RESERVOIR GROUP

End of Well Coring Report

GEOTHERMAL RESOURCE GROUP

MU-ESW1

BEAVER CO., UTAH

22 SEPTEMBER 2017

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1. Introduction

The purpose of this report is to provide a detailed overview of the coring program that was carried out by Reservoir Group Coring personnel, on the Geothermal Resource Group's MU-ESW1 well in Beaver County, Utah.

2. Objective

The primary objective for RG Coring was to utilise the 7.125" CHD conventional coring system to obtain core samples in the Granite zone. Operational procedures and coring parameters were tailored to maximise coring performance in these formations.

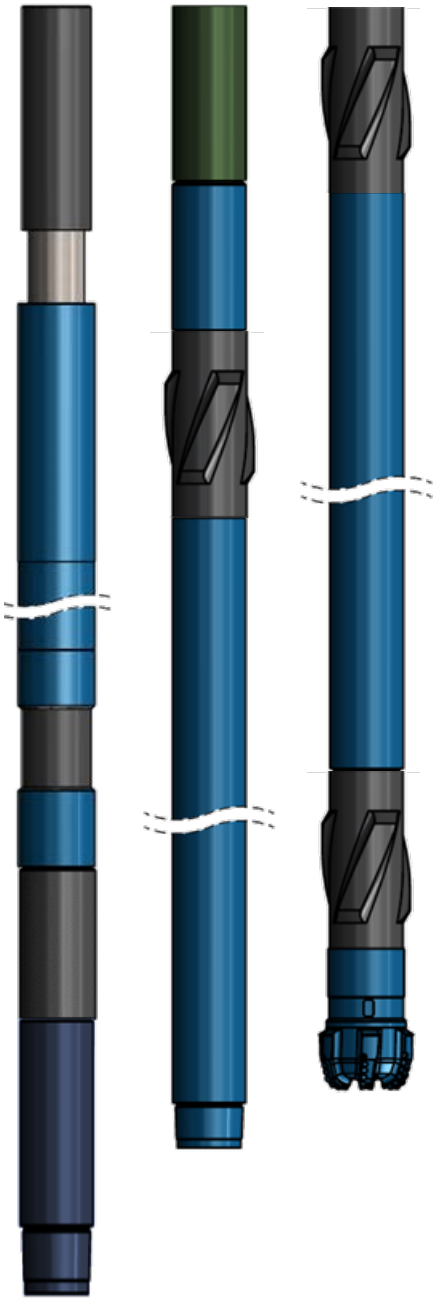
3. Well Overview

Customer:	Geothermal Resource Group
County	Beaver Co., Utah
Coring Technicians:	Dan Windham / Leonel Flores / Clint Porche
TSS Processing Technicians:	Brian Bentley / Rusty Linn
Job Duration:	Sept 3rd – 6th & Sept 10th – 13th, 2017
Drilling Contractor:	Kenai Drilling 10
Well Name:	MU-ESW1
Core Point(s):	6,800ft & 7,440'
Coring System:	7.125" CHD
Core BBL Assembly:	7.125" x 4" x 20'/40'
Inner BBL:	4" Half Moon On-Ice
Amount Cored:	32.0 feet
Overall Core Recovery:	20.2 feet
Core Head Size	8-1/2" x 4"
Core Bit Type:	MCI 905
Core Bit Serial Number:	84069 / 100014

4. Coring BHA

4.1 Core Run 1 – 40' Core Barrel

Coring - Bottom Hole Assembly



Equipment Specifications

Core Barrel	
Barrel Dimensions (OD/ID/Length)	7.125" x 5.625" x 40'
Top Connection	4-1/2 IF
Top Sub ID	3.0"
Stabilizer Fishneck Length	11.5"
Stabilizer OD	8.375"
Make-Up Torque	30,000 ft-lbs
Yield Torque	70,000 ft-lbs
Overpull	860,000 lbs

Inner Barrel	
Inner Barrel/Tube Type	Half Moon On-Ice
Dimensions (OD x ID)	4.40" x 4.125"

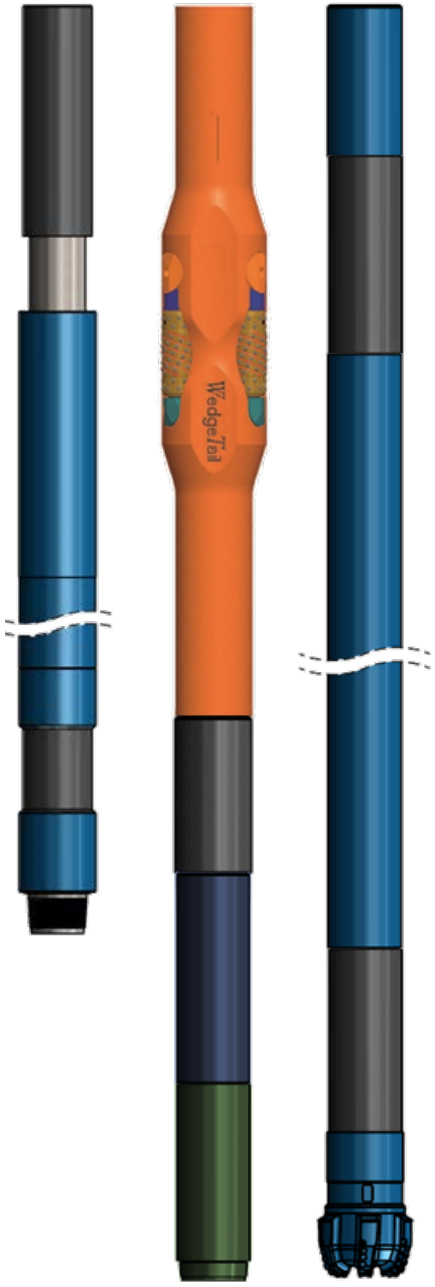
Core Head	
Type	MCI 905
OD x ID	8.5" x 4.0"
Core Size	4.0"
Blade Count	14
TFA (Inner Gauge)	1.7 in²

BHA Tally

ITEM No	DESCRIPTION	Length (ft)
1	Core Head	1.3
2	Stablizer	2.5
3	Outer Barrel	17.5
4	Stablizer	2.5
5	Outer Barrel	17.5
6	Gyro Stabilizer	2.5
7	Outer Barrel Head	2.0
8	Circulating Sub	2.7
9	Float Sub	2.7
10	Crossover (4-1/2 XH x 4-1/2 IF)	1.6
11	Coring Jar	17.4
	BHA Total Length (ft)	**70.2**

4.2 Core Run 2 – 20' Core Barrel

Coring - Bottom Hole Assembly



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Core Size	4.0"
Blade Count	14
TFA	1.7 in²

BHA Tally

ITEM No	DESCRIPTION	Length (ft)
1	Core Head	1.3
2	Slick Sub	2.5
3	Outer Barrel	17.5
4	Gyro Slick Sub	2.5
5	Outer Barrel Head	2
6	Circulating Sub	2.7
7	Float Sub	2.7
8	Crossover (4-1/2 IF x 4-1/2 XH)	1.6
9	Wedgetail Roller Reamer	5.9
10	Coring Jar	17.4
	BHA Total Length (ft)	**56.1**

5. Core Head Details

The MCI 905 core head is designed for use in hard and/or abrasive formations with high to very high compressive strengths, high to very high cementation and abrasiveness. Applications include cemented sandstones, granite, igneous rock, etc. This corehead was selected based on the formation description provided by the client.

6. Bit Dull Grade

Core Bit:	MCI 905 (Serial Number: 84069)						
Inner	Outer	Dull Char	Location	Bearings	Gauge	Other Char	Pulled
0	4	RO	G	X	I	NO	PR

Core Bit:	MCI 905 (Serial Number: 100014)						
Inner	Outer	Dull Char	Location	Bearings	Gauge	Other Char	Pulled
0	0	NO	A	X	I	NO	TD

7. Core Run Overview

The following is a brief summary of the core runs made on the MU-ESW1 well. The core logs are available by clicking on the button in the tables below.

7.1 Core Run 1

Core Run #1							
Bit Type	Serial No.	Depth In	Depth Out	Cored	Recovered	Time (hr)	Formation
MCI 905	84069	6,800.0’	6,812.0’	12.0	10.6	8.2	Granite
Core Head Dull Grade - Rerun							
Inner	**Outer**	**Dull Char**	**Location**	**Bearing**	**Gauge**	**Other Char**	**Pulled**
0	4	RO	G	X	4	NO	PR
Core Log							

Run Analysis

When tripping in with the coring BHA, one foot of fill needed to be washed/circulated out to establish bottom. The initial core run began with 55 RPM and 4Klbs WOB. After bedding the core head the parameters were increased to 80 RPM and 12Klbs WOB which achieved an average ROP of 1.4 ft/hr over the entire run.

At ~6807 ft (~ 7 ft into run 1), a torque spiked causing the rotary to stall out. The string was picked up to decrease the WOB and allow the rotary to stabilize. At this point there was an immediate SPP pressure drop of ~150 psi. It continued to fall another ~50psi before becoming erratic, trending back up into the original range. This pressure fluctuation was possibly caused by fluid seepage through the damaged stabilizer connection (see failure analysis).

The run was terminated when the ROP dropped off to 0.5 ft/hr and then made no advancement of the hole for 30 minutes. When the core barrel was tripped to surface, it was found that the pin connection of the stabilizer in the middle position of the coring assembly had failed. The inner barrel was intact and nothing abnormal was noted. The top two stabilizers did sustain considerable damage (see plate 1 below).

Plate 1 – Heavy Wear to Stabilizer Blades

Core Head Evaluation

The core head on this run saw excessive wear to the gauge. When ring gauged it was under 8” in diameter, down from its new condition of 8.5”. It is probable that there was something in the hole as this is abnormal wear (see plate 2 below).

Plate 2 - Core Head Ring Out

7.2 Core Run 2

Core Run #1							
Bit Type	Serial No.	Depth In	Depth Out	Cored	Recovered	Time (hr)	Formation
MCI 905	100014	7,440.0’	7,460.0’	20.0	12.0	16.3	Granite
Core Head Dull Grade - Rerun							
Inner	**Outer**	**Dull Char**	**Location**	**Bearing**	**Gauge**	**Other Char**	**Pulled**
0	0	NO	A	X	I	NO	BHA
Core Log							

Run Analysis

In response to the issue on the first core run, several adjustments were made for run #2.

1. The core barrel length was reduced to 20'.
2. The full hole stabilizers were replaced with slick subs to reduce torque.
3. An 8-1/2" Wedgetail Roller Reamer was installed above the core barrel to dampen any string harmonics and stick slip from above the BHA, in addition to removing any potential for whirl in the BHA.

Upon tripping in for the second core, there was ~3 ft of fill that was washed through and circulated clear before coring began. After bedding the core head, the WOB was gradually increased to 12-14 Klbs, and then maintained for the remainder of the run. The RPM, pump rate and SPP were are very consistent through the run. At ~7,450' – 7,451' the torque did become erratic in comparison to the first half of the run. At 20' the run was ended (full barrel) and tripped out of the hole. The average ROP over the run was 1.2 ft/hr.

On surface 12 ft of core was recovered, with the Coring Technician noting the bottom 4-5 ft of the core was quite fractured including some sections resembling gravel. He also indicated the core catcher was not in its lowest position. The position of the catcher combined with the description of the core sample indicated that due to the nature of the core, the catcher was not able to function as intended. When the run ended and the coring BHA was hoisted, the core fell through the catcher and lower shoe until a section of core solid enough to engage the catcher was encountered.

Core Head Evaluation

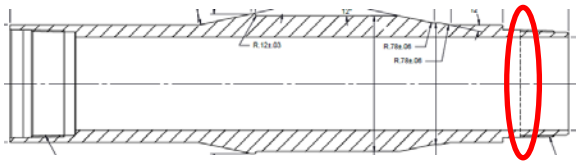
No damage was noted concerning the core head.

8. Core Barrel Failure Analysis

Upon recovering the coring BHA to surface after run 1, it was discovered that the pin connection on the bottom of the mid-barrel stabilizer had failed.

8.1 Observations

The location of the failed connection is shown in the diagrams below.



The pin connection on the downhole end of the stabilizer parted about 1.5” from the seal face, leaving the components below in the hole, as well as most of the pin connection of the failed stabilizer. A photograph of the failed end of the recovered stabilizer is shown below.

The failed stabilizer showed significant signs of impact damage on the uphole end of the blade crests, as well as impact marks in the waterways. Detailed images of some of the impact marks are shown in the photographs below.

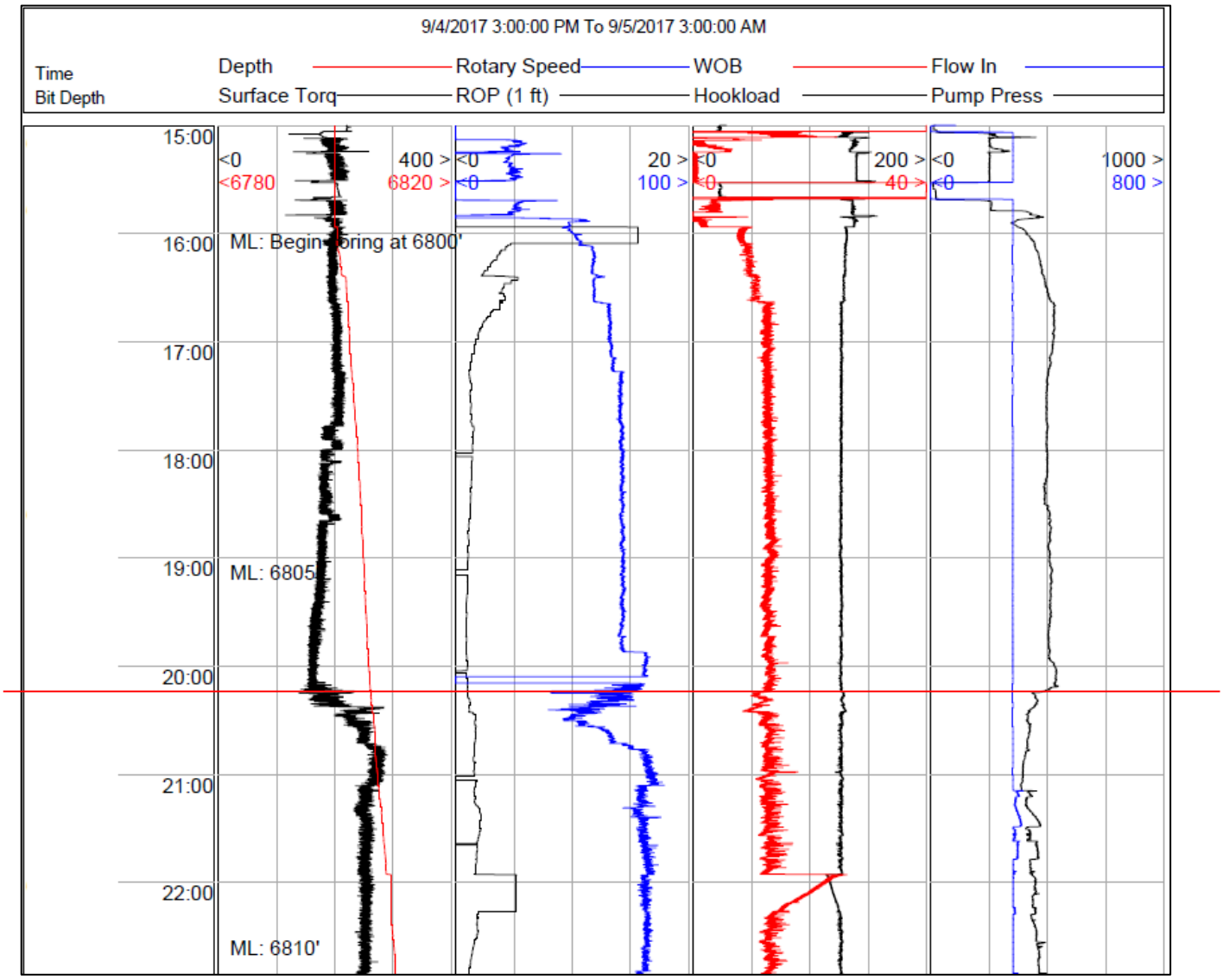
The downhole end of the stabilizer did not show any significant signs of damage.

The parted end of the pin had approximately 1.5 - 2 threads remaining. The seal face was largely undamaged, with no plastic deformation or galling seen. Photographs of the failed pin connection are shown below.

There are 2 steps in the parted end of the connection, about 160 degrees apart. Note that the connection is a double start thread, so a fracture would have to cross two threads before fully separating.

The fractured end of the connection demonstrated areas with two qualitatively different textures. One of these had intact indications consistent with fluid erosion (washing). The other showed extensive mechanical wear or galling. The areas with mechanical wear were also severely plastically deformed, with metal flared in towards the axis of the tool. These areas are visible in the photographs above. More detailed images showing the fluid erosion and plastic deformation are shown below.

The rig data logs were also reviewed in order to identify when the failure occurred based on changes in surface parameters. The log showing the interval during this run is shown below.



The core run started at a depth of 6800' at 16:00.

At around 19:50, RPM was increased from 70 to 80 RPM. This was at a depth of about 6807'.

At around 20:10, pump pressure dropped sharply from about 525psi, and leveled off at about 375psi by 21:10. RPM and surface torque also became erratic during this period. Coring progressed during this period until the run was aborted.

8.2 Conclusions

The appearance of the fractured end of the connection indicates that fluid erosion was occurring over a period of time. This was likely during the period between 20:10 and 21:10 where pump pressure dropped about 30% with no change in pump rate or other relevant

parameters. This indicates that the connection fractured at least partially at about 20:10, allowing fluid to leak through the crack and erode the fracture surface.

The wear present on the high spots of the fractured end indicates that the connection remained engaged after parting. The parted ends rotated relative to one another, deforming and wearing away the protruding sections ahead of the steps in the fracture. It is possible that the connection continued to transmit torque and rotation after fracture through the steps in the fracture surface, ratcheting over the step at times during torque spikes.

The failure occurred 7' after the start of the run. At this point, the core bit and lower stabilizer would have been in the 8.5" rathole, with the rest of the BHA in the 8.75" section above. The connection that failed was the bottommost connection still in the 8.75" drilled section.

The severe mechanical damage on the uphole end of the stabilizer blades and in the waterways suggests that there was one or more large pieces of hard debris present in the hole, just above the stabilizer. The size of the impact marks indicate that interaction with the debris produced large transverse forces on the body of the stabilizer. The large borehole gap allowed larger deflections and thus abnormal bending stresses.

The observations of the failed connection are most consistent with a bending fatigue failure of the pin. Bending forces due to interaction with debris, possibly exacerbated by resonant vibration of the BHA as RPM was increased to 80 RPM appear to have initiated a fatigue crack in the pin connection. The fracture propagated around the thread and stepped over both starts to fully part the connection.

8.3 Recommendations

Recommendations to prevent recurrence of the failure are as follows:

- Ensure that no large pieces of debris are present in the well when coring
- When rathole coring, configure the BHA with a close-to-gage stabilizer or roller reamer immediately above the coring assembly. This will better support the BHA at the upper end to reduce lateral deflections

9. Key Observations

The following list details key events during the coring operations.

- The well was completed with no Lost Time HSE incidents and all operations were completed in accordance with the JSA's of ALS Coring.

- The stabilizer located at the middle position of the coring assembly parted during core run 1. A fishing trip was required to recover the lower section of the assembly (see Section 8 – Core Barrel Failure Analysis).
- Following run 1, heavy damage was observed on the top 2 stabilizers as well as ringing of the OD on the core head.
- Core recovery was low, averaging 70.6% over both runs.
- The core sample from run 2 was noted to be quite fractured while the core from run 1 was more cemented.

10. Conclusion

Most importantly the coring portion of this project was completed safely, and the personnel worked well together to accomplish the objective.

There was a failure during run 1 and as explained in section 8, extemporaneous conditions seem to have contributed to this incident. In future applications it is recommended to customize the amount of stabilization based on BHA length. This step in the planning process in conjunction with running a full hole Wedgetail Roller Reamer would ensure a minimal amount of torque generated by the BHA while mitigating transmission of lateral and axial vibration from the string to the BHA.

The core loss seen on run 2 is largely due to the nature of the formation. The recommendation to address this would be employing one of the full closure system offered by Reservoir Group Coring. When taking into consideration the nature of the formation, the most effective system would be the sliding basket lower shoe assembly. This assembly includes a basket catcher that is positioned above the catcher, providing 2 benefits when encountering fractured/rubbled core. First the basket fingers allow core to pass through but form a barrier that impedes the passage of core fragments back through the shoe and out the bottom of the inner barrel. Second, when the assembly is hoisted and the core pushed against the basket catcher, it in turn applied downward pressure to the main catcher assisting in seating it in the lowest possible position. This is a very good option for unconsolidated formations.

Reservoir Group Coring has been pleased to provide the coring services for this project and post well analysis. We look forward to being considered as a partner for any future endeavours.

If there are any questions regarding this report, please contact Chad Beck – Operations Manager at 281 776 5300 or chad.beck@alsglobal.com.