SAND2016-10562C

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Sandia National Laboratories

Advanced Geothermal Drilling Technology Demonstration in the Chocolate Mountains, CA

David W. Raymond

California Geothermal Forum

October 20, 2016

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NNSA National Nuclear Security Administration

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Background

- **Overview**
  - Conventional geothermal drilling is difficult
    - hard/ abrasive/fractured rock
    - high temperatures
    - loss 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

Acknowledgements

- DOE/EERE/Geothermal Technologies Office
- ARRA Program Sponsorship
- Steve Bjornstad; U.S. Navy Geothermal Program Office
- Aaron Schen; NOV Downhole
- Joel Barbour and the crews from Rig 77; Barbour Drilling
- Prospect Geotech
- Steven Knudsen (ret.), Doug Blankenship, Dennis King & Jiann Su; Sandia National Laboratories
- Keith Barrett; PrimeCore Systems Inc.

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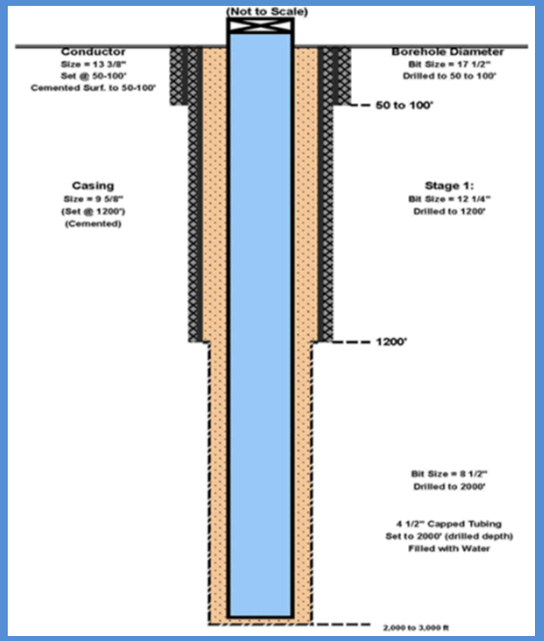
2011 Drilling Project Description

- Identify Geothermal Developer/Drilling Company
- US Navy GPO agreed to collaborate by providing wells of opportunity
- MOU with Sandia/Navy (DOE/DOD)
- Barbour Well, Inc.,
- USN GPO drilling contractor
- 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



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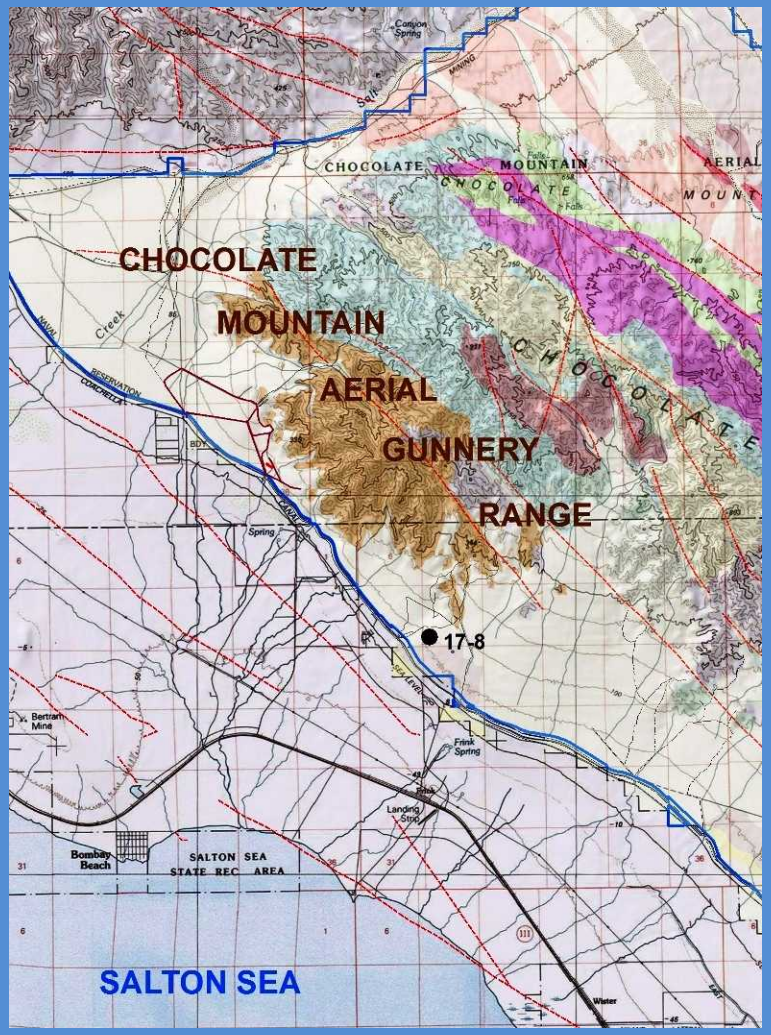
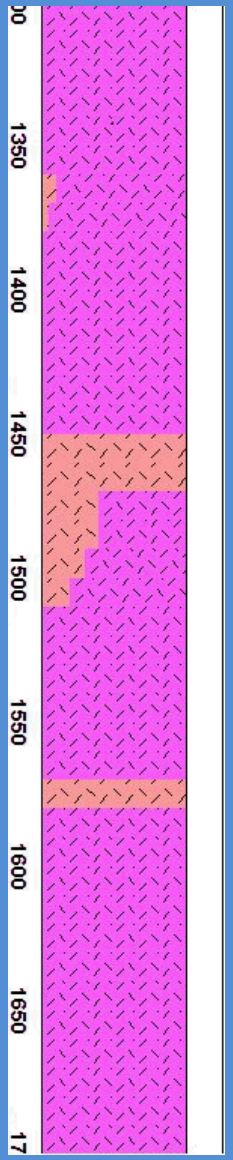
LOCATION



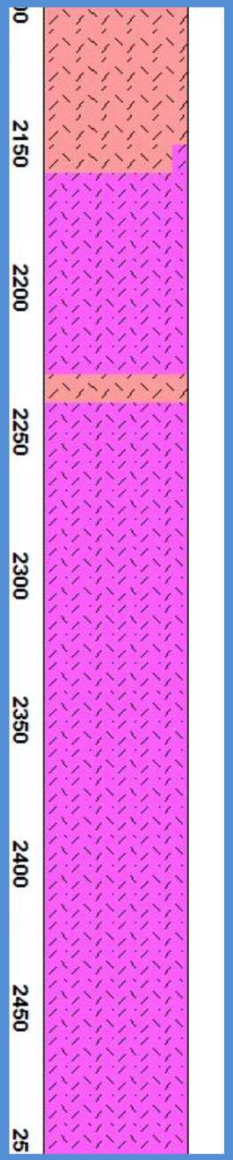
SAMPLE GEOLOGY



BIT 1

Andesite

Granite



BIT 2

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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)-5x6x11 Centrifugal Mixing Pump, (1)-5x6x11 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)*

Rotary Transmission Specifications are as followed:

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

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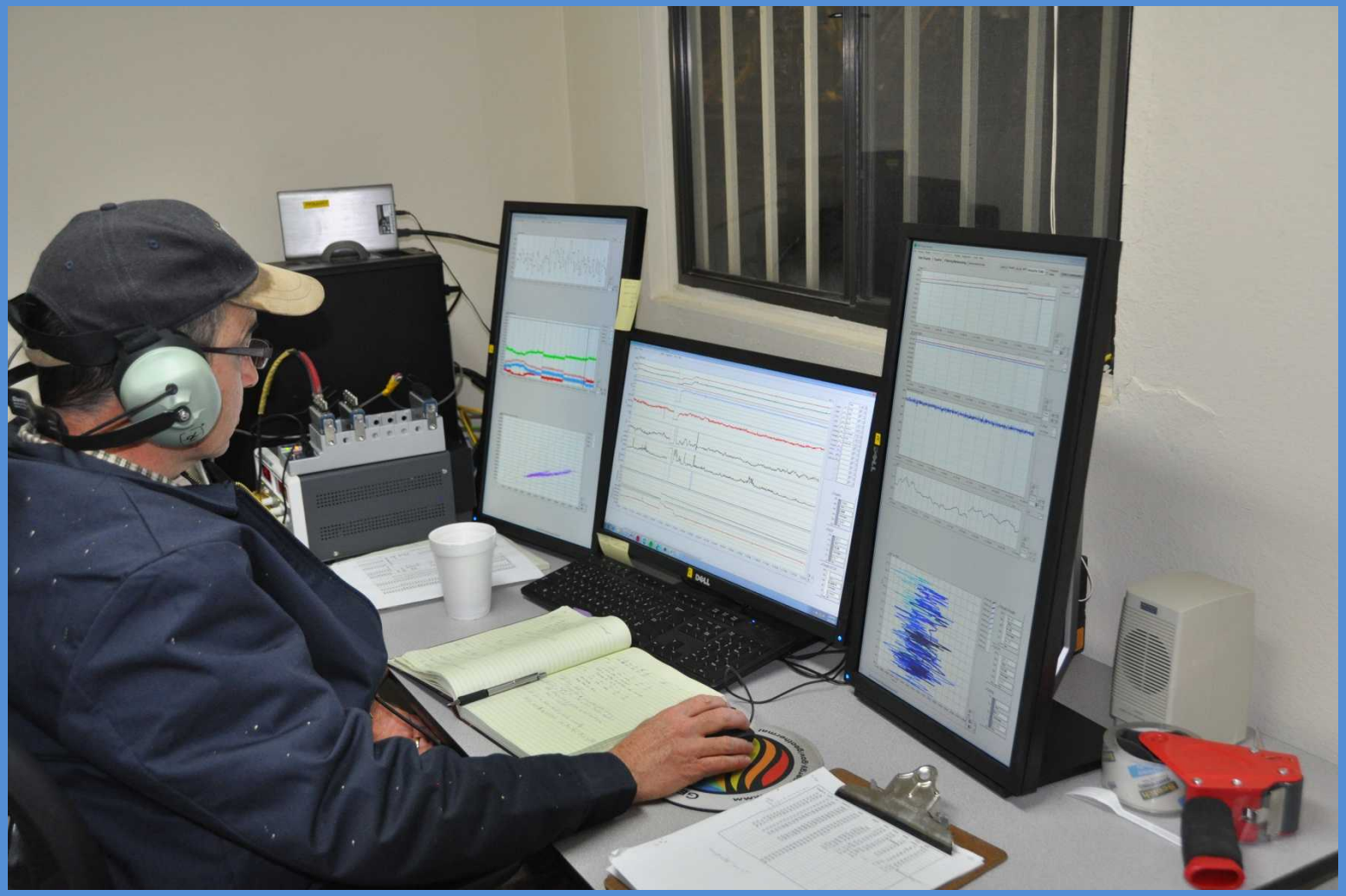
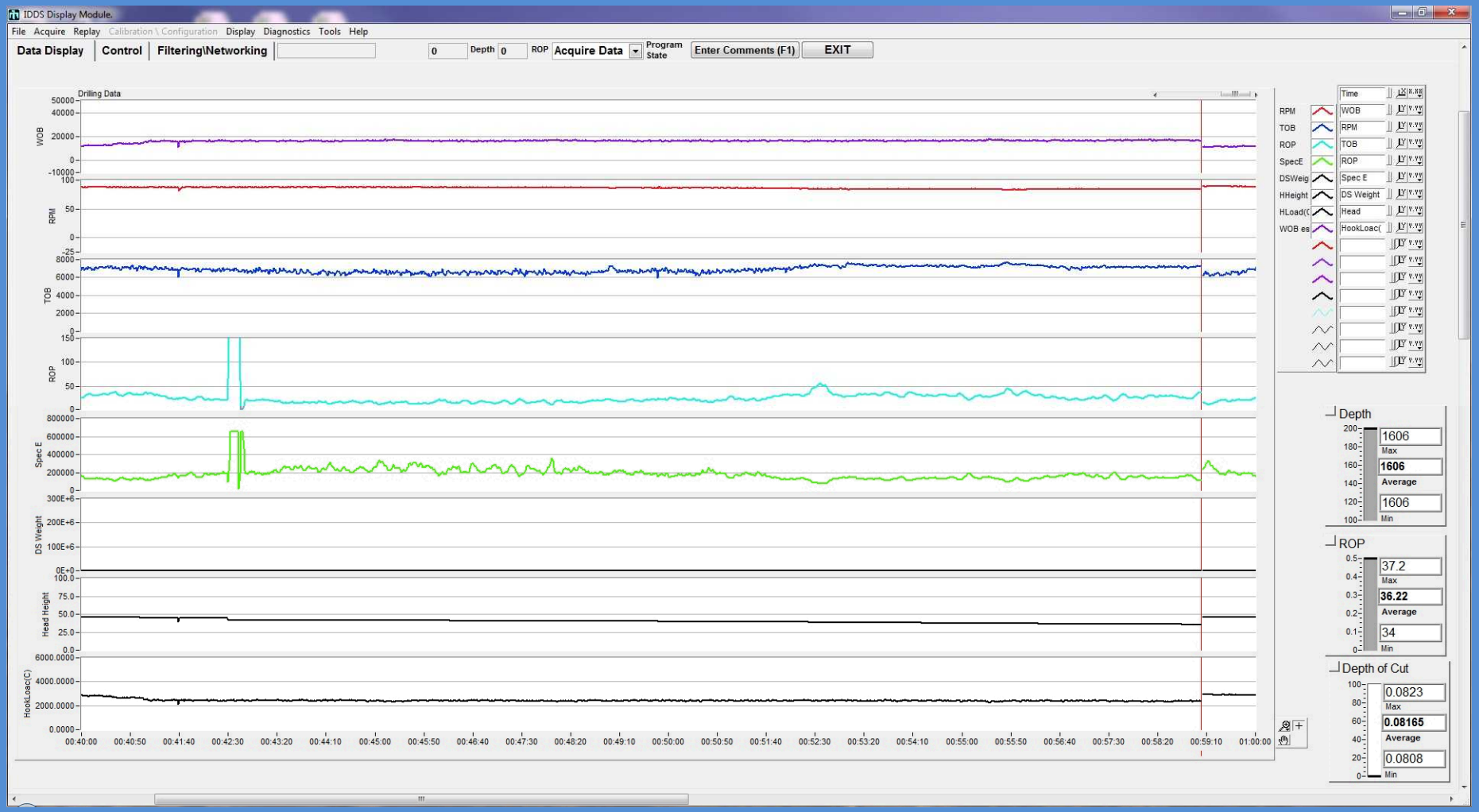
DATA SYSTEMS AND ACQUISITION



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



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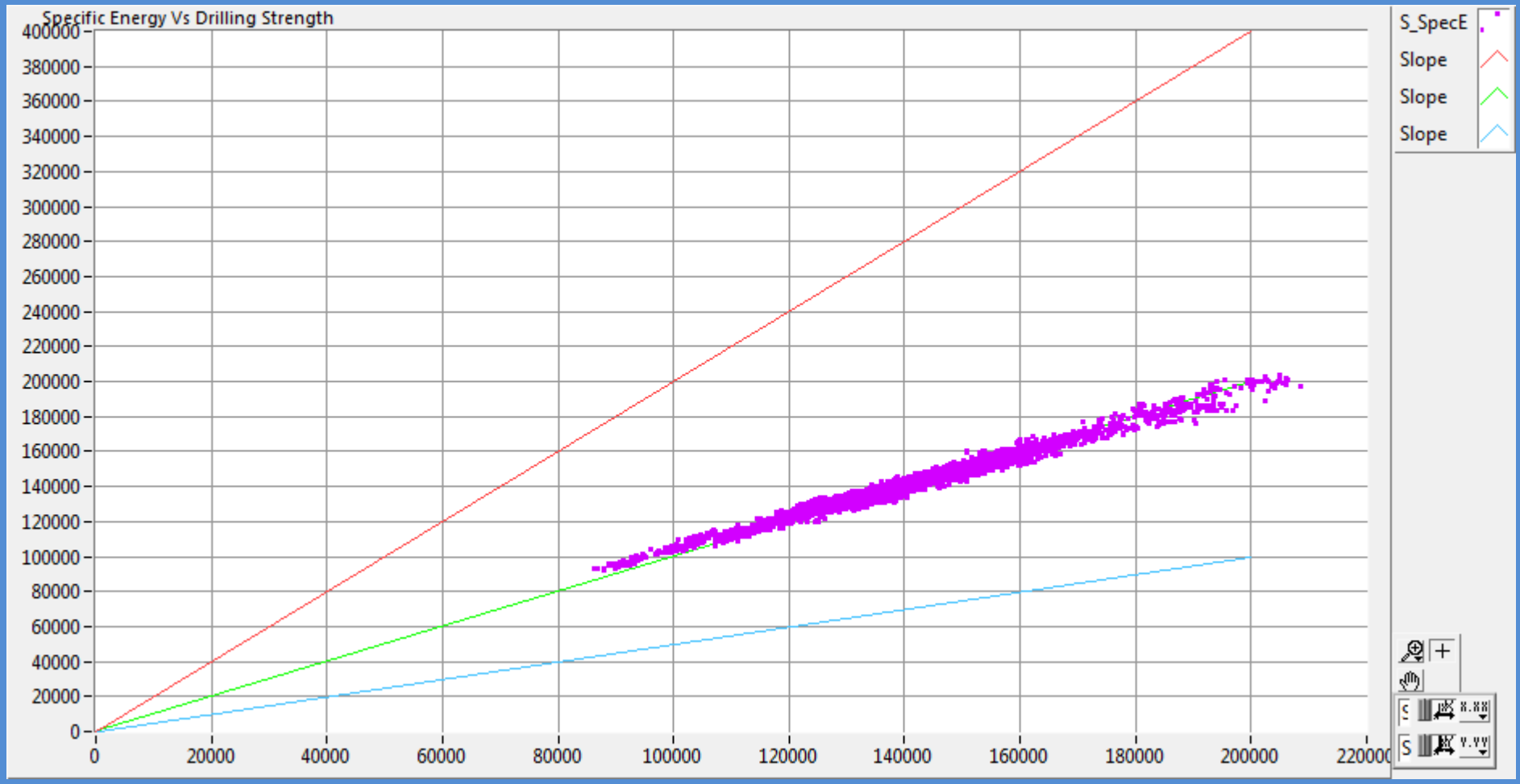
BIT 1 -- 6-DEC-2011 08:19



BLACK BOX HARDWARE

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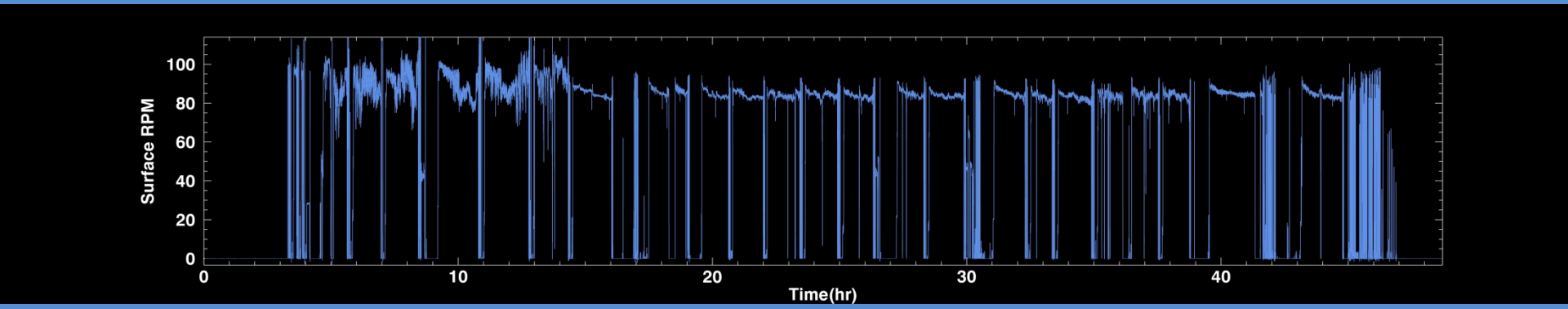
Drilling Summary

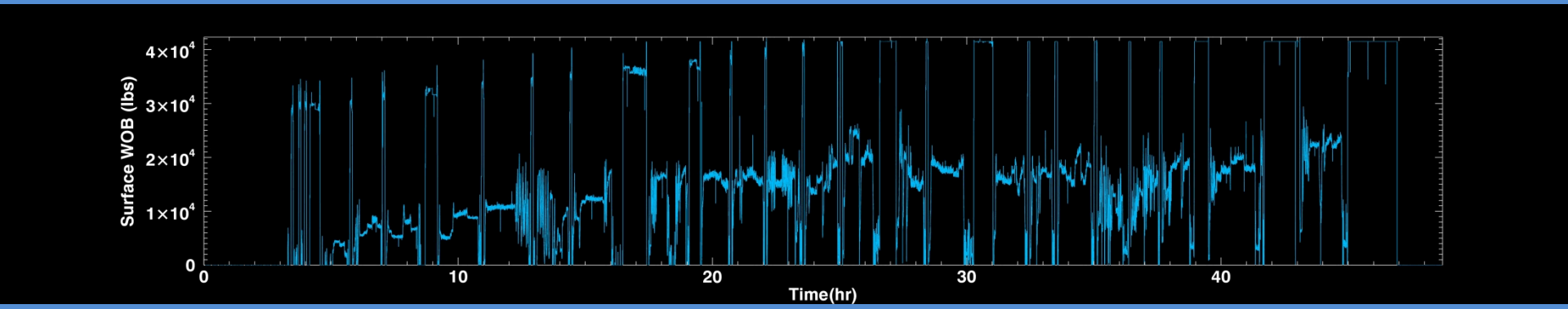
Date	Start ft	Finish ft	Bit Size inches	Drilling Hours	Daily ROP	Activity
11/27/2011	0	0	12.25			Rig Up
11/28/2011	115	647	12.25	18.5	28.76	
11/29/2011	647	844	12.75	18	10.94	
11/30/2011	844	916	12.75	15	4.80	
12/1/2011	916	1225	12.75	21.5	14.37	
12/2/2011	1225	1225				Surface Logging
12/3/2011	1225	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	

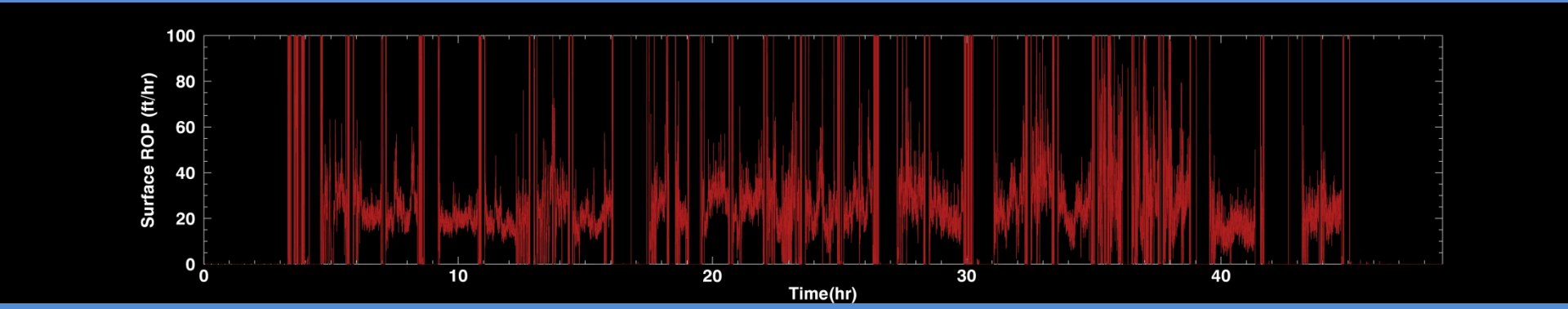
Bit Vendor	Type	Depth in	Depth Out	Feet Drilled
HTC	GX-C1V	115	734	619
Smith	GF-S15	734	911	177
Security	S84F	911	1225	314
HTC	WE824	1190	1245	55
HTC	GT-09	1234	1345	111
Reed	813	1345	2070	725
Reed	713	2070	2643	573
Security	XSD30D	2643	2929	286
HTC	GT09	2929	3020	91

BIT 1 – NEW – 6-DEC-2011

BIT 1







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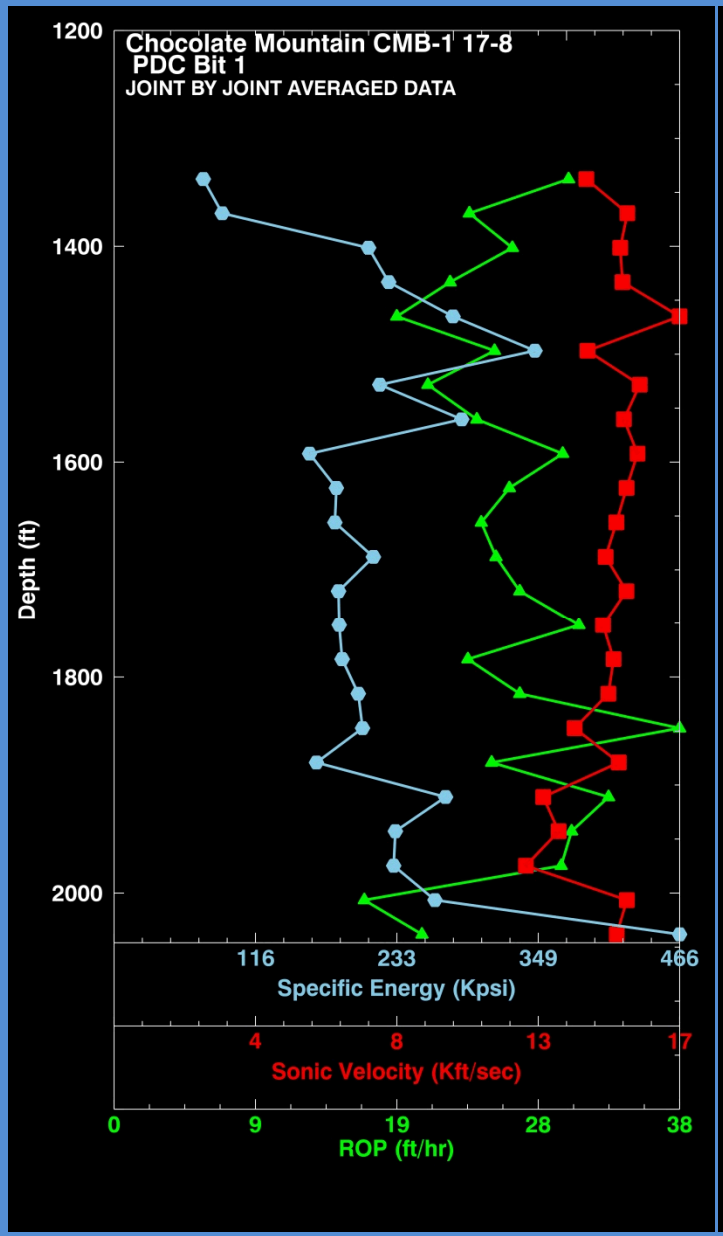

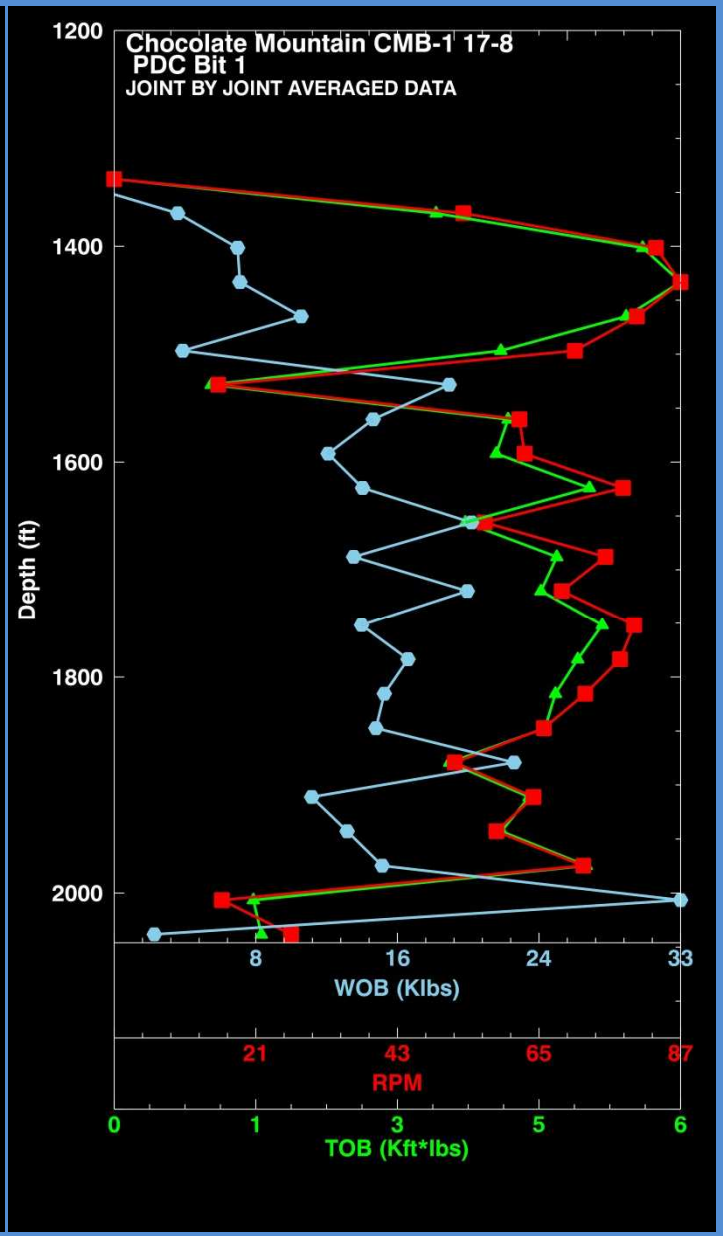

Start Depth	Stop Depth	ROP	Total Depth
1337.7	1369.4	30.7	31.7
1369.4	1401.4	24	63.7
1401.4	1433.2	26.9	95.5
1433.2	1465	22.7	127.3
1465	1496.8	19.1	159.1
1496.8	1528.3	25.7	190.6
1528.3	1560.4	21.2	222.7
1560.4	1592.2	24.5	254.5
1592.2	1624	30.3	286.3
1624	1656	26.7	318.3
1656	1687.9	24.8	350.2
1687.9	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		26.45217	
MIN		16.9	
MAX		38.2	

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

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

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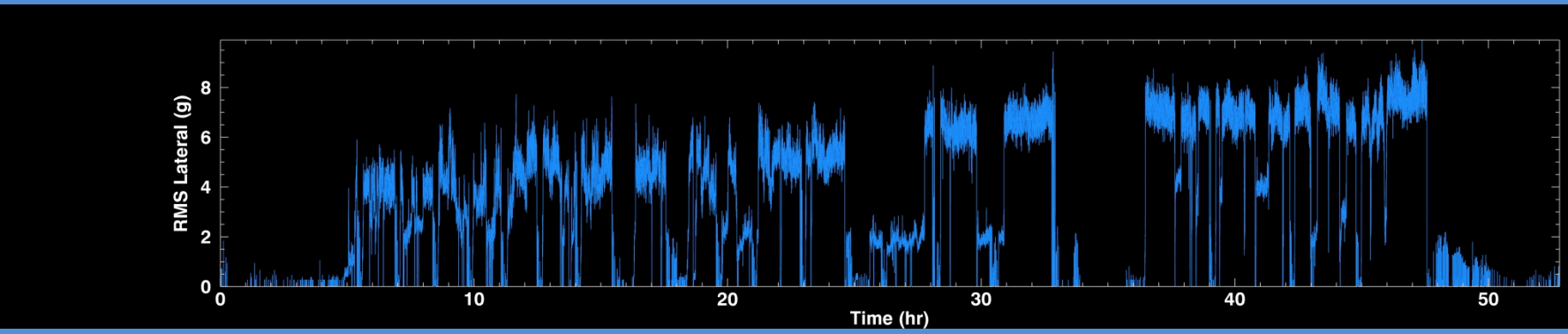
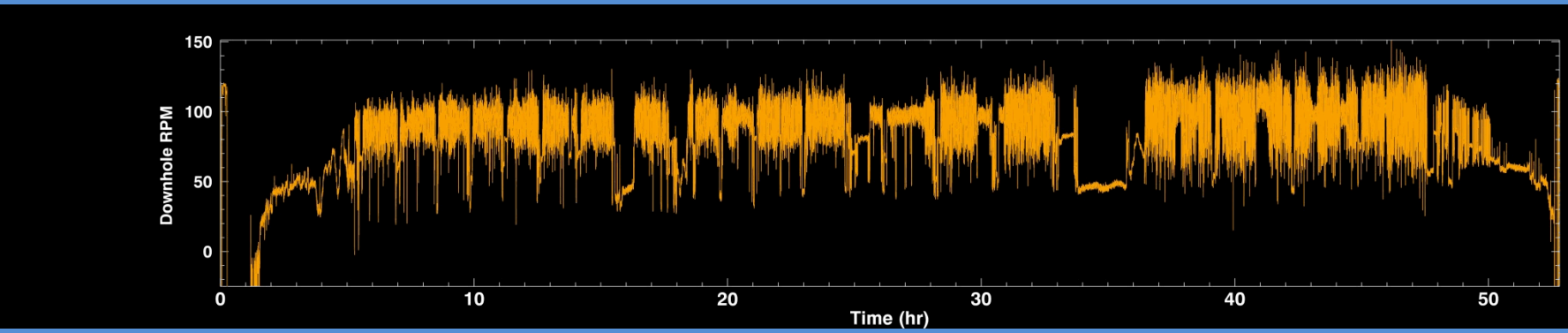
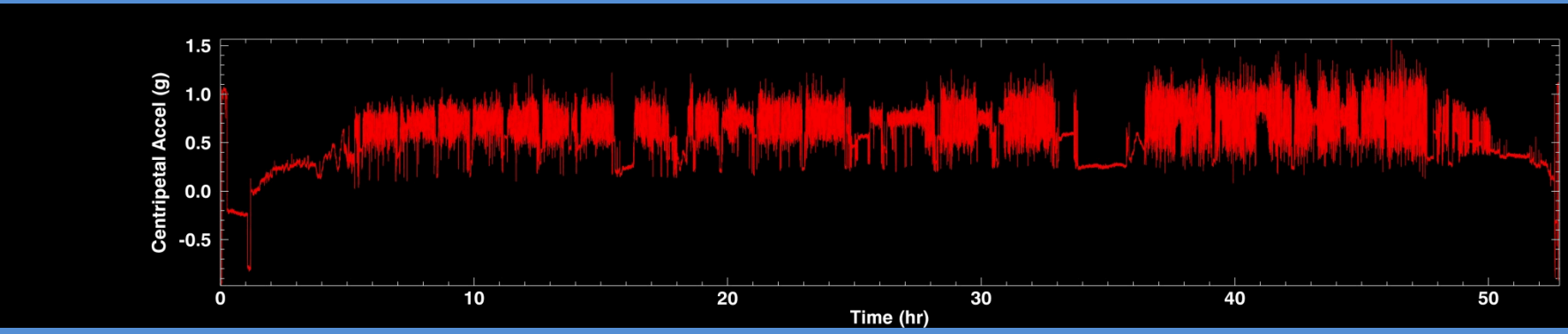
BIT 2







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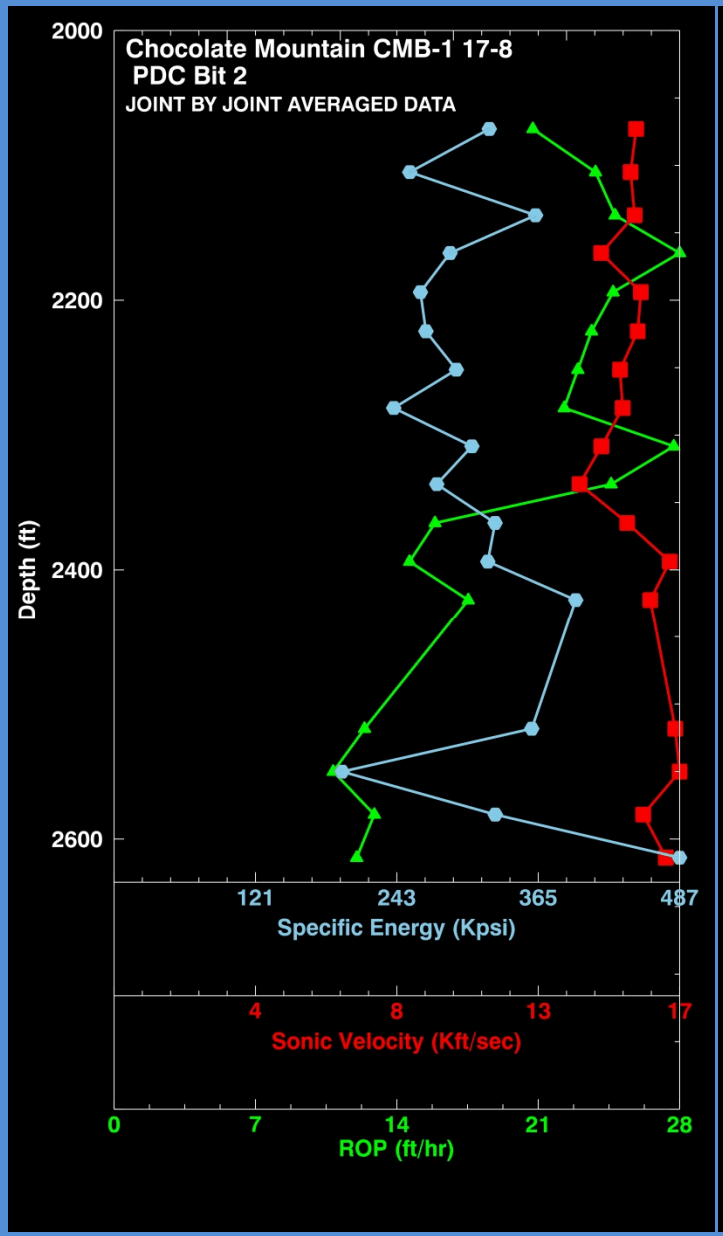

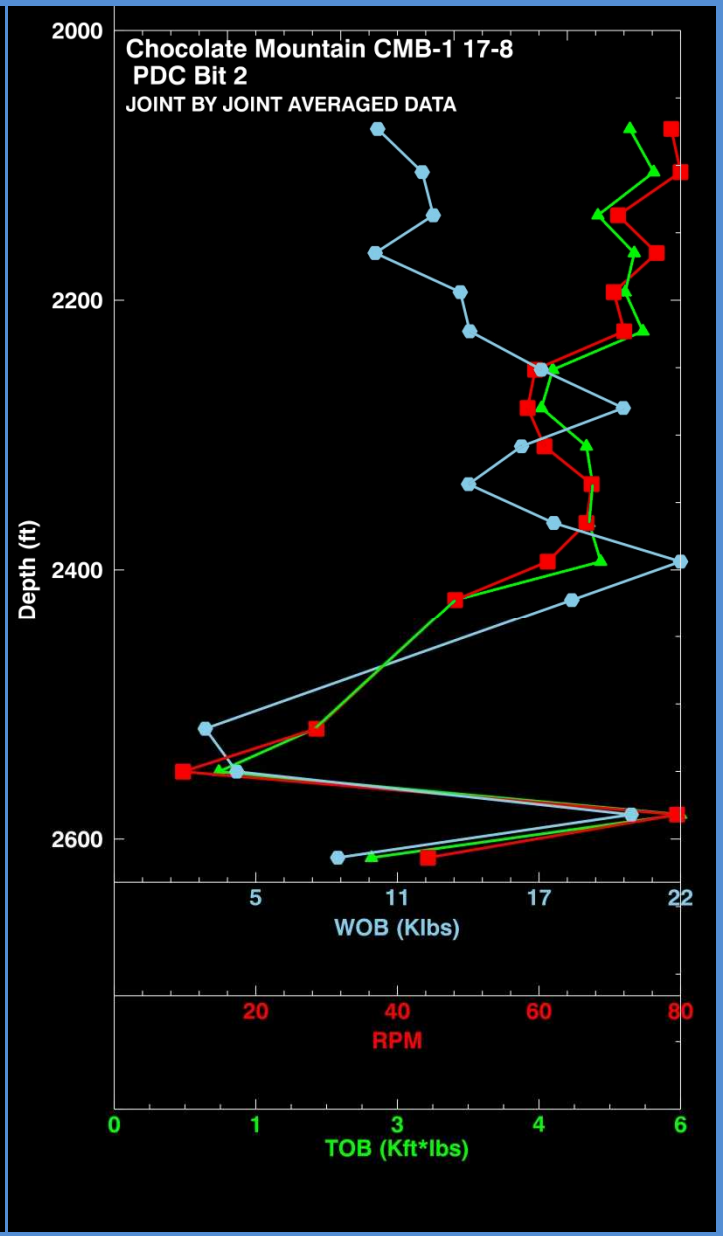

Start Depth	Stop Depth	ROP	Total Drilled
2073	2105	21.4	32
2105	2137	24.6	64
2137	2165	25.6	92
2165	2194	28.9	121
2194	2223	25.5	150
2223	2251.5	24.4	178.5
2251.5	2279.9	23.7	206.9
2279.9	2308.3	23	235.3
2308.3	2336.4	28.6	263.4
2336.4	2365.2	25.4	292.2
2365.2	2393.8	16.4	320.8
2393.8	2422.4	15.1	349.4
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		20.36842	
MIN		11.2	
MAX		28.9	

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

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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	9.88144	63.9
2706.9	2738.8	14.9719	95.8
Average		10.71778	
MIN		7.3	
MAX		14.9719	

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	

Path Forward

PHASE TWO

- New bit design developed and manufactured
- Integrated optimal features in both phase one bits yielding PDC bit design for geothermal drilling
- Torque control components are part of phase two design to control rig torque up

PHASE THREE

- Awaiting possible field test opportunities with industry

Conclusions

- **Advanced Drilling Technology Demonstrations Successful**
  - Field trial with National Lab/Operator/Service Company participation
  - Advanced PDC Bits for geothermal drilling
  - Downhole tool deployment for monitoring
  - Operating Conditions and Specific Energy monitoring using advanced surface rig displays
  - Driller coordination and communication for improvements

- **Results**
  - Demonstrated PDC bits can drill geothermal/prevail over roller cone bits
    - Improved ROP
    - Longer Life
  - Matching PDC bits with rig capability is necessary for best performance
  - Specific Energy monitoring with driller coordination/communication has demonstrated performance gains/cost reductions

Thank You

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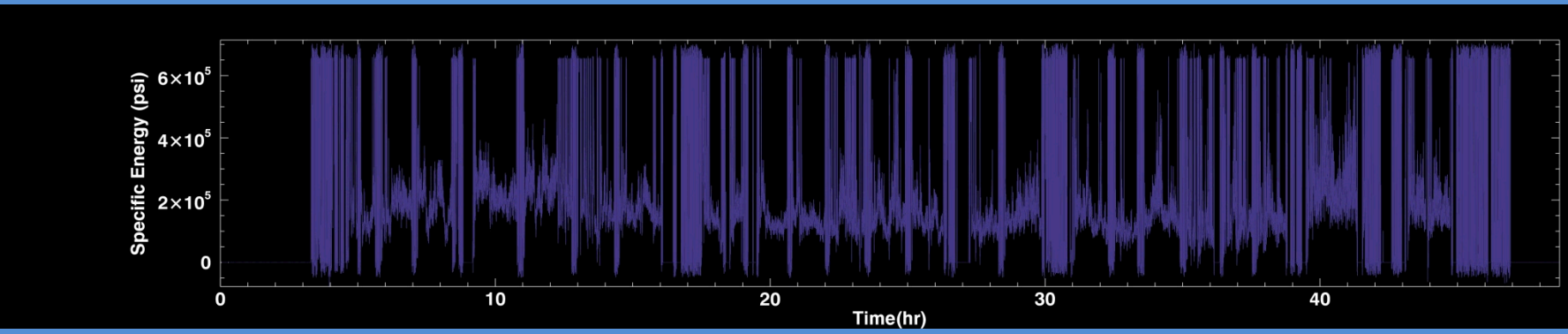
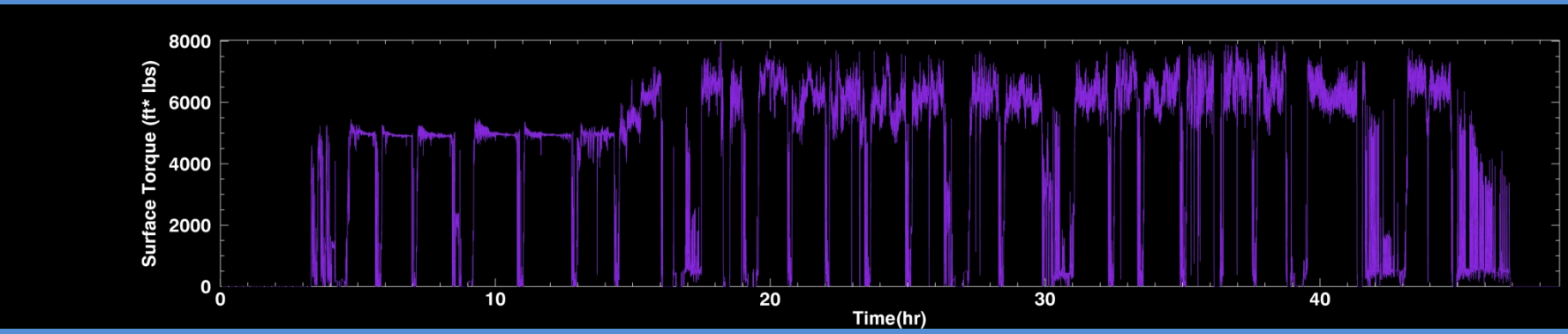
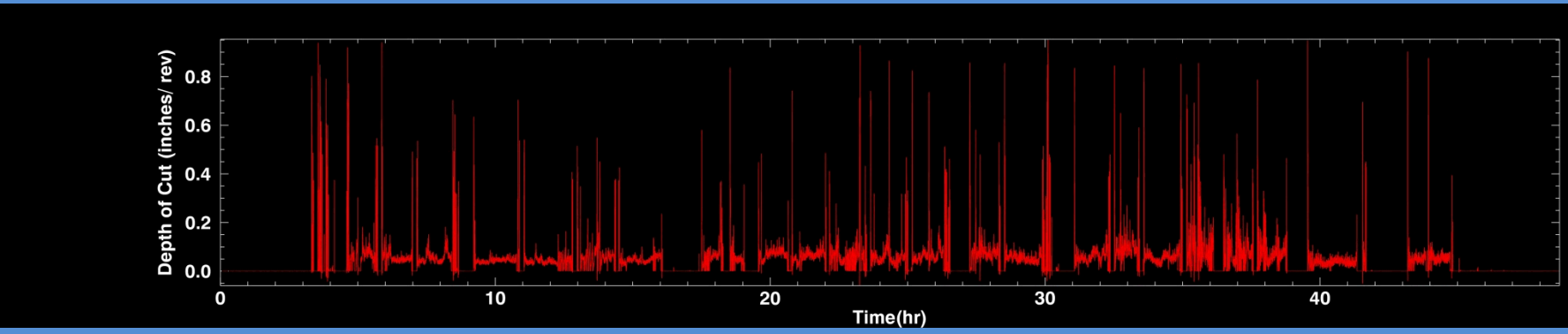
Backup Slides

BIT1







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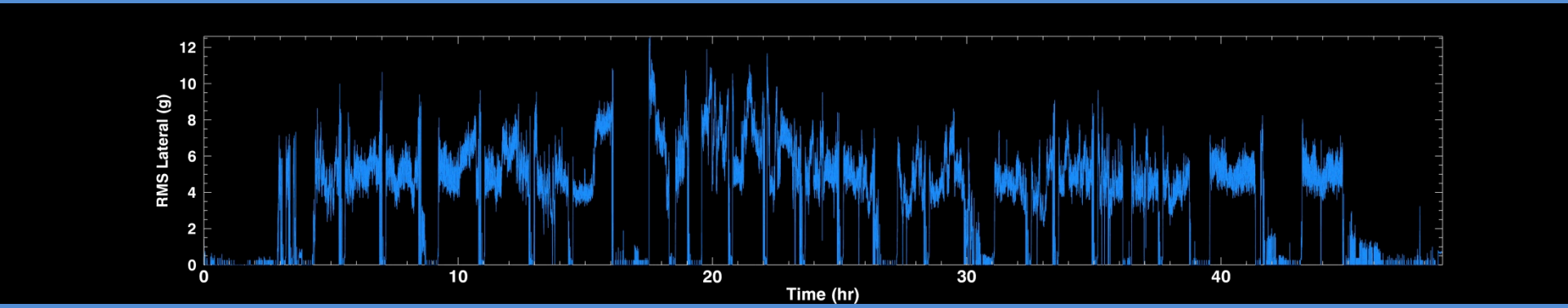

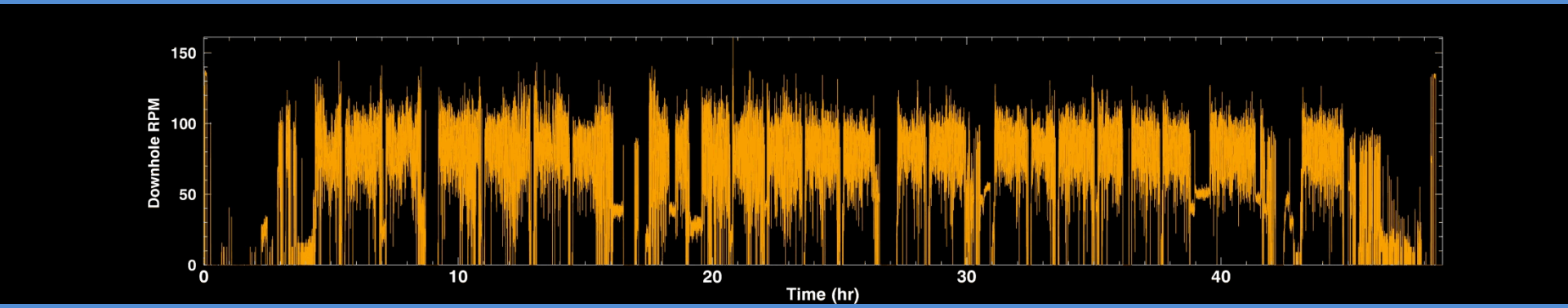

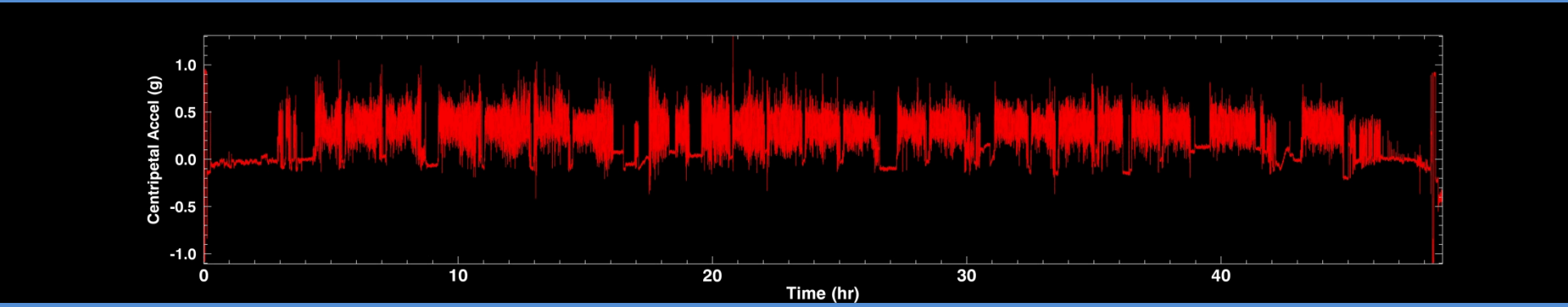

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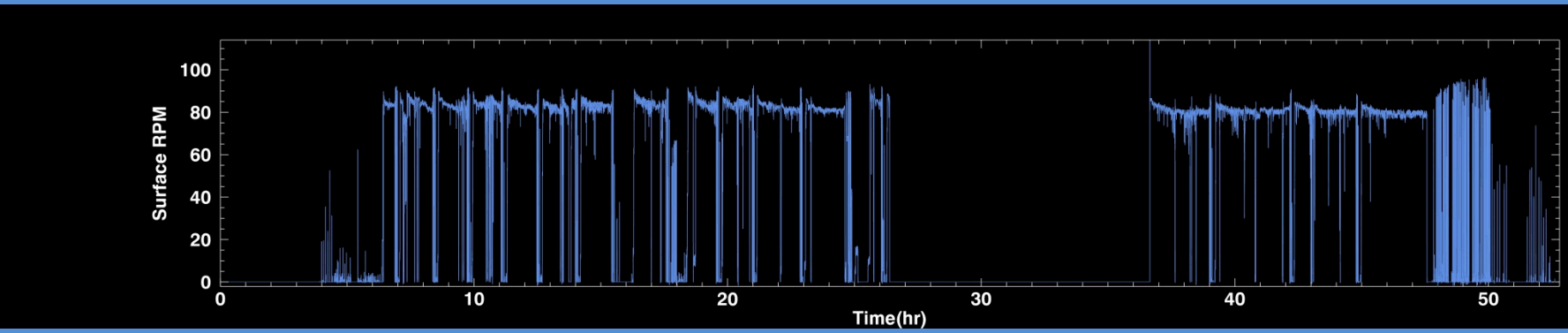
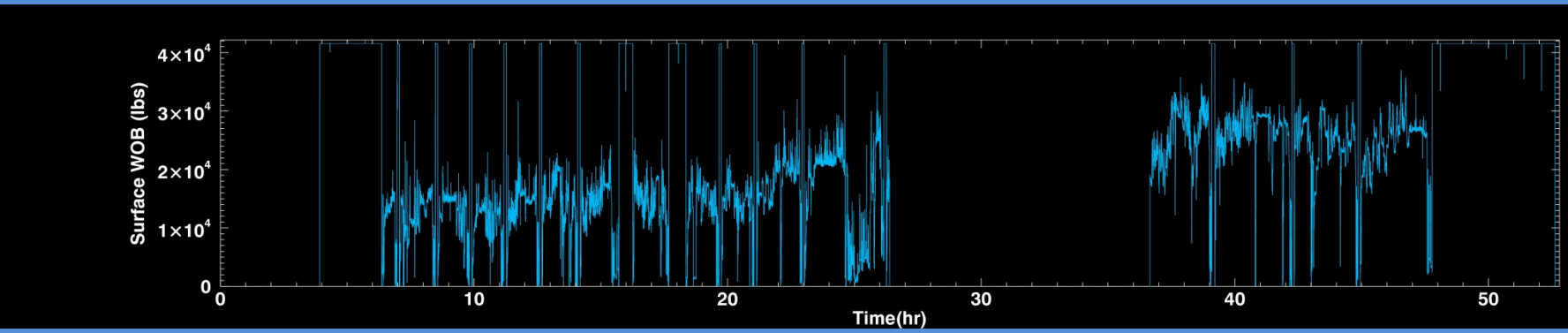
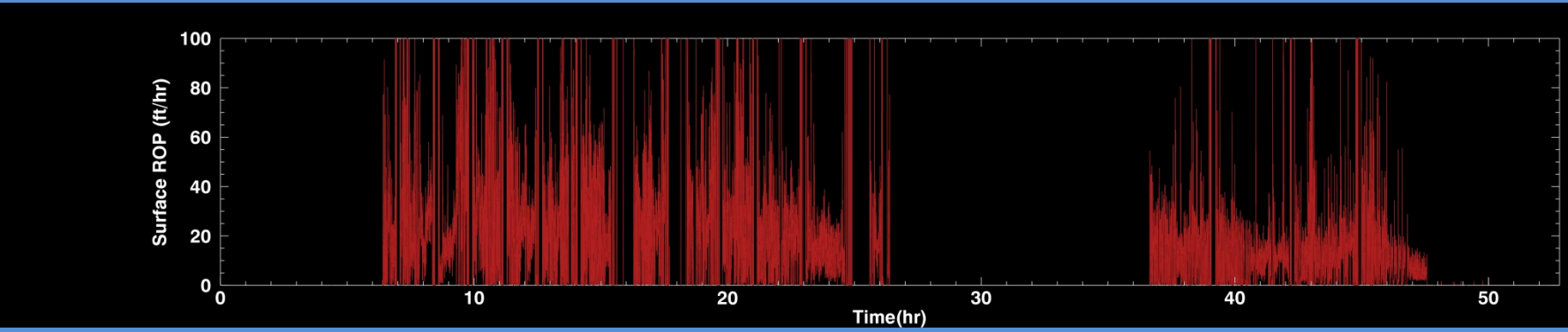
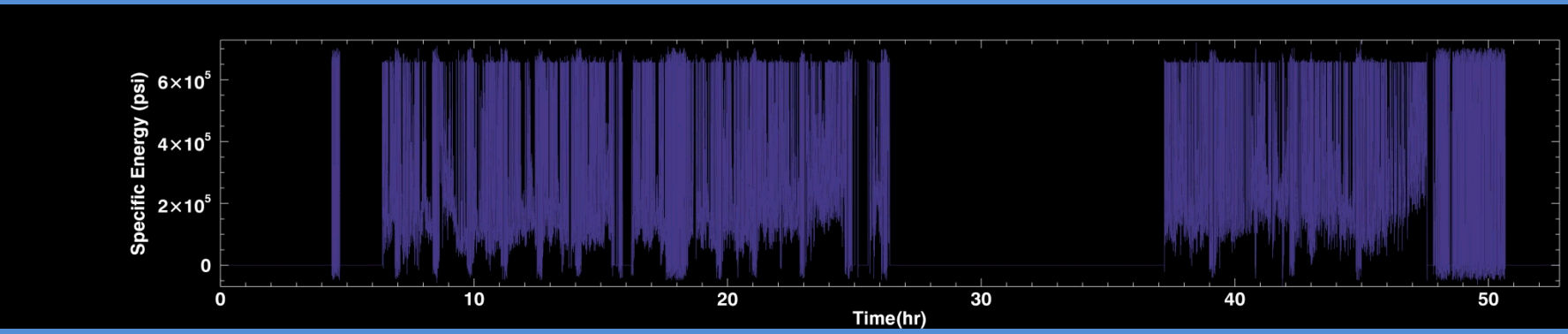
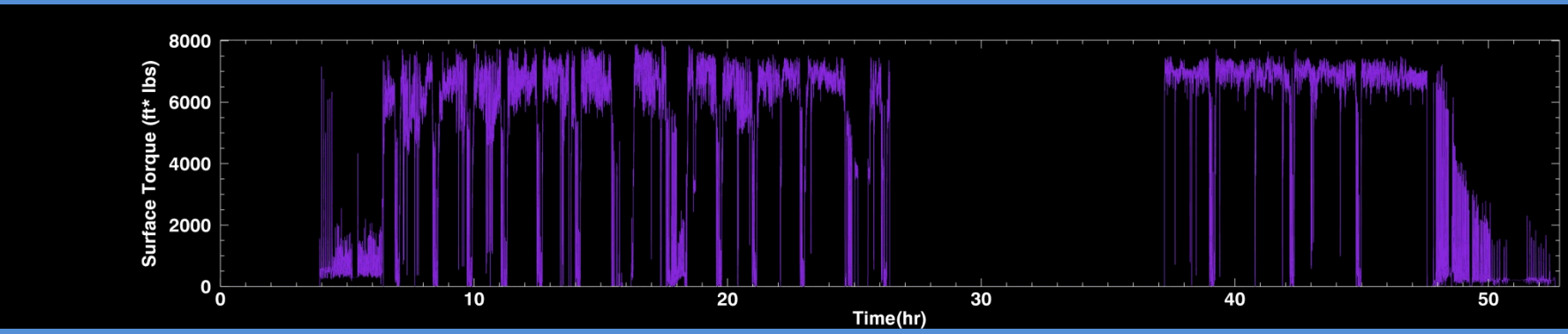

Surface RPM
100
80
60
40
20
0
0
10
20
30
40
50
Time(hr)

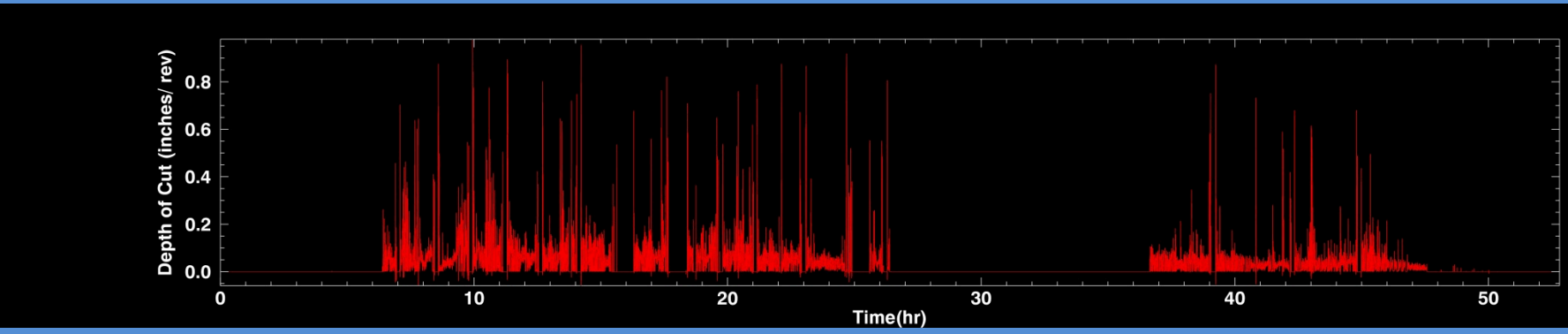

Surface WOB (lbs)
4×10^4
3×10^4
2×10^4
1×10^4
0
0
10
20
30
40
50
Time(hr)


Surface ROP (ft/hr)
100
80
60
40
20
0
0
10
20
30
40
50
Time(hr)

BIT 2







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