

PDC Bits Outperform Conventional Bit in Geothermal Drilling Project

David Raymond, Steven Knudsen, Doug Blankenship; Sandia National Laboratories
Steve Bjornstad; U.S. Navy Geothermal Program Office
Joel Barbour; Barbour Drilling
Aaron Schen; NOV Downhole

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND 2012-7841C

Background

- **Overview**

- Conventional geothermal drilling is difficult
 - hard/ abrasive/fractured rock
 - high temperatures
 - lost circulation
- Migrate mature/proven rock penetration systems used in Oil & Gas/Minerals industry to improve geothermal drilling

- **Barriers to PDC bit adoption**

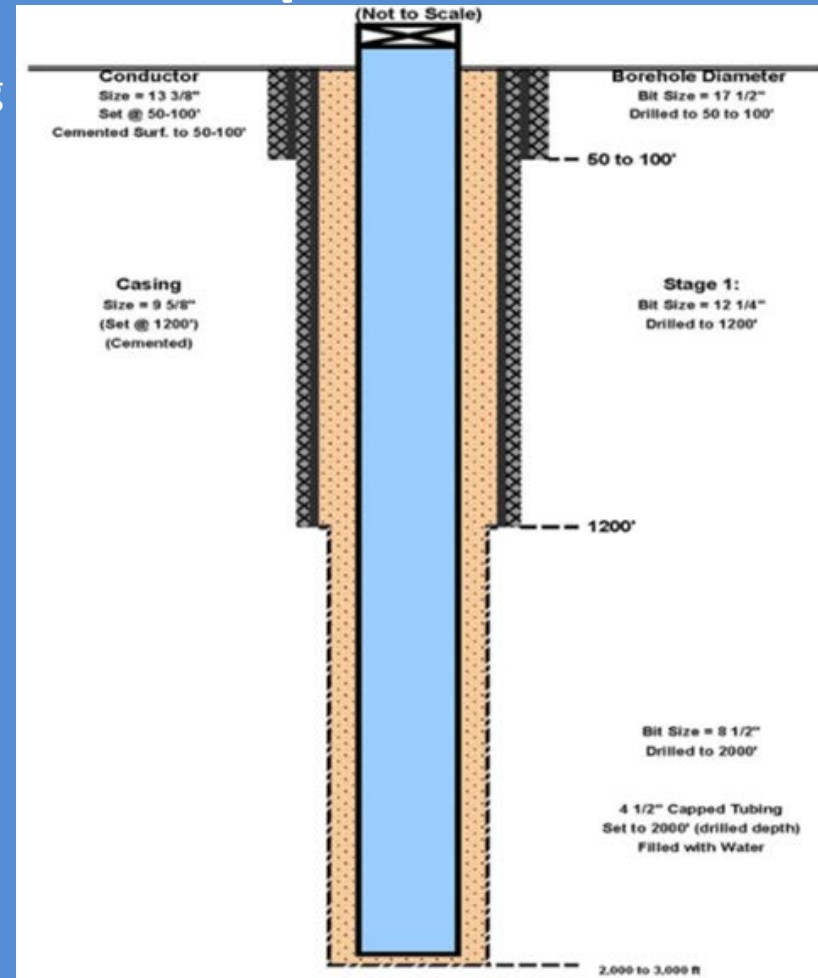
- Lack of wells
- Service industry absence
- Poor performance in early field trials

- **Project Approach**

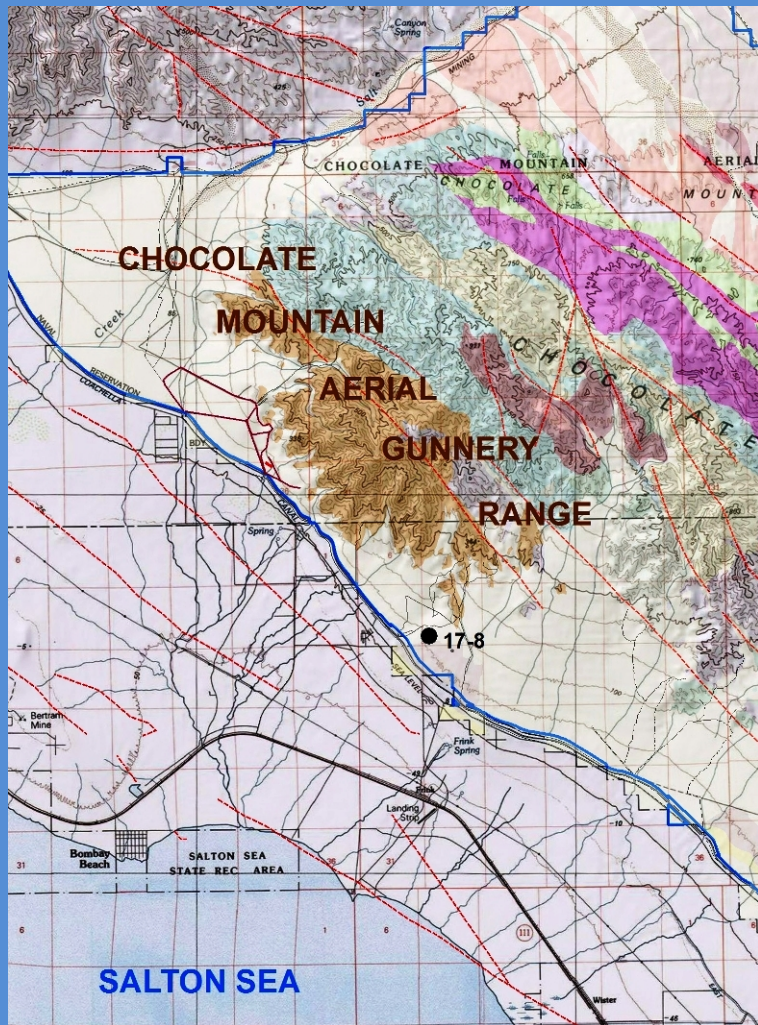
- Phase 1 - Preliminary field trials to demonstrate potential & highlight deficiencies
- Phase 2 - Service company involvement in performance remediation and custom development
- Phase 3 - Secondary/Follow-Up field trials **for verification & validation**

Drilling Project Description

- Identify Geothermal Developer/Drilling Company
 - US Navy GPO agreed to collaborate by providing wells of opportunity
 - MOU with Sandia/Navy (DOE/DOD)
 - USN GPO drilling contractor
 - Barbour Well, Inc.,
 - Provide drill rig time, integration, and coordination with test plan
- Identify Test Site/Well of Opportunity
 - Chocolate Mountains Aerial Gunnery Range, CA
 - Two geophysical test holes planned; One pursued
 - Investigate temperature field/hydrothermal alteration
 - Metamorphosed volcanic rocks anticipated



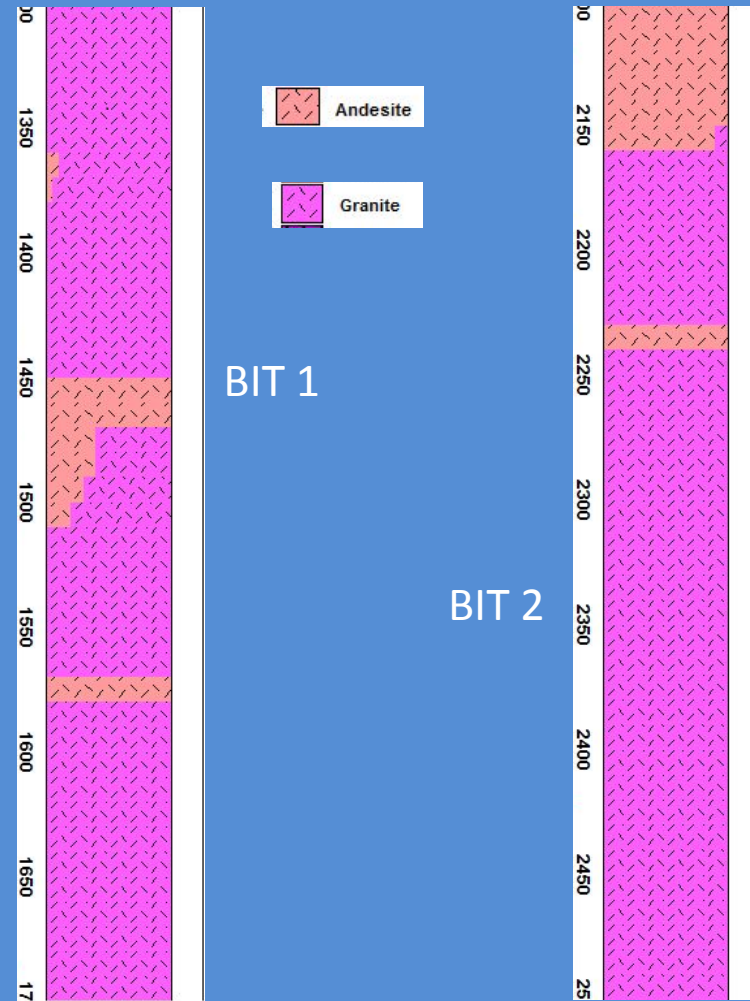
LOCATION



SAMPLE GEOLOGY

% Rock Volume
0 100

% Rock Volume
0 100



BARBOUR RIG 77



Barbour Rig 77

Specifications

Pulling Capacity: 200,000 lb

Drawworks: Taylor RT 5000 Driven by (1) C15 CAT 500 HP Diesel Engine.

Mast: Taylor RT 5000 Square set Derrick rated @ 200,000LBS Static Hook Load, Height 70 feet.

Substructure: Height 13.6 feet with 15 foot K.B elevation.

Mud Pump #1: Gardner Denver PZ7 Triplex Pump Powered by (1) Series 60 Detroit 600 HP Tier 3 Engine. Centrifugal Charge Pump.

Mud Pump #2: Gardner Denver PZ7 Triplex Pump Powered by (1) Series 60 Detroit 600 HP Tier 3 Engine. Centrifugal Charge Pump.

Rotary Table: DSM Hydraulically adjustable 18

Swivel & drilling block: McKisick 6 Line 100 Ton Swivel PG 60 Western Rubber.

Tripping block: McKisick 6 Line 100 Ton

Generators: (1) magnum 235 KW, (1) Magnum 185 KW (when needed), generator trailer.

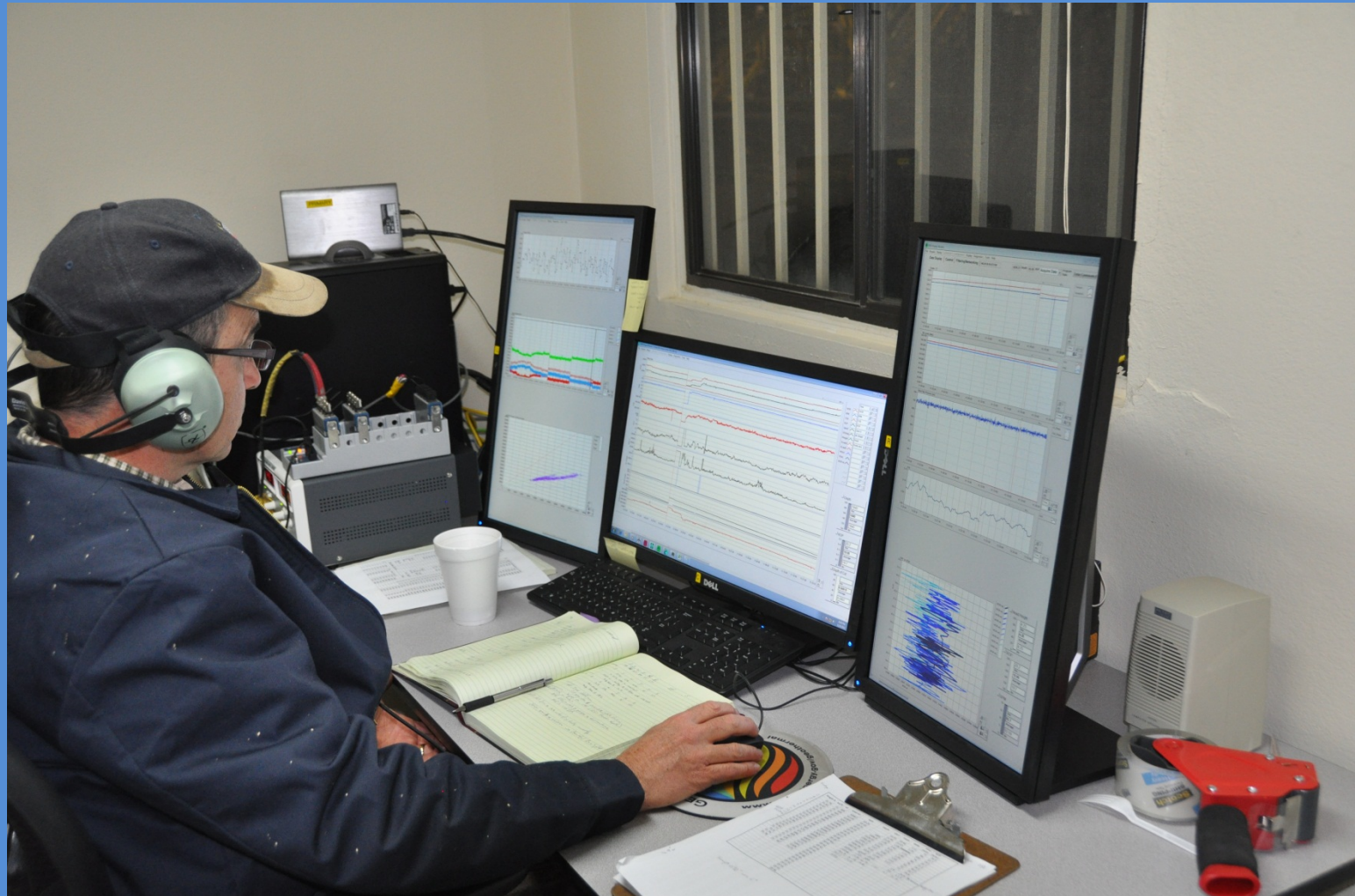
Mud System: (2)-240 Barrel, 3-Compartment Mud Tank, (1)-5xöx11 Centrifugal Mixing Pump, (1)-5xöx11 Centrifugal Desilting Pump. (Second 220 bbl. Mud Tank by request)

Fuel Storage: (2) 2000 Gallon Fuel Tanks.

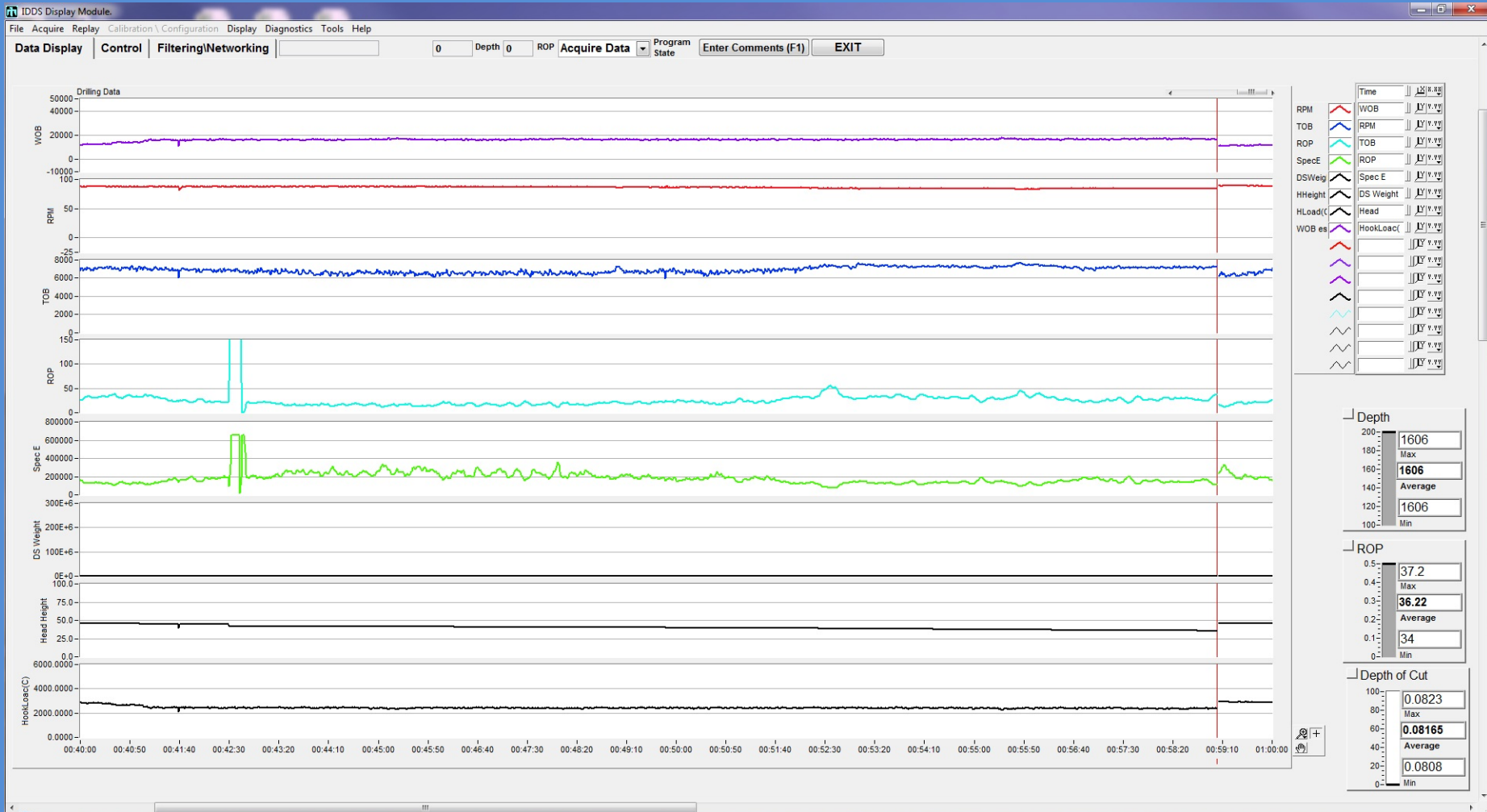
Auxiliary Equipment: Survey Machine with 5000 feet of e-line, Pipe Wrangler, 10,000 lbs Multifunction Loader (forklift, front loader and jib boom)

TRANSMISSION T-14607A GEAR RATIO	PSI= 5000 SPEED/RPM	RINEER 20 CUBE TORQUE/FT LBS
1 10.50	15.00	83,777.40
2 6.13	25.00	48,910.00
3 3.71	41.00	29,601.30
4 2.51	61.00	20,026.70
5 1.83	84.00	14,601.20
6 1.34	114.00	10,691.50
7 1.00	152.00	7,978.80

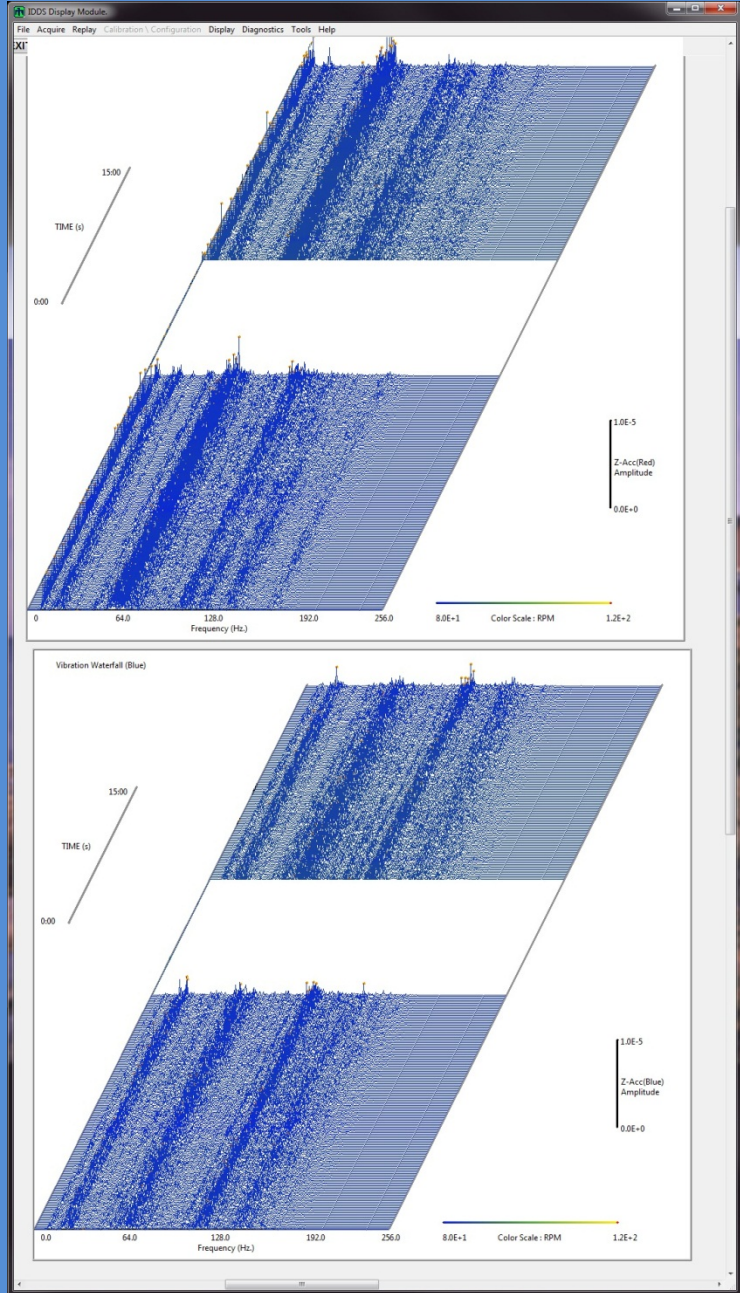
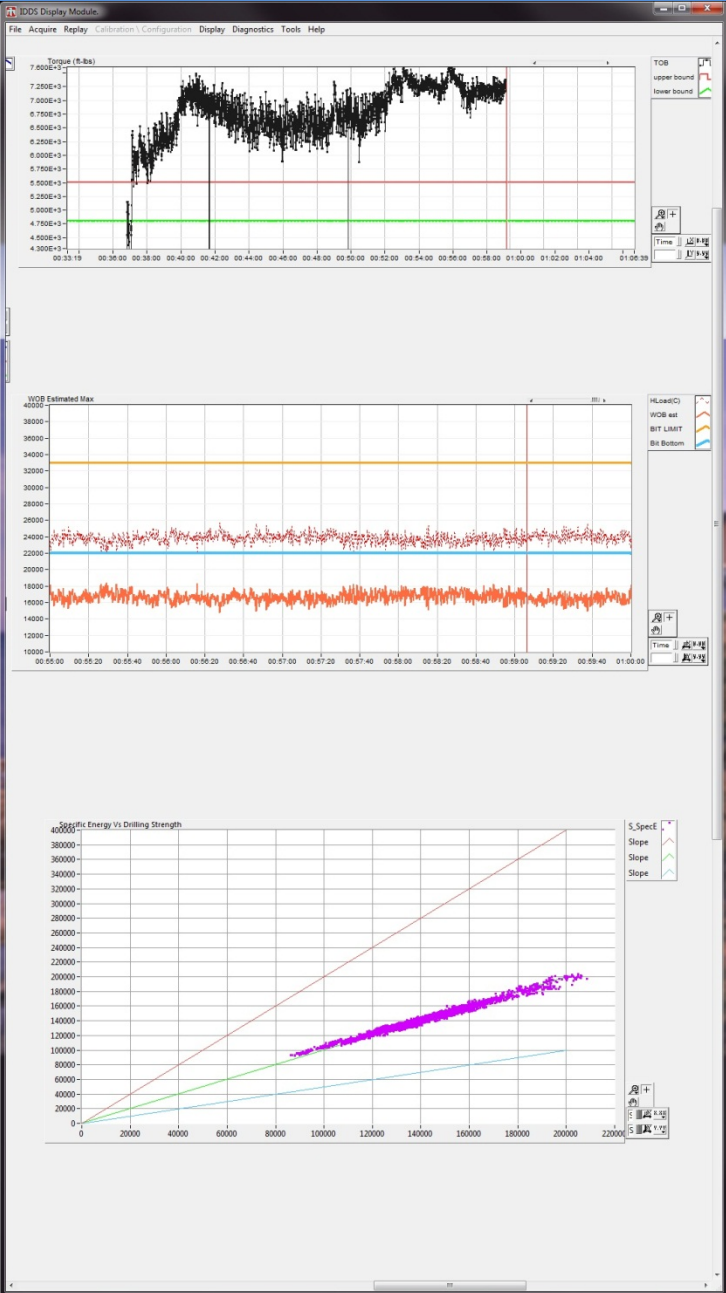
DATA SYSTEMS AND ACQUISITION



CENTER SCREEN BIT 1 6-DEC-2011 08:19



LEFT
BIT 1 - 6 - DEC - 2011
08:19
RIGHT



BLACK BOX HARDWARE



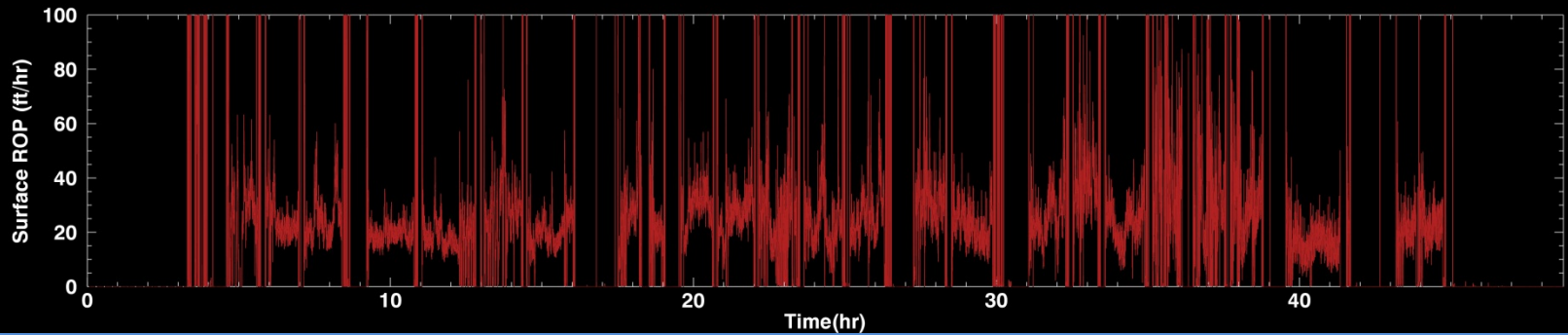
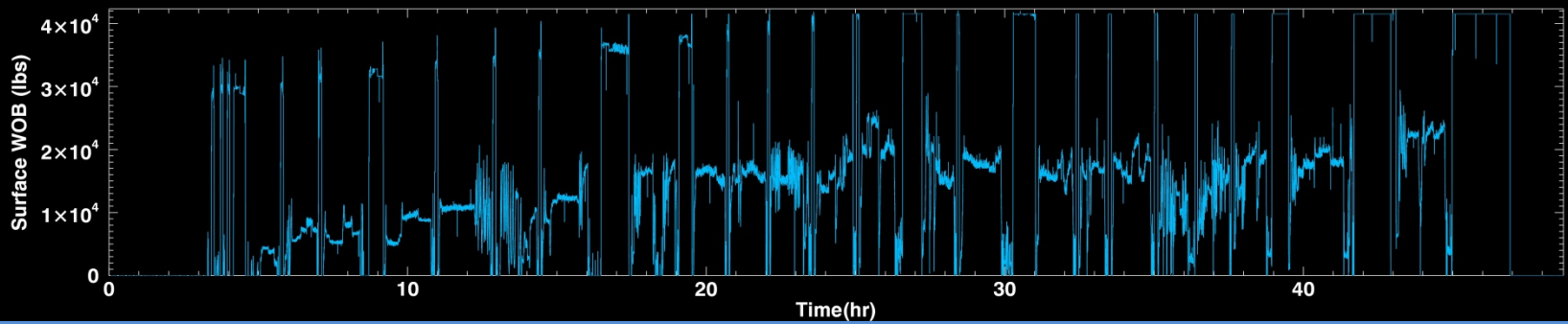
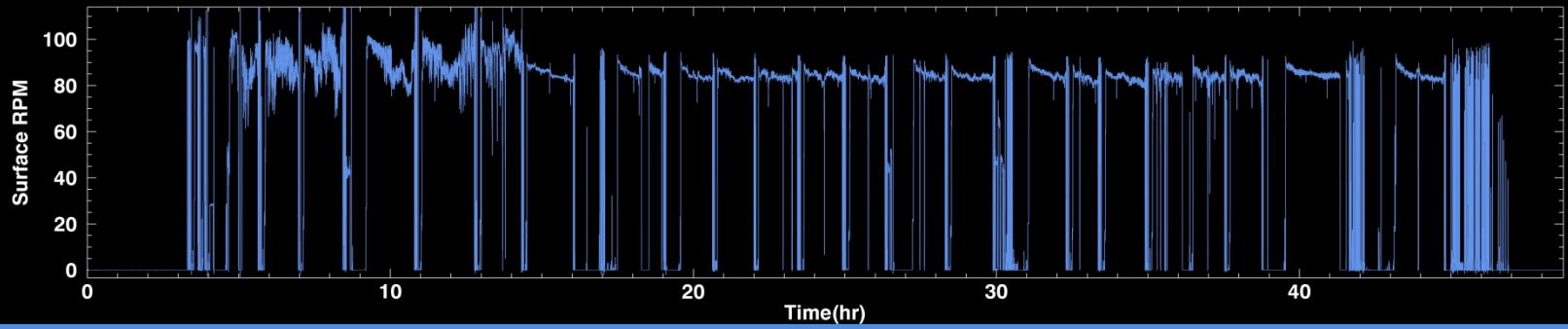
Drilling Summary

Date	Start ft	Finish ft	Bit Size inches	Drilling Hours	Daily ROP	Activity
11/27/2011	0	0	12.25			Rig Up
11/28/2011	115	647	12.25	18.5	28.76	
11/29/2011	647	844	12.75	18	10.94	
11/30/2011	844	916	12.75	15	4.80	
12/1/2011	916	1225	12.75	21.5	14.37	
12/2/2011	1225	1225				Surface Logging
12/3/2011	1225	1225				Surface Casing
12/4/2011	1190	1234	8.5	1.5	29.33	
12/5/2011	1234	1472	8.5	9.5	25.05	
12/6/2011	1472	1918	8.5	20.5	21.76	
12/7/2011	1918	2194	8.5	13.5	20.44	
12/8/2011	2194	2518	8.5	20	16.20	
12/9/2011	2518	2647	8.5	13	9.92	
12/10/2011	2647	2856	8.5	22.5	9.29	
12/11/2011	2856	2929	8.5	8	9.13	
12/12/2011	2929	2929				Fishing
12/13/2011	2929	2929				Fishing
12/14/2011	2929	3007	8.5	11	7.09	
12/15/2011	3007	3020	8.5	3	4.33	

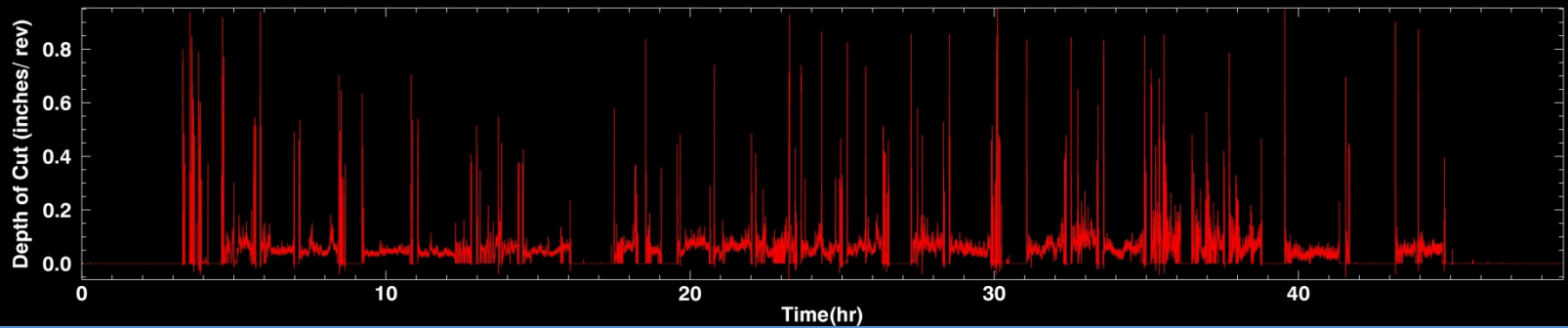
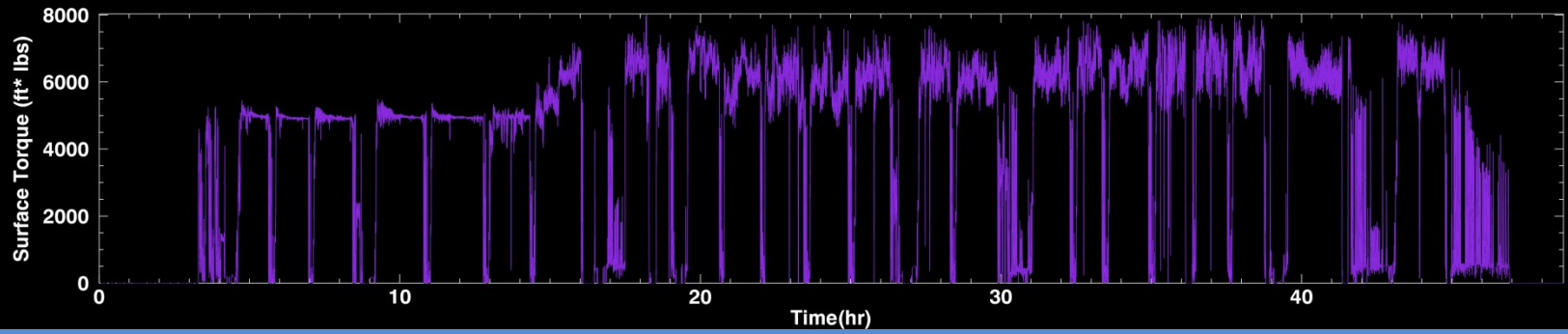
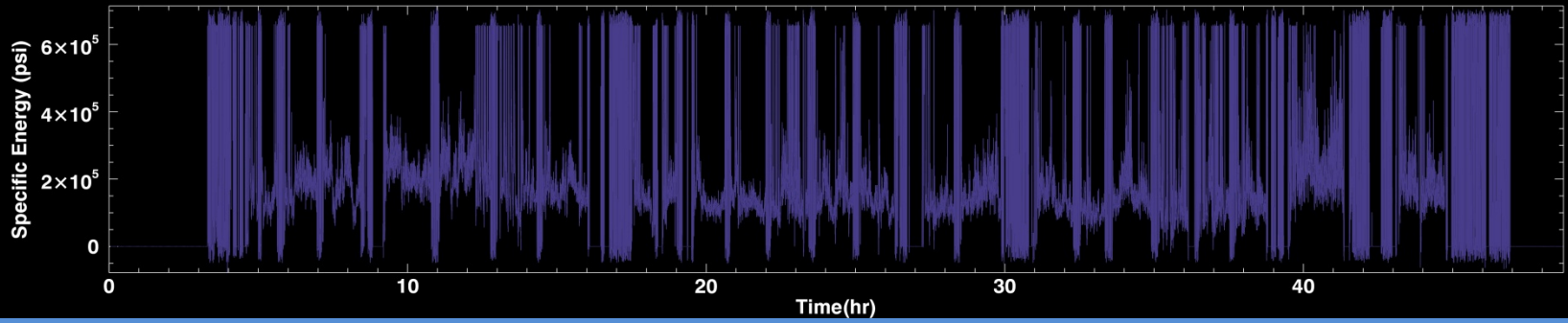
Bit Vendor	Type	Depth in	Depth Out	Feet Drilled
HTC	GX-C1V	115	734	619
Smith	GF-S15	734	911	177
Security	S84F	911	1225	314
HTC	WE824	1190	1245	55
HTC	GT-09	1234	1345	111
Reed	813	1345	2070	725
Reed	713	2070	2643	573
Security	XSD30D	2643	2929	286
HTC	GT09	2929	3020	91



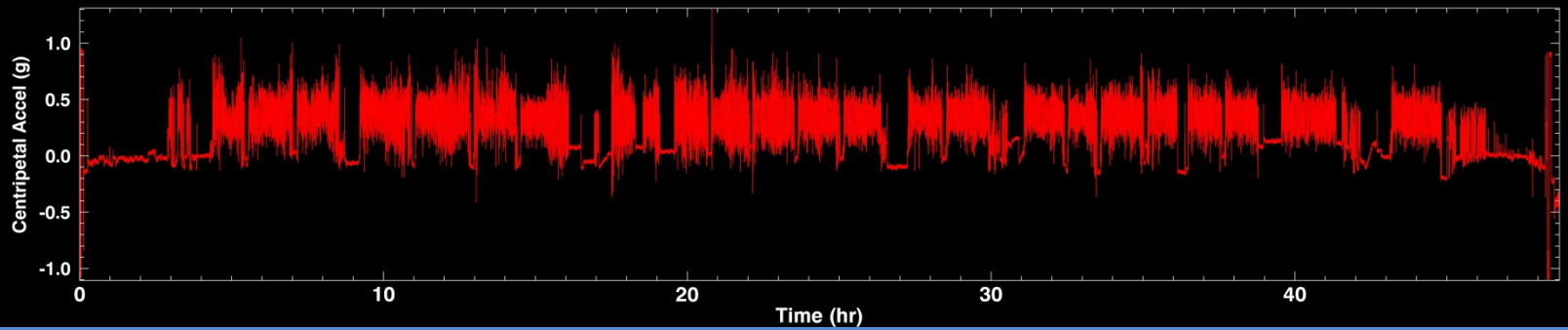
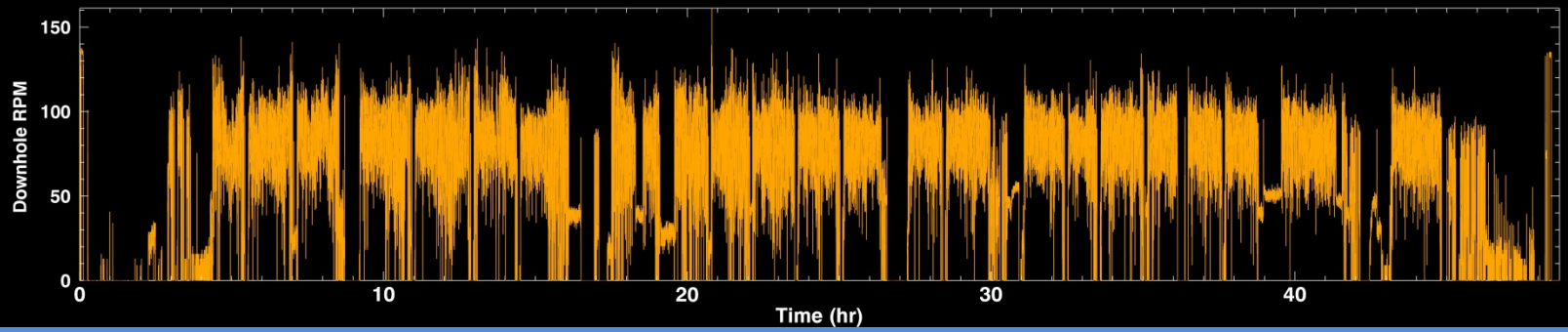
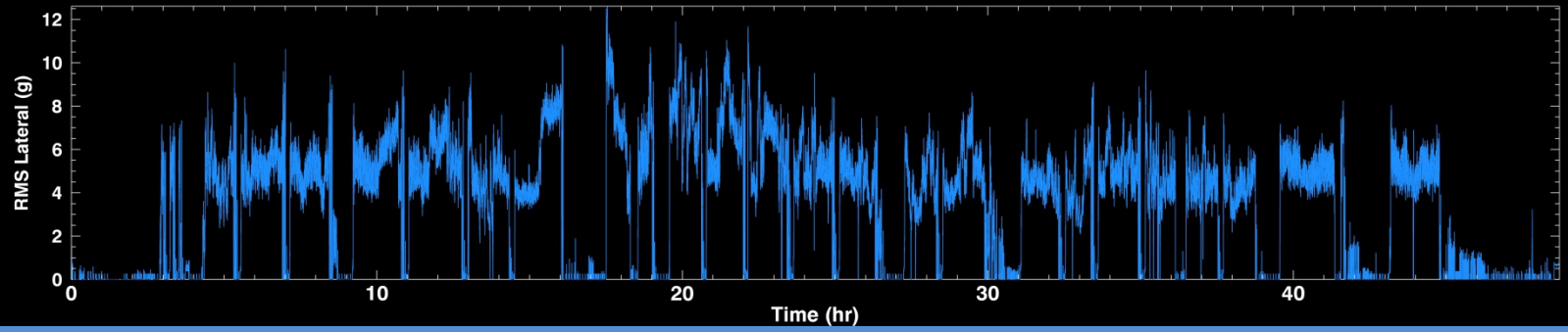
BIT 1

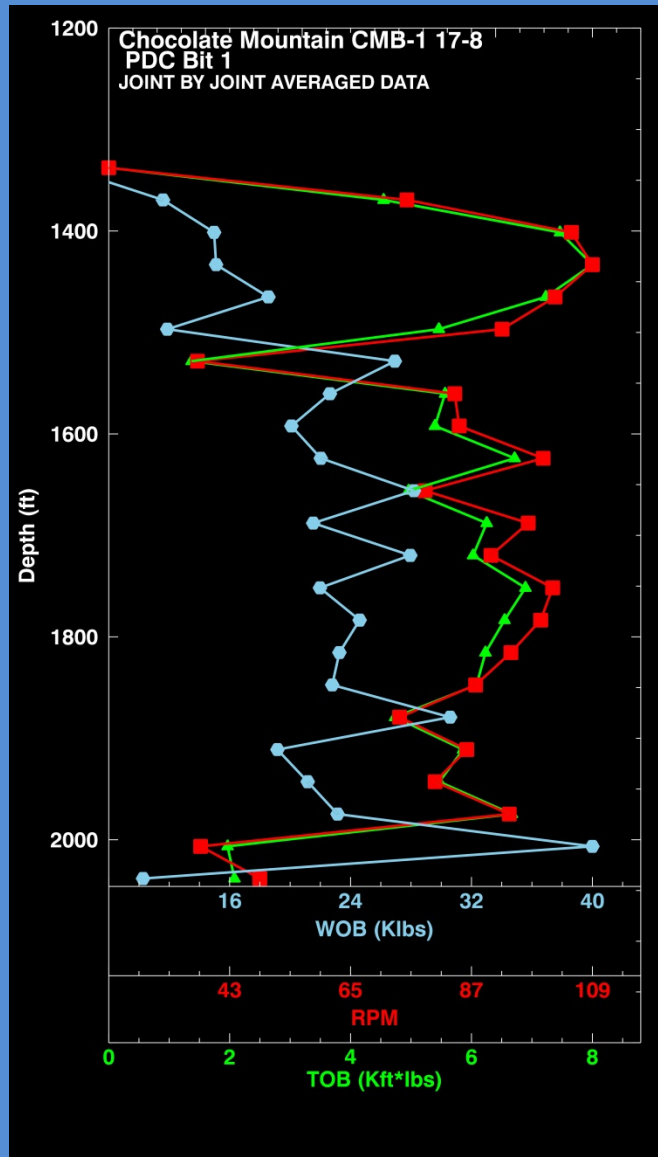
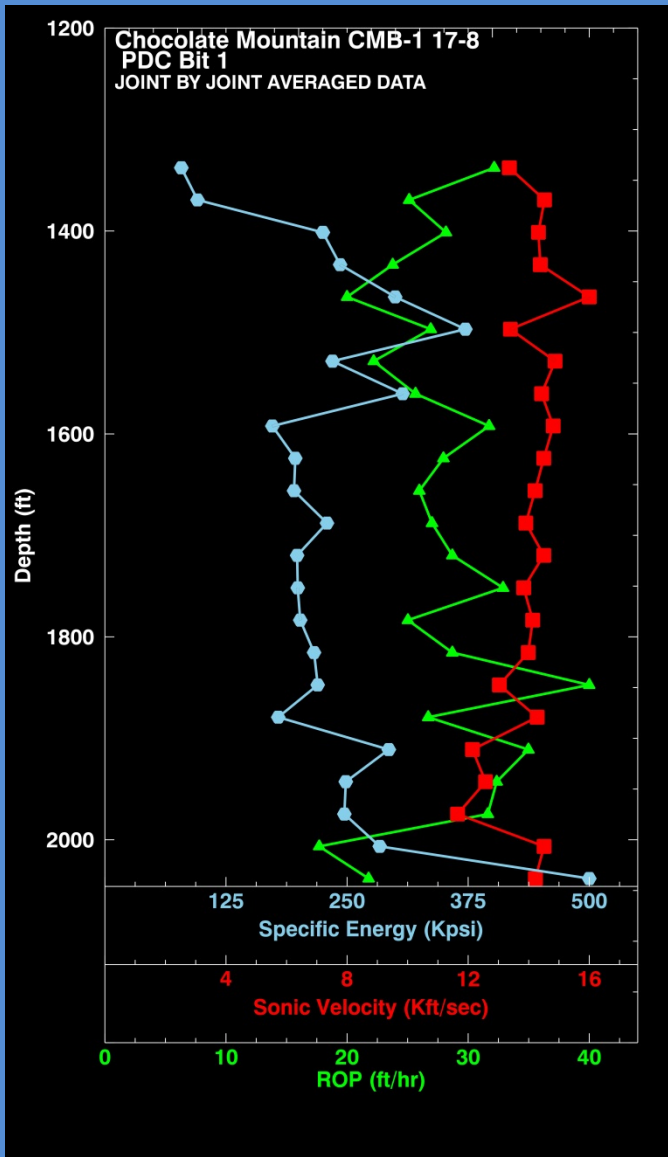


BIT1



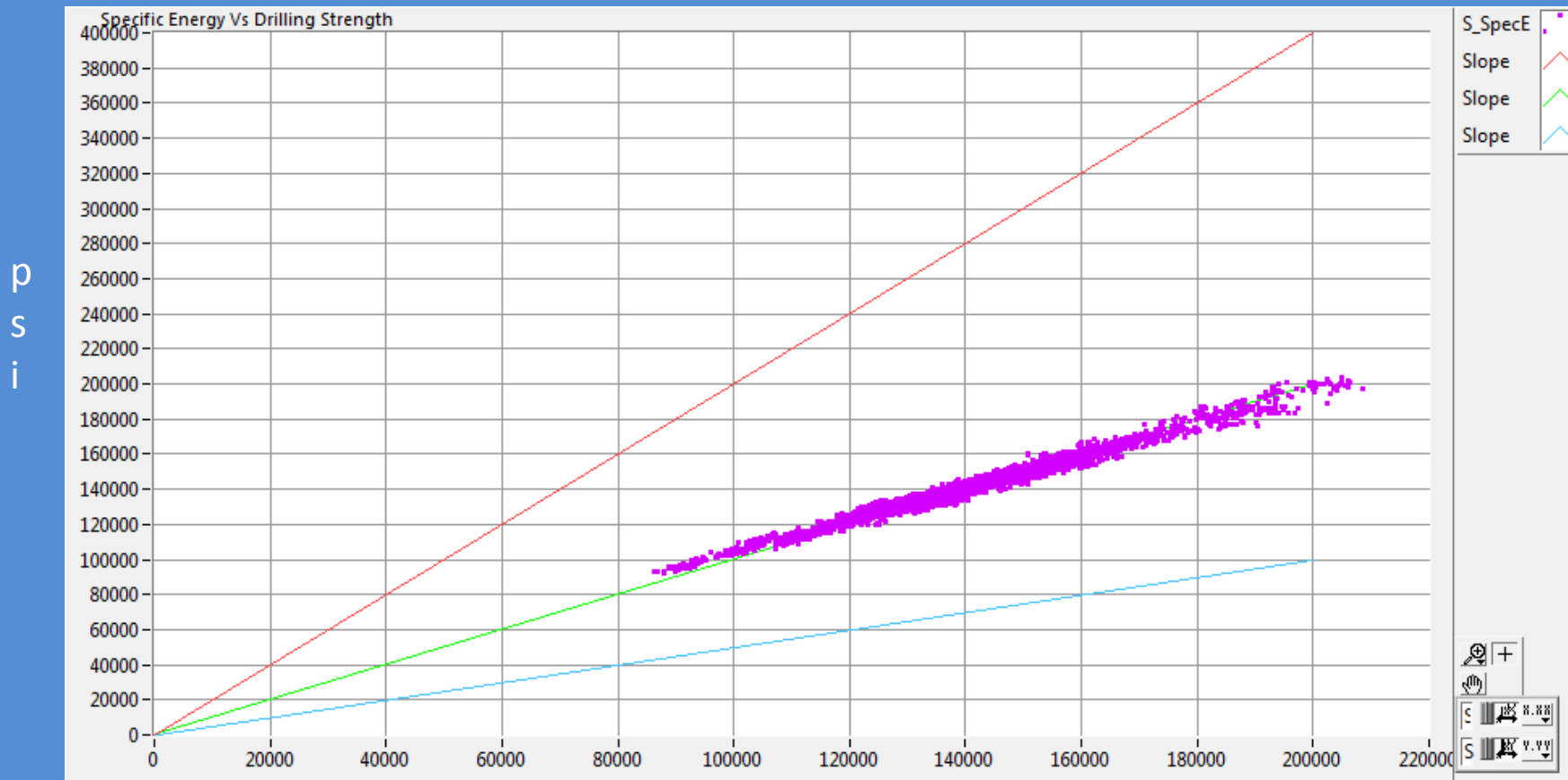
Bit 1





Start Depth	Stop Depth	ROP	Total Depth
1337.7	1369.4	30.7	31.7
1369.4	1401.4	24.0	63.7
1401.4	1433.2	26.9	95.5
1433.2	1465	22.7	127.3
1465	1496.8	19.1	159.1
1496.8	1528.3	25.7	190.6
1528.3	1560.4	21.2	222.7
1560.4	1592.2	24.5	254.5
1592.2	1624	30.3	286.3
1624	1656	26.7	318.3
1656	1687.9	24.8	350.2
1687.9	1719.7	25.8	382
1719.7	1751.7	27.4	414
1751.7	1783.5	31.4	445.8
1783.5	1815.5	23.9	477.8
1815.5	1847.4	27.4	509.7
1847.4	1879.2	38.2	541.5
1879.2	1911.1	25.5	573.4
1911.1	1942.8	33.4	605.1
1942.8	1974.7	30.9	637
1974.7	2006.5	30.2	668.8
2006.5	2038.2	16.9	700.5
2038.2	2070.1	20.8	732.4
Average		26.5	
MIN		16.9	
MAX		38.2	

BIT 1 -- 6-DEC-2011 08:19



psi

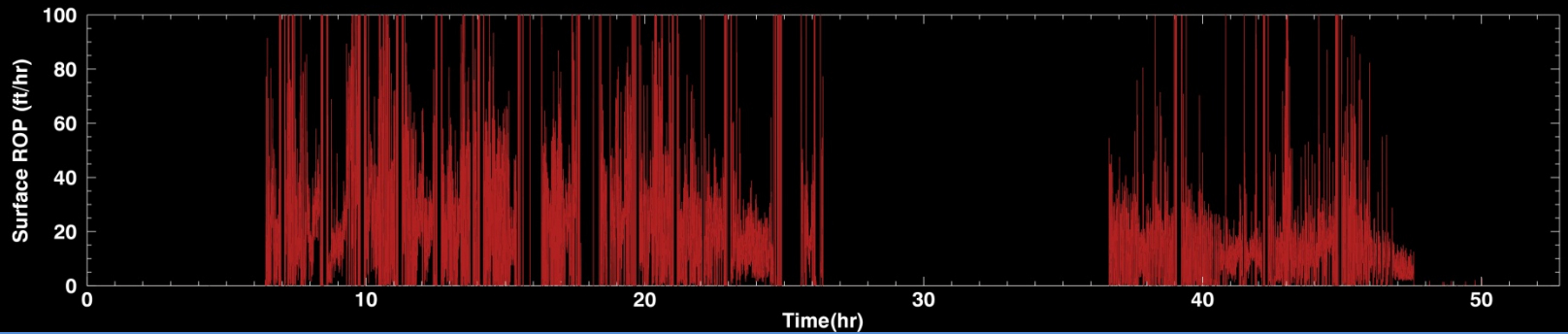
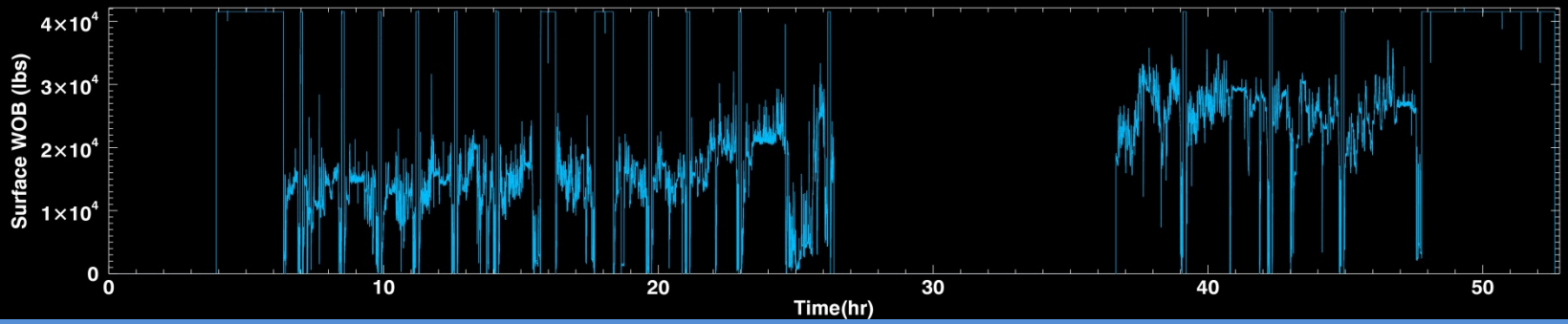
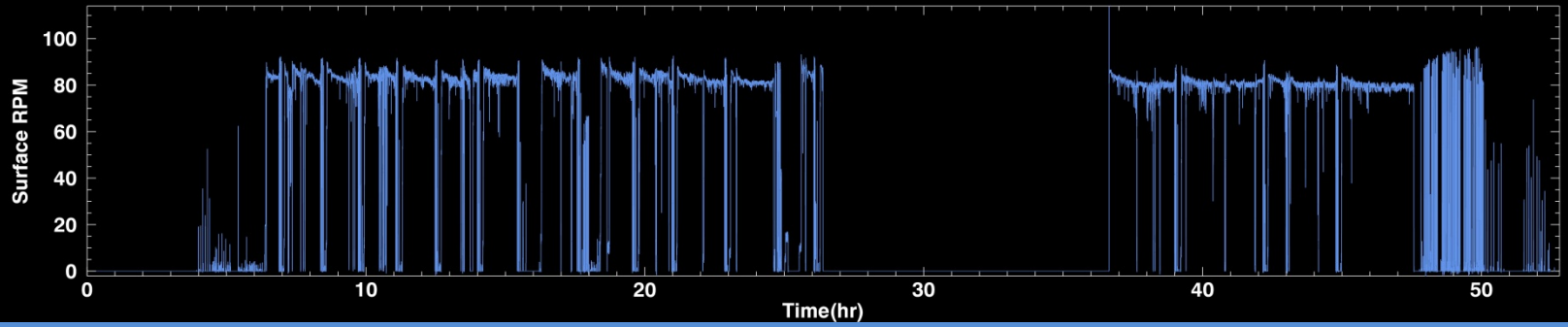
BIT 1 AFTER REMOVAL 7-DEC-2011 -- 725 FT DRILLED -- 26 FT/HR AVERAGE ROP



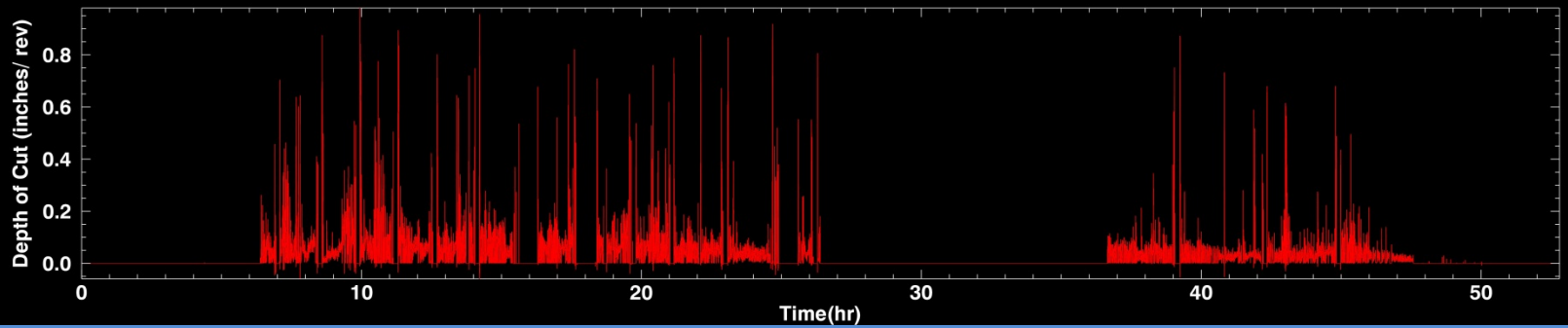
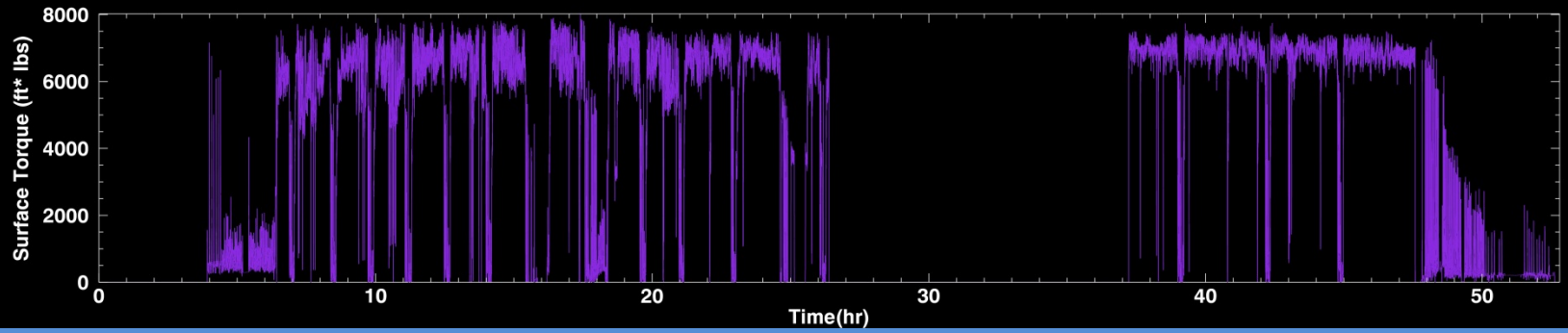
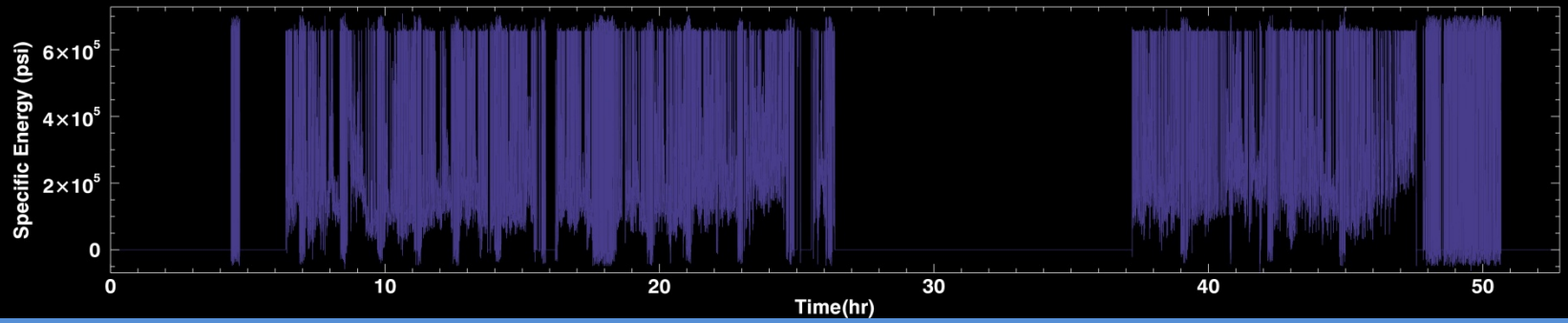
BIT 2 -- NEW -- 7-DEC-2011



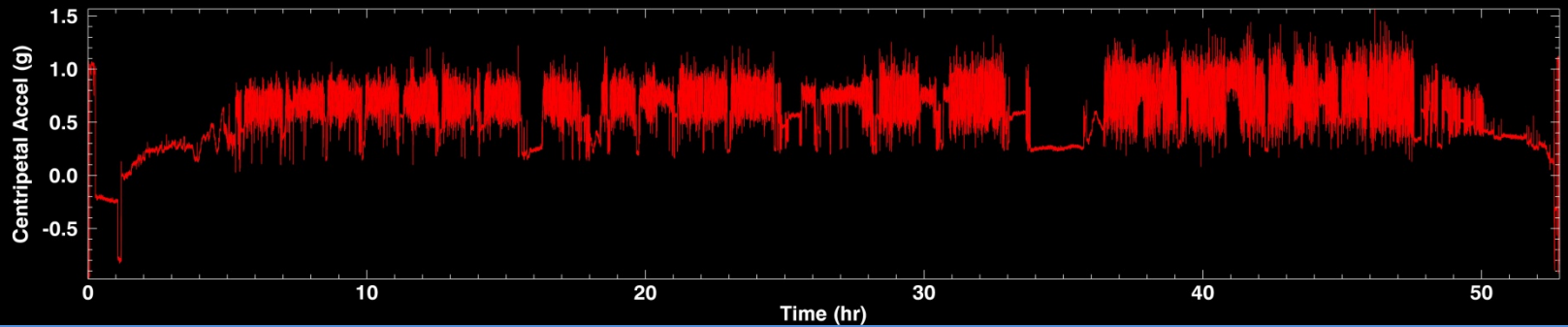
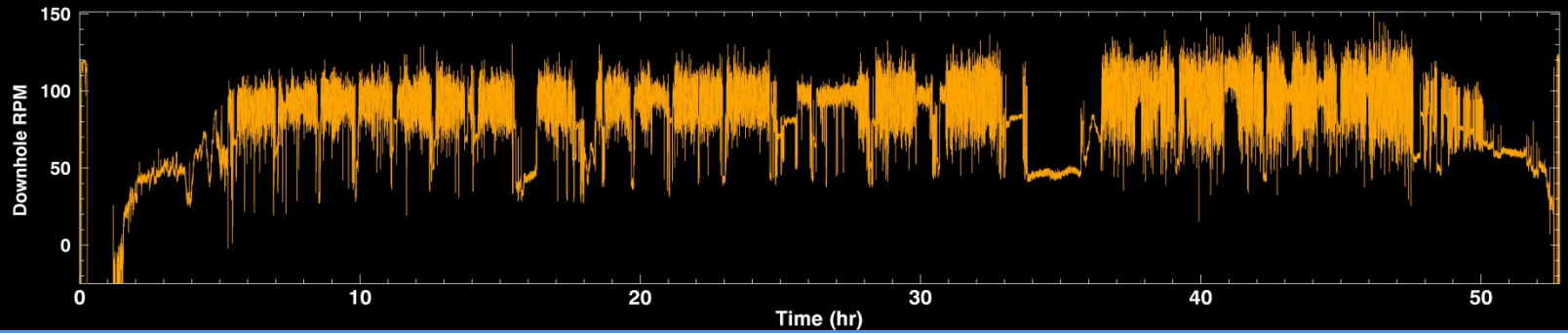
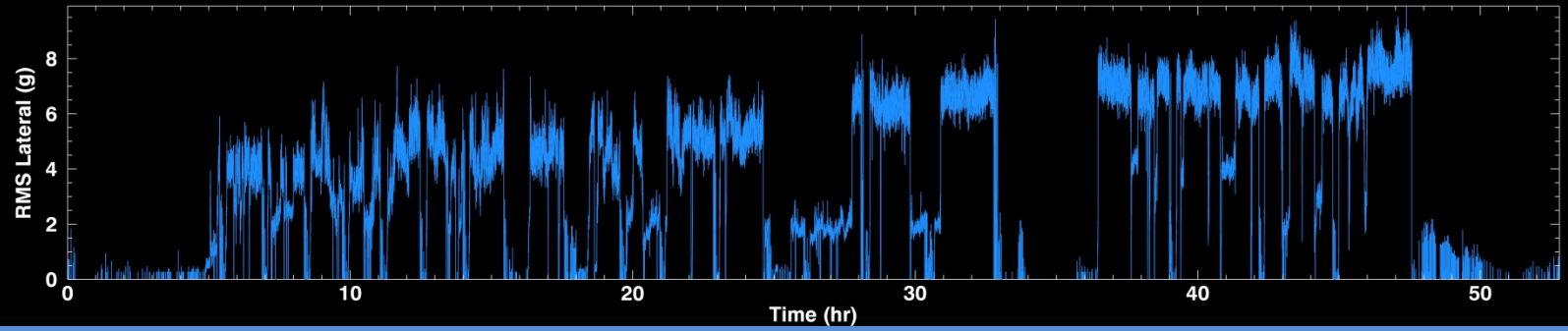
BIT 2

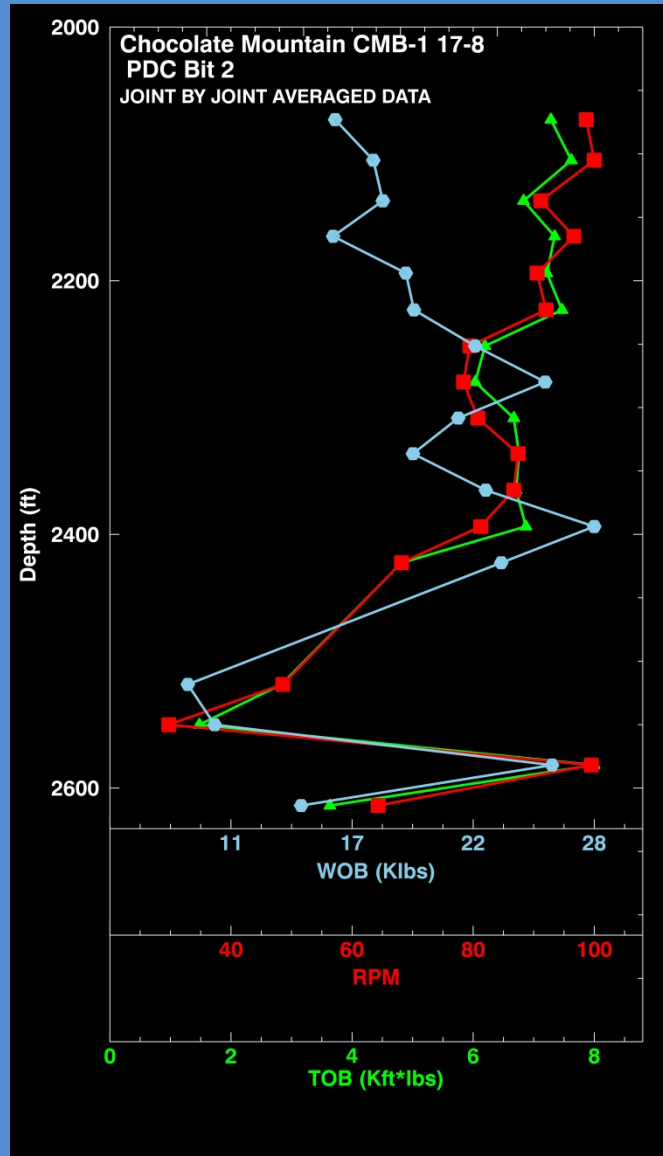
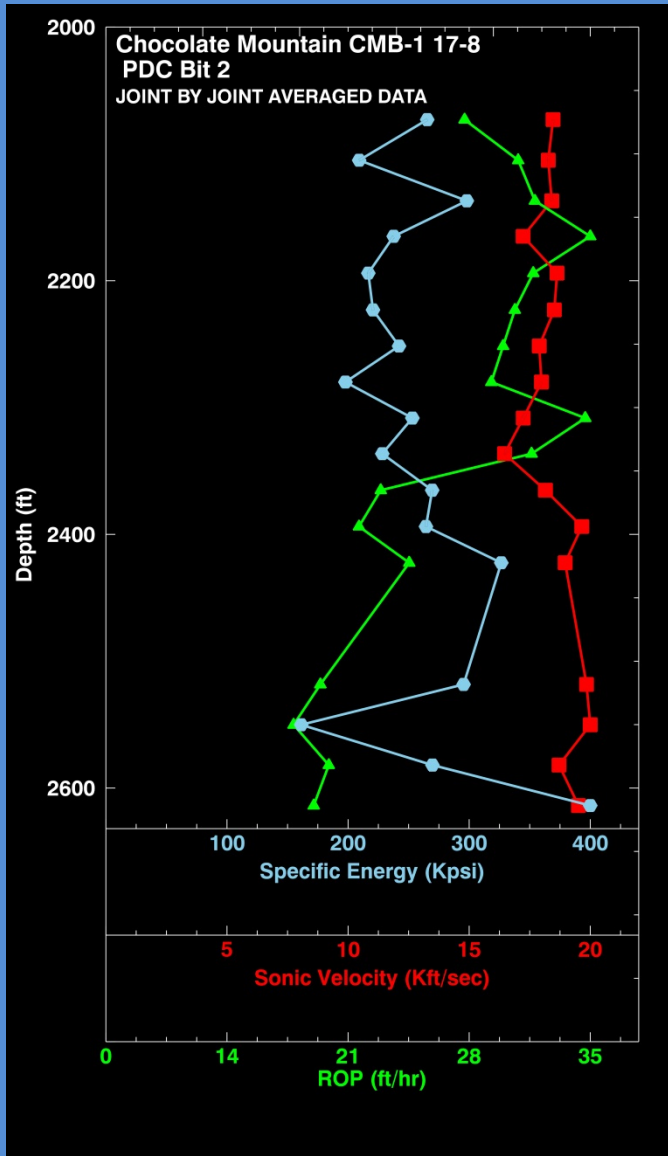


BIT 2



BIT 2





Start Depth	Stop Depth	ROP	Total Drilled
2073	2105	21.4	32
2105	2137	24.6	64
2137	2165	25.6	92
2165	2194	28.9	121
2194	2223	25.5	150
2223	2251.5	24.4	178.5
2251.5	2279.9	23.7	206.9
2279.9	2308.3	23.0	235.3
2308.3	2336.4	28.6	263.4
2336.4	2365.2	25.4	292.2
2365.2	2393.8	16.4	320.8
2393.8	2422.4	15.1	349.4
2422.4	2454.4	18.1	381.4
2454.4	2486.3	19.2	413.3
2486.3	2518.3	17.4	445.3
2518.3	2550.1	12.8	477.1
2550.1	2581.9	11.2	508.9
2581.9	2613.8	13.3	540.8
2613.8	2645.8	12.4	572.8
Average		20.4	
MIN		11.2	
MAX		28.9	

BIT 2 AFTER REMOVAL 9-DEC-2011 -- 573 FT DRILLED -- 20 FT/HR AVERAGE



BIT 3 – NEW – 9-DEC-2011



Start Depth	Stop Depth	ROP	Total Footage Drilled
2643	2674.9	7.3	31.9
2674.9	2706.9	9.9	63.9
2706.9	2738.8	15.0	95.8
Average		10.7	
MIN		7.3	
MAX		15.0	

Drill Cost Comparisons

Rock Reduction Component of Drilling Costs.											
Case	Bit Type	Bit	Scenario	Bit Cost, BC [\$]	ROP [ft/hr]	Footage Drilled, L [ft]	Initial Depth, ID [ft]	Drilling Time, DT [hr]	Trip Time [hr]	Cost Per Foot [\$/ft]	Interval cost [\$k]
A	PDC	Bit 1	Actual performance	\$ 15,000.00	26.5	725	1345	27.4	2.1	\$ 45	\$ 32,780
B	Roller Cone	Bit 3	if Bit 3 drilled the Bit 1 interval	\$ 3,200.00	10	400	1345	40.0	1.7	\$ 71	\$ 52,507
				\$ 3,200.00	10	325	1745	32.5	2.1	\$ 74	
C	PDC	Bit 2	DBR	\$ 46,888.00	20.4	566	2070	27.7	2.6	\$ 115	\$ 65,243
D	PDC	Bit 2	Adequate rig torque - no DBR	\$ 15,000.00	20.4	566	2070	27.7	2.6	\$ 59	\$ 33,355
E	Roller Cone	Bit 3	if Bit 3 drilled the Bit 2 interval	\$ 3,200.00	10	400	2070	40.0	2.5	\$ 72	\$ 43,681
				\$ 3,200.00	10	166	2470	16.6	2.6	\$ 89	

Conclusions

- PDC bits are capable of providing better ROP in geothermal drilling than roller cone bits
- PDC bits have demonstrated a longer lifetimes than roller cone bits in geothermal drilling
- Matching PDC bits with rig capability is necessary for best performance

Acknowledgements

- Barbour Drilling and the crews from rig 77
- DOE
- NOV Downhole
- PrimeCore Systems Inc.
- Prospect Geotech
- United States Navy GPO
- Curtis Lanning

Phase Two

- New bit design conceived
 - Optimize features found in both phase one bits to produce a geothermal-specific PDC bit design for geothermal drilling
 - Torque control components included to control rig torque up
 - Currently being manufactured
- Expect to field test phase two bit late 2012 or early 2013

Questions & Comments