvey-4 Summary Bit Record

Date	From (m)	To (m)	Interval* (m)	Size	Type	Style	Formation (Downhole Interval)
13/12/2014	0.0	61	61	17.1/2''	Tricone	TCi	Leederville Fm (0-165m)
15/1/2015	61	266.5	205.5	12.1/4"	Tricone	TCi	
28/01/2015	266.5	336	70	8.1/2"	PCD		Eneabba Fm (165-1020m)
31/01/2015	336	474	138	8.1/2''	PCD	HF	
3/02/2015	474	655	181	8.1/2''	Tricone	TCi	
7/02/2015	655	661	6	8.1/2''	PCD		
9/02/2015	661	662	1	8.1/2''	Tricone	HF	
12/02/2015	662	810	148	8.1/2''	Tricone	Milltooth	
14/02/2015	810	815	5	8.1/2''	PCD		
15/02/2015	815	893	78	8.1/2''	Tricone	Milltooth	
17/02/2015	893	908	15	SQ3 core	Diamond	Impreg	
20/02/2015	908	912	4	8.1/2''	Tricone	TCi	
21/02/2015	912	921	9	8.1/2''	PCD		
23/02/2015	921	1121	200	8.1/2''	Tricone	Milltooth	
1/03/2015	1121	1303	182	8.1/2''	Tricone	TCi	Yalgorup Mbr (1020-1579m)
20/03/2015	1303	1303.7	.7	7.7/8''	Junk	Basket	
24/03/2015	1303.7	1308	4.3	8.1/2''	Tricone	TCi	
28/03/2015	1308	1323	15	8.1/2''	Tricone	TCi	
31/03/2015	1323	1326	3	8'' core	Diamond	Impreg	
4/04/2015	1326	1665	339	8.1/2''	PCD	4 wing HF	
11/04/2015	1665	1666.7	1.7	SQ3 core	Diamond	Impreg	Wonnerup Mbr 1579-1802.6
12/04/2015	1666.7	1792.7	126	8.1/2''	PCD	4 Wing HF	
20/04/2015	1792.7	1802.6	9.9	SQ3 core	Diamond	Impreg	

** Bit Interval colour code :* **0-5m** **5-10m** **10-25m** **25-50m** **>50m**

10. Community Engagement

Working collaboratively with DMP and KD1 staff throughout the Harvey drilling program, both DDH1 and DCA sought to:-

- establish and maintain good relations with local land-owners,
- locally source accommodation and messing (rather than bringing the company's camp onto site),
- purchase of non-drilling consumables from local suppliers,
- engage local tradespeople and services when necessary (e.g. electrical, mechanical, engineering, cementing, some transport, etc.),
- facilitate safe rig site access for client-hosted Open Days and Site Visits,
- minimise traffic, dust, noise, stock disturbance, etc., both at the rig site and on local roads,
- address any concerns promptly and respectfully,
- maintain a clean, tidy, secure and safe work site,
- minimise environmental disturbance at all times.

During the Harvey-4 drilling program, many visitors came to site including local community representatives and various academics, as well as CSIRO and DMP staff. Visitors were hosted by the DMP with safety input from DDH1 and DCA and they engaged positively with the on-site drilling and geological staff.

Whilst the locations of all the Harvey drill holes became well known to the local community, there were no instances of unauthorised access to the drill sites and no obvious opposition to the drilling activity. In general, the Harvey town-site and rural community were very welcoming and co-operative towards the drilling crews.

11. Discussion of Outcomes

Harvey-4 was successful in achieving the desired total depth, complete wireline logs, planned casing program, water sampling and, with one exception, the planned coring intervals. However, its overall rate of progress was significantly slower than anticipated (Figure 1). Analysis of the Harvey-4 drilling program suggests that the extended time-frame may be related to several factors including:

- Harder-than-expected formations based on observation of cored intervals from Harvey-1. It is not known whether these differences are related to inherent variability in the sedimentary pile or are perhaps due to differential silicification.
- The presence of fragile and down-hole formations squeezing into the hole necessitated increased time-consuming reaming, both when pulling pipe and when returning gear to bottom.
- Frequent bit changes in the attempt to determine the optimal bits for drilling progress and bit life.
- The over-running of several bits which led to significant time lost in retrieving down-hole junk.
- Accidentally-dropped gear in hole.
- Slower-than-anticipated core recovery due to the rig's pipe handling speed and less-than-ideal hole conditions.
- Several staffing level issues which resulted in numerous single shifts and in a rig shut-down due to break requirements.

In the first and third cored intervals in Harvey-4, core recoveries were excellent and the retrieved core was of high quality. The significantly-reduced recovery in the second coring interval was due in part to a lack of supervision. The final coring run at 1800m represents the world's deepest use of the Atlas Copco SQ3 Geobor coring system to date.

It is possible that some of the Harvey-4 drilling issues may have been avoided by:

- Engagement of a full time Mud Engineer to constantly monitor and oversee the drilling fluids program.
- Earlier intervention to increase the mud weight and improve hole stability.
- Allowances for a greater depth of intermediate casing (say to 500-700m) which would have been the most effective way to reduce formation exposure in the fragile upper portion of the hole (within the Leederville Formation).
- Early consultation with a drill-bit specialist when the short bit life and penetration rate issues became apparent.
- A more-conservative approach to maximum in-hole bit life.

- Increased drilling supervision and contractor staffing levels to avoid accidents and down-time.

As Harvey-4 was essentially a fixed-price metre-rate contract, additional costs incurred by the extended drilling period were limited to accommodation and supervision. The final Harvey-4 costs are considered reasonable relative to those likely incurred by a dedicated petroleum rig with its attendant third party support and energy-based supplier charges.

The Harvey-4 drilling fluid costs also exceeded initial budget – largely because the true formation characteristics were not adequately recognised at the planning stage. Assuming similar down-hole conditions to Harvey-4 in future Harvey drill holes, the new well mud proposals could reasonably include higher concentrations of KCl, barite and increased LCM usage.

12. References

Millar A S and Reeve J, 2014. GSWA Harvey 1 Well completion and preliminary interpretation report, southern Perth Basin, GSWA Record 2014/12.

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Nims P and Pollock M, T, December 2015. Harvey-3 Well Drilling Report, South West Hub Carbon Capture and Storage Project. Report to Department of Mines and Petroleum Western Australia, unpublished.

APPENDICES

APPENDIX 1: Harvey-4 DCA Daily Drilling Reports (provided as digital copy only)

APPENDICES

APPENDIX 2: Australian Mud Company Harvey-4 Drilling Fluid Summary Report

Harvey-4
Drilling Fluid Summary Report

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TABLE OF CONTENTS

LIST OF TABLES

ATTACHMENTS

1. Introduction

In September, 2014, the Australian Mud Company (AMC) was engaged by DDH1 Drilling to provide technical support and ongoing mud supplies for deep drill holes Harvey-2, -3 and -4 in the South West Hub Carbon Capture and Storage (CCS) Project.

AMC's brief was to provide:-

- Pre-drill test work on historic samples from drill hole Harvey-1 with a view to designing and costing the most appropriate mud program(s) for Harvey-2, -3 and -4,
- Ongoing monitoring and technical support for holes Harvey-2 and -3 (to be cored by DDH1 Drilling) and Harvey-4 (to be rotary drilled by Drilling Contractors Australia with limited coring intervals),
- Mud product supply,
- A review of the effectiveness of the various mud programs with the aim of informing future drilling in the Harvey sequestration project.

This report describes AMC's input into the Harvey-4 drilling program.

2. General Design Principles for the Drilling Fluids Program

In designing the Harvey Project mud programs, AMC considered the following issues:

- Geotechnical characteristics of likely down-hole formations including formation integrity,
- Choice of the most effective fluid(s) to stabilise down-hole conditions with appropriate parameters to address encapsulation, inhibition and filtration control,
- Analysis of on-site "make-up" water,
- Ease of use of the selected fluid(s),
- The need to minimise costs (without adversely impacting fluid effectiveness),
- The need to minimise any potential environmental impacts of the fluids used,
- Ease of disposal of mud products at the completion of the program.

3. Harvey-1, Data Review and Geotechnical Testwork

A review of the well drilling report for Harvey -1, drilled in 2012, showed that the well was initially drilled with a basic Gel / PHPA system. It was evident from the recap that the integrity of the hole had been compromised due to the fact no inhibitive fluid was used.

To further address these issues, samples from some of the more challenging sections in Harvey-1 were collected from the GSWA Perth Core Library and forwarded to AMC' Perth Laboratory for further analysis. The sampling program encountered some difficulties in finding cutting samples that could be could be considered truly representative of the broader formation intervals and were also sufficiently stable and of sufficient volume to conduct meaningful laboratory tests.

Immersion and integrity tests of the samples were conducted in two stages in September and November, 2014. Sample intervals and test fluid combinations for the programs are shown in Table 1 and Attachments A and B provide photographic records of the test work observations over zero, 3-hour and 72-hour intervals.

Table 1: Sample intervals and fluid combinations selected for Phase 1 and Phase 2 test work on historic Harvey-1 cuttings and core

	AMC Test 1 (cuttings only) (September, 2014)	AMC Test 2 (sectioned core samples) (November, 2014)
Sample Interval	H1 1269 to 1270m H1 1270 to 1272m H1 1276 to 1278m H1 1333 to 1334m Box 4, 5, 13, 14, 15, 16, 17.	495 to 510m 675 to 690m 1210 to 1215m 1225 to 1230m 1270.7m 1277m 1333.3m 1340 to 1345m
Test Fluid Combinations	Solution 1: 1.5kg COREWELL + 3kg PAC L + 1% SHALEHIB ULTRA Solution 2: 2.5kg PAC R + 3kg PAC L + 3kg CLAY DOCTOR + 1% SHALEHIB ULTRA	Blank: (Water) Mud 1: 20kg Aus-Gel +3kg PAC R +4kg PAC L + 4%KCl Mud 2: 20kg Aus-Gel +3kg PAC R +4kg PAC L + 8%KCl Mud 3: 2.5kg PAC R +3kg PAC L + 8kg Clay doctor + 3%KCl Mud 4: 2.5kg PAC R +3kg PAC L + 8kg Clay doctor + 1% SHALEHIB Mud 5: 1.5kg COREWELL + 1% SHALEHIB + 3kg PAC L

Results from both phases of test work (refer Attachments A and B) showed that the clays encountered in Harvey-1 were more dispersive than swelling in nature. The best containment results came from AMC's CORE-WELL based system, which is a premium encapsulating agent.

4. "Make-Up" Water Analysis

In addition to formation integrity testing, the "make-up" water to be used in the mud program from the on-site, mains water was analysed with results as follows:

- pH 7 - 8,
- Total Hardness: 50 mg/l,
- Chlorides: 250 mg/l.

5. Drilling Fluid Proposal

AMC's original drilling fluid proposal for Harvey-4 envisaged a two-component program as follows:

- For the pre-collar section - a conventional gel/polymer mix was recommended to give the best hole cleaning characteristics and to allow good filtrate control as well as hole stabilisation

- For the 8½" section – a conventional polymer/KCl mix was recommended. This system would provide additional formation protection with the use of KCl, where the main focus of the system was on formation stability and filtration control rather than core recovery and integrity. A contingency was also allowed in the mud program for adding a weighting agent (Barite) to the system to obtain a mud weight similar to that of Harvey-1 if needed.

However, due to various formational and hole-stability issues encountered early in the drilling of Harvey-4, the mud weight of the fluid had to be increased to counteract pressured formations. The issues in Harvey-4 were similar to those that were being encountered simultaneously in Harvey-2 (Russell and Pollock, 2015). In both holes, KCl was used as the principle weighting agent but Barite also had to be used as mud weights of 11.3ppg were eventually required to control the hole in Harvey-4.

6. Mud Program Operations

6.1 Pre-Collar Section (0-266.5m)

Depth / Hole Size/ Date	:	0-61m / 17½" (13/12/14 - 18/12/14) and 61-266.5m / 12¼" (12/01/15 - 26/01/15)	
Mud Type	:	Gel/Polymer (as per AMC proposal)	
Fluid system used	:	Soda Ash	0.5 kg/m³
		AUS GEL XTRA	15 – 20 kg/m³
		AMC PAC L	2.0 – 3.0 kg/m³
		AMC PAC R	1.5 – 2.0 kg/m³
		SODIUM BICARBONATE	2.0 kg/m³ pre-treatment

The 17½" and 12¼" sections were completed successfully with no anomalies recorded. Both cemented sections were drilled out with as per the proposed fluid system that was pre-treated with sodium bicarbonate.

6.2 Production Section (266.5-1792.7m)

Depth / Hole Size/ Date	:	266.5-1792.7m/8½" (28/01/15- 22/04/15)	
Cored Section (SQ)	:	893 to 899.3m	
	:	898.4 to 908.35m	
	:	1324 to 1326.6m	
	:	1665.1 to 1666.9m	
	:	1792.7 to 1802.6m (EOH)	
Mud Type	:	PAC/KCl (as per AMC proposal)	
Fluid system	:	Soda Ash	0.5 kg/m³
		AMC PAC L	3.0 – 4.0 kg/m³ (Filtration control)
		AMC PAC R	2.0 – 2.5 Kg/m³ (Viscosifier/Filtration control)
		Potassium Chloride	30 – 40 kg/m³ (Inhibition)

This mud system remained the base system for this section, however due to the abrasive nature of the formation, several bit changes were required. Upon removal and reinstallation of the drill pipe, an increase in torque was observed and, to reach bottom, reaming was often required.

As in Harvey-2 (Russell and Pollock, 2015) it appeared that the formation was pressurised and the mud weight was increased accordingly. This was done with a gradually increasing concentration of KCl to a weight of approximately 10.2ppg by 1250m. At 1304m a calliper run was undertaken which indicated numerous wash-out zones between the depths of ~260 to 960 metres. It was decided to increase the mud weight to 11.0ppg by the addition of Barite to assist in controlling any further washouts. Due to the increased mud weights, excessive fluid loss was noted and loss circulation material was added to the system on a daily basis.

Upon pulling out to start the final planned coring run at 1792.7m, an increase in torque pressure was again noted and the pipes had to be drilled out. It was assumed that the formation had again begun to squeeze in, which instigated another increase in mud weight. The fluid was increased to a weight of 11.3ppg with the addition of more Barite. This weight was maintained to the end of the hole without experiencing any further formation issues.

7. Materials Consumption and Cost Analysis of the Harvey-4 Drilling Fluid Program

A review of programmed vs actual materials consumption in Harvey-4 is presented in Table 2 and overall variance in costs for the original (un-weighted) and revised (weighted) programs is shown in Table 3. The overall increase in hole costs can be attributed to:

- The increased length of time on the hole due to the firmness and abrasiveness of the formation. This caused slow penetration rates and repetitive bit changes, as well as increased fluid consumption through losses (approximately 2000 litres/day throughout the hole),
- Higher than expected formation pressure which was likely to have accentuated fluid losses in more permeable zones.
- Increased pressurisation which necessitated the change from the initial un-weighted mud system to a weighted mud system. Mud weights were increased from 8.5ppg to 10.0ppg, to eventually a mud weight of 11.3ppg.
- The initial change from Barite to more expensive Potassium Chloride as a weighting agent.

8. Conclusions and Recommendations

Based on the results of the Harvey-4, the following recommendations are made in relation to drill fluid support for future core drilling programs in the Harvey Carbon Sequestration Project:-

- Use an inhibitive system from the start of the hole (either KCl or an amine-based product),
- If possible include a PHPA in the fluid system to assist with cuttings integrity and to assist with the removal of excess fines,
- Monitor seepage losses and correlate to increases in mud weight to assist in controlling over-pressurization and use loss circulation material accordingly,
- Make allowances for running an additional intermediate casing string.

*Table 2: Harvey-4, Programmed vs Actual Materials Consumption and Costs**

Product	Unit Size	Product Costs	Programmed Quantity	Programmed Costs	Actual Quantity	Actual Costs	Variance
SODA ASH	25kg	$22.95	10	$229.50	11	$252.45	$22.95
AUS GEL XTRA	25kg	$17.50	98	$1,715.00	264	$4,620.00	$2,905.00
PAC R	25kg	$157.50	96	$15,120.00	134	$21,105.00	$5,985.00
PAC L	25kg	$157.50	102	$16,065.00	146	$22,995.00	$6,930.00
SODIUM BICARBONATE	25kg	$24.19	16	$387.04	8	$193.52	-$193.52
POTASSIUM CHLORIDE	25kg	$24.50	546	$13,377.00	3071	$75,239.50	$61,862.50
BARITE	25kg	$16.16	3869	$62,523.04	1295	$20,927.20	-$41,595.84
AUS DET XTRA	25L	$76.39	10	$763.90	0	$0.00	-$763.90
MAGMA FIBRE	40lb	$98.50	5	$492.50	0	$0.00	-$492.50
LIQUISPERCE	25kg	$137.54	10	$1,375.40	4	$550.16	-$825.24
AUSPLUG	8kg	$76.39	5	$381.95	0	$0.00	-$381.95
BIOCIDE	25lt	$151.20	0	$0.00	8	$1,209.60	$1,209.60
CAUTIC SODA	25kg	$50.85	0	$0.00	16	$813.60	$813.60
KWICKSEAL	25lb	$67.33	0	$0.00	43	$2,895.19	$2,895.19
			Totals	**$112,430.33**		**$150,801.22**	**$38,370.89**

NB: Programmed quantity includes weighting agent (Barite) and inhibitor (KCl) from the weighted program)

*Table 3: Harvey-4, Summary of Cost Variance for the Original (Un-Weighted) and Revised (Weighted) Mud Programs**

Cost Base	Original (Unweighted) Mud Program	Revised (Weighted) Mud Program
Programmed	$ 65,234.82	$ 119,292.60
Actual	$ 150,801.22	$ 150,801.22
Variance	$ 85,566.40	$ 31,508.62

** Costs relate to only the products that were used on site during the drilling process.*

9. References

Millar A S and Reeve J, 2014. GSWA Harvey 1 Well completion and preliminary interpretation report, southern Perth Basin, GSWA Record 2014/12.

Russell R and Pollock M, November 2015. Harvey-2 Final Well Report, South West Hub Carbon Capture and Storage Project. Report to Department of Mines and Petroleum Western Australia, unpublished.

Nims P and Pollock M, December 2015. Harvey-3 Final Well Report, South West Hub Carbon Capture and Storage Project. Report to Department of Mines and Petroleum Western Australia, unpublished.

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GSWA Harvey-1 Immersion Testing Program 1, September, 2014

Introduction

11 samples from GSWA Harvey-1 were sent to AMC R&D lab to be evaluated and to provide visual observations on the clays' dispersion properties and advise on the optimal mud system to stabilise these types of formations.

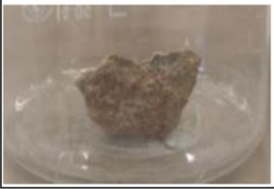
System 1: The first system was to evaluate samples marked H1 1269-1270m, H1 1270-1272m, H1 1276-1278m and H1 1333-1334m using a Core-Well, PACL and Shalehib system.

System 2: The second system was to evaluate samples marked Box 4, 5, 13, 14, 15, 16 and 17 using a Pac-R, Pac-L, Clay-Doctor and Shalehib system.

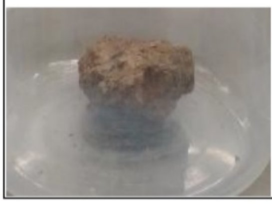
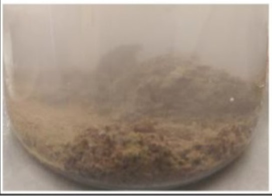
Observations

System 1 (1.5kg,1000L Core-Well, 3kg,1000L Pac-L a 1% Shalehib)

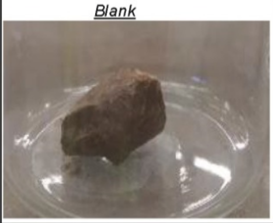
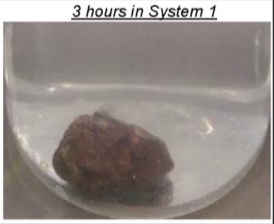
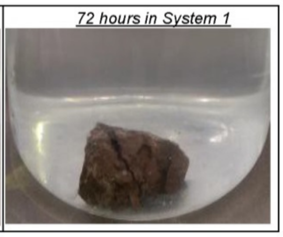
H1 1269-1270 = Firm piece of core, very little dispersion in water

Blank	*Water*	*3 hours in System 1*	*72 hours in System 1*
			

H1 1270-1272 = Brittle, dispersive clay, however System 1 provides the encapsulation required to stabilise this formation

Blank	*Water*	*3 hours in System 1*	*72 hours in System 1*
			

H1 1276-1278 = Brittle, dispersive clay, however System 1 provides the encapsulation required to stabilise this formation

Blank	*Water*	*3 hours in System 1*	*72 hours in System 1*
			

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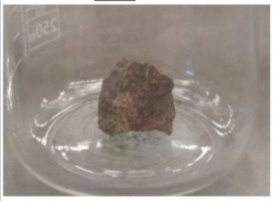
H1 1333-1334 = Brittle, dispersive clay, however System 1 provides the encapsulation required to stabilise this formation

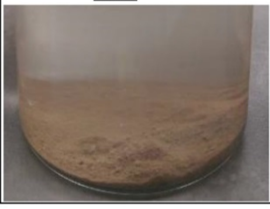
Blank	Water	3 hours in System 1	72 hours in System 1
			

System 2 (2.5kg,1000L PAC-R, 3kg,1000L Pac-L, 3kg,1000L Clay-Doctor and 1% Shalehib)

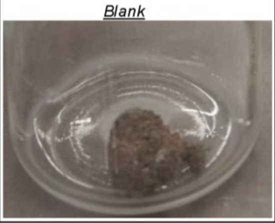
BOX 4 = Brittle, dispersive clay, System 2 provides some encapsulation however nowhere as well as System 1 to stabilise this formation

Blank	Water	3 hours in System 2	72 hours in System 2
			

BOX 5 = Brittle, dispersive clay, System 2 provides some encapsulation however nowhere as well as System 1 to stabilise this formation

Blank	Water	3 hours in System 2	72 hours in System 2
			

BOX 13 = Brittle, dispersive clay, System 2 provides some encapsulation however nowhere as well as System 1 to stabilise this formation

Blank	Water	3 hours in System 2	72 hours in System 2
			

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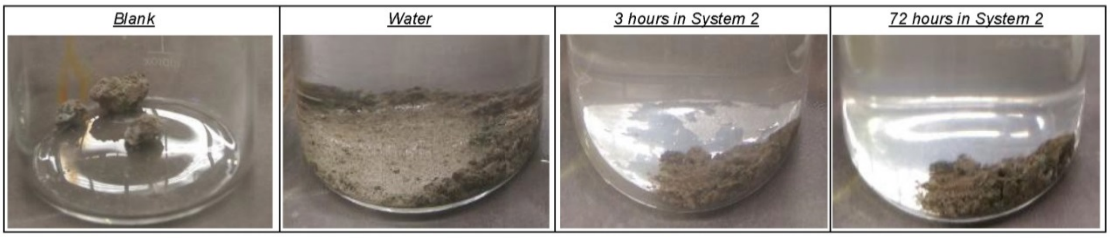
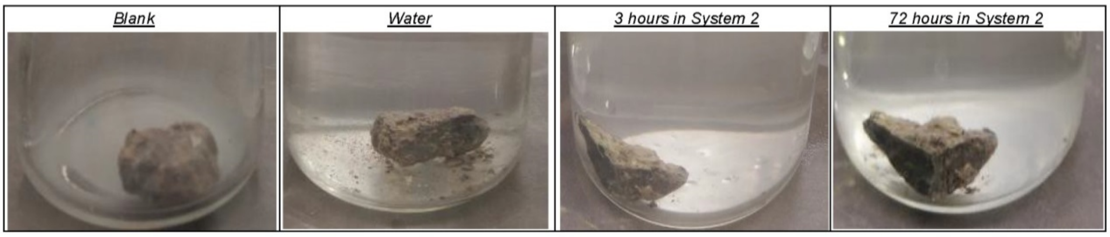
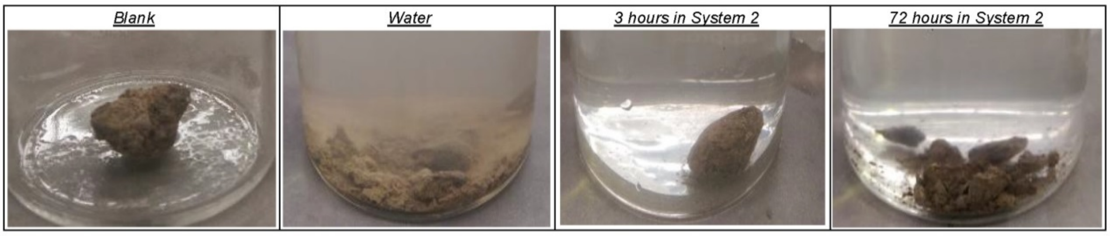
BOX 14 = Brittle, dispersive clay, System 2 provides some encapsulation however nowhere as well as System 1 to stabilise this formation



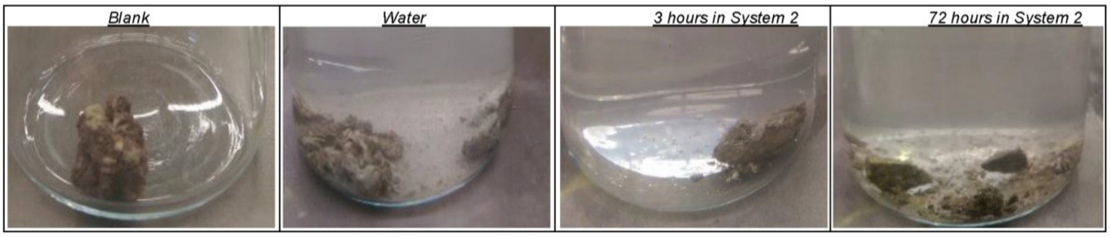
BOX 15 = Firm piece of core, very little dispersion in water



BOX 16 = Brittle, dispersive clay, with System 2 providing initial encapsulation and stabilising the formation, however it breaks down over a longer period of time.



BOX 17 = Brittle, dispersive clay, with System 2 providing initial encapsulation and stabilising the formation, however it breaks down over a longer period of time.

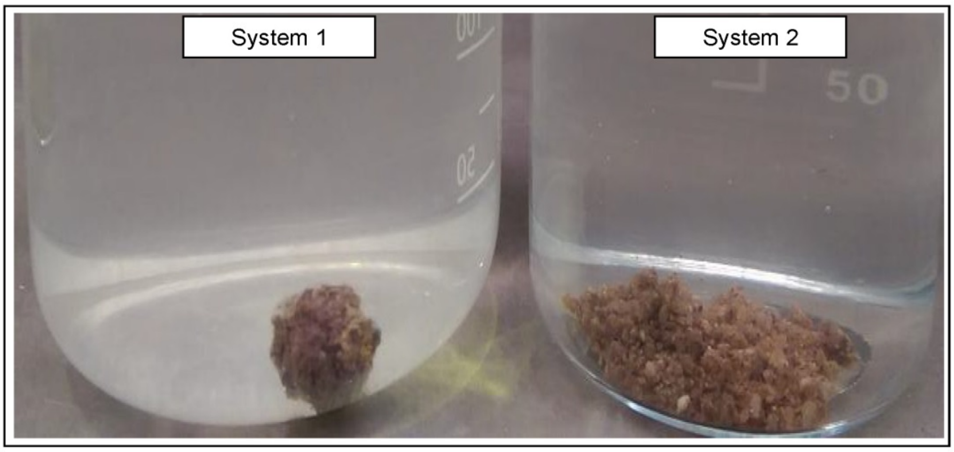


Conclusions

The majority of the samples supplied from Harvey-1 were more dispersive clays rather than swelling clays.

Mud System 1 containing AMC CORE-WELL is more effective in these types of formation as its crossed linked (web like) structure encapsulates the clay better and therefore provides better formation stability. With the added Shalehib for inhibition, it provides the perfect combination to controlling reactive, dispersive clays.

Below is an example comparing the benefits of System 1 vs System 2 on the same sample ("Box 4") over a 72 hour period.



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GSWA Harvey-1 Immersion Testing Program 2, November, 2014

Introduction

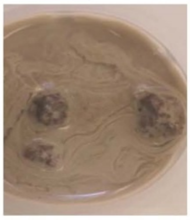
8 samples from GSWA Harvey-1 were sent to AMC R&D lab for a second time to be evaluated and provide a visual observation on the clays dispersion properties and advise on the optimal mud system to stabilise these types of formations.

The Mud Systems tested were as follows:-

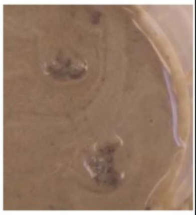
- Blank (Water)
- Mud 1 (20kg Aus-Gel +3kg PAC R +4kg PAC L + 4%KCL)
- Mud 2 (20kg Aus-Gel +3kg PAC R +4kg PAC L + 8%KCL
- Mud 3 (2.5kg PAC R +3kg PAC L + 8kg Clay doctor + 3%KCL)
- Mud 4 (2.5kg PAC R +3kg PAC L + 8kg Clay doctor + 1% Shalehib)
- Mud 5 (1.5kg COREWELL + 1% Shalehib + 3kg PAC L)

Observations

Harvey 1 (495m-510m) G32721)

Blank	*Mud 1*	*Mud 2*	*Mud 3*	*Mud 4*	*Mud 5*
					

Harvey 1 (675m-690m) G32721)

Blank	*Mud 1*	*Mud 2*	*Mud 3*	*Mud 4*	*Mud 5*
					

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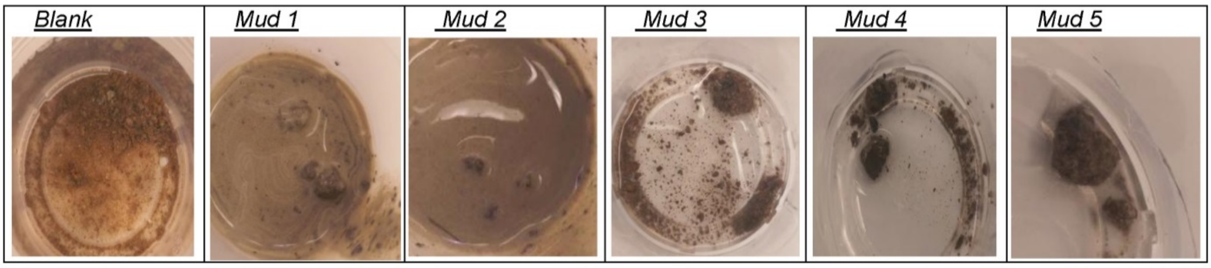
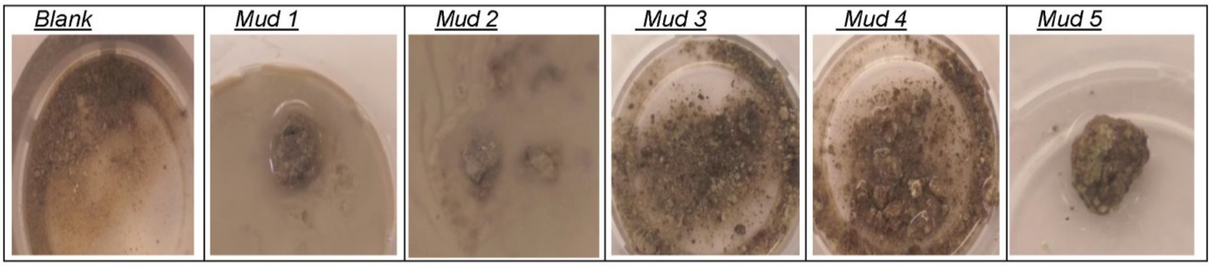
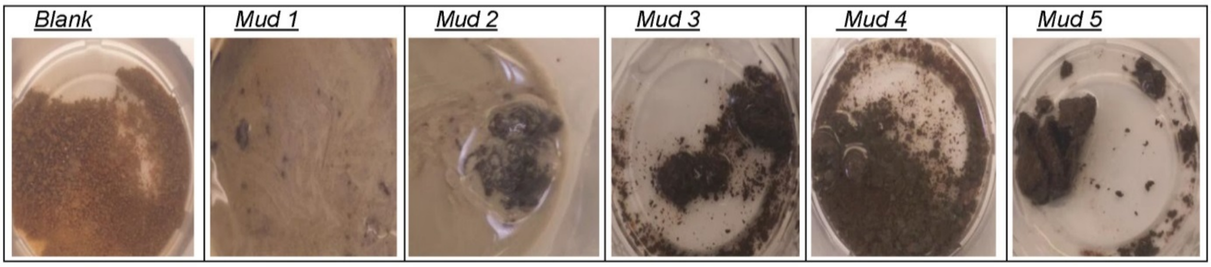
Harvey 1 (1210m-1215m) G32721)



Harvey 1 (1225m-1230m) G32721)



Harvey 1 (1270.7m) G32721)



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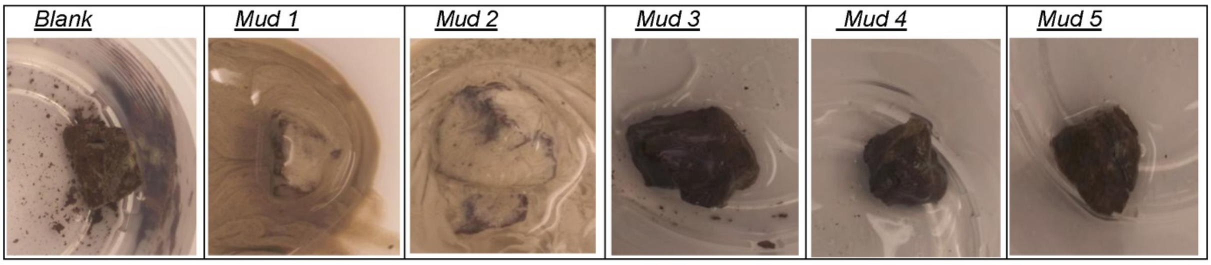
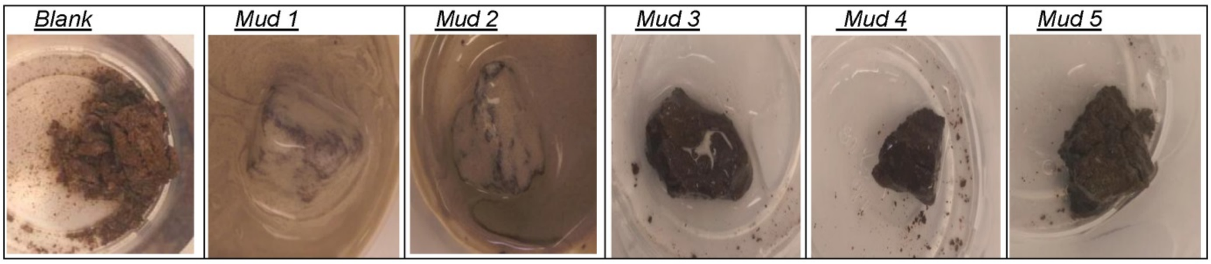
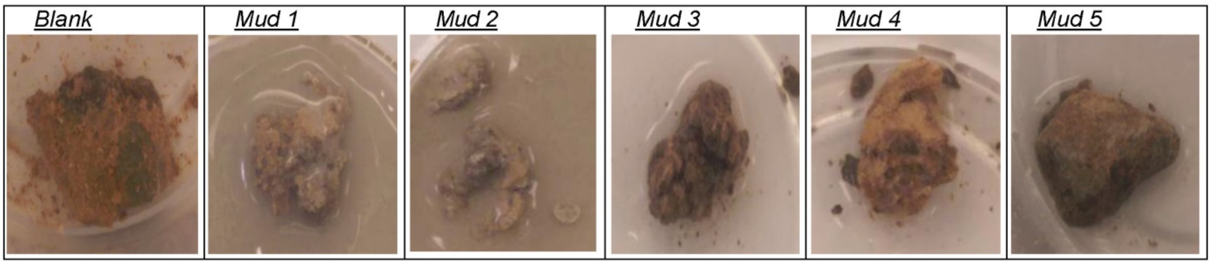
Harvey 1 (1277m) G32721)



Harvey 1 (1333.3m) G32721)



Harvey 1 (1340m- 1345m) G32721)



Conclusions

Overall depending on application/Drill rig MUD 5 would be the optimal system to run on these types if dispersive clays especial the top section. However, if there is concern about blinding off screens using Mud 5, then either MUD 1 or MUD 2 would work well as an alternative system to stabilise the formation.

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