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U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

2022 PROJECT PEER REVIEW
U.S. DEPARTMENT OF ENERGY
GEOTHERMAL TECHNOLOGIES OFFICE

Drilling Technologies Evaluation – Utah FORGE

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Angel Nieto/Project Officer, Total Project Funding $400k, Date of Presentation 05/16/2022

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Section 1: Program Policy Factors

Relevance to Geothermal Technologies Offices' (GTO) Objectives

- The Multi-Year Program Plan outlines the primary goals of GTO to support the growth and long-term contribution of geothermal energy. To what degree do the objectives of this effort align with the goals of GTO?
  - Improve technology transfer to the geothermal drilling industry by surveying technologies and processes in comparable drilling industries that can be applied to improve means for drilling and completion of geothermal wells.
  - Current project focus is on evaluating PDC bit performance at Utah FORGE
- How will the project strengthen the geothermal body of knowledge?
  - Improve drilling operations
  - Improve well construction quality
  - Improve offset drilling performance

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Relevance to Industry Needs

- To what degree do the objectives address the needs of the geothermal industry at large? Will the project achieve additional goals that are not specifically outlined by the GTO objectives? How has the project improved the identification, access, and development of geothermal resources? How has the project overcome technical and non-technical barriers?
  - This project provides a mechanism to lower the cost of geothermal drilling by introducing technologies and processes that have proven useful in related drilling industries.
  - It also can provide technology support to benefit other DOE-funded drilling programs.

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Resilience to COVID-19

- The COVID-19 pandemic presented various operational and logistical challenges to many institutions that received federal funding. Were project modifications necessary to ensure the success of the project and were they a result of the COVID-19 pandemic? How did the project team adapt to the barriers that were caused by COVID-19?
  - Project started during COVID-19 pandemic
  - Project staff would have normally travelled to the Utah FORGE drill site to improve understanding of technology in use but were limited by mission critical travel restrictions

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Diversity, Equity, and Inclusion

- Executive Order 13985 describes federal advancing of racial equity and support for underserved communities. To what degree has the project promoted Diversity, Equity, and Inclusion (DEI)? Has the project bolstered underserved communities? If the project does not explicitly include DEI initiatives, are there inherent attributes of the project that demonstrate inclusivity? If the DEI plans are limited in capacity, is there availability to promote inclusivity and diversity in the future?
  - Diversity, Equity, and Inclusion are part of guiding principles at Sandia National Laboratories
  - Project has been supported by Jaiden Norton, M.S. Mechanical Engineering Candidate and Student Intern

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Section 2: Technical Review

Methods/Approach

Task: Surface Data Access and Review of Utah FORGE bit performance

- Project Management Summary
  - Collaborate with Utah FORGE and the digital mudlogging subcontractor to access and review surface drilling data from well construction operations
  - Become familiar with sensor types, data formats and displays
  - Potentially act in advisory capacity on future Utah FORGE wells
- Technical Approach to Project Objective
  - Comprehensive data collection effort
    - Daily drilling reports, EDR data downloads, Channel assignment reviews
  - Use rock reduction model to interpret bit response
  - Develop Code/Script for Advanced Analytics
    - Data Filter
    - Data Displays and Interpretations
    - Data Reporting (Bit wear state, specific energy, etc)
  - Drilling Interval cost tracking
    - ROP vs Life constraint

- Well Data Access Status:
  - 16A(78)-32 Status
    - Nabors RigCLOUD data accessed, downloaded, analyzed, summarized
    - Prepared Sandia FORGE Profile
    - Data standardization underway; Evaluations continue
  - 56-32 Status
    - Pason US DataHub data accessed, downloaded, analyzed, summarized
    - Prepared Sandia FORGE Profile
    - Data standardization underway; Evaluations continue
  - 78B-32 Status
    - Pason US DataHub data accessed, downloaded, analyzed, summarized
    - Prepared Sandia FORGE Profile
    - Data standardization underway; Evaluations continue
  - Data Viewer
    - Developed in LabVIEW
    - Available for use by staff to supplement EDR viewers

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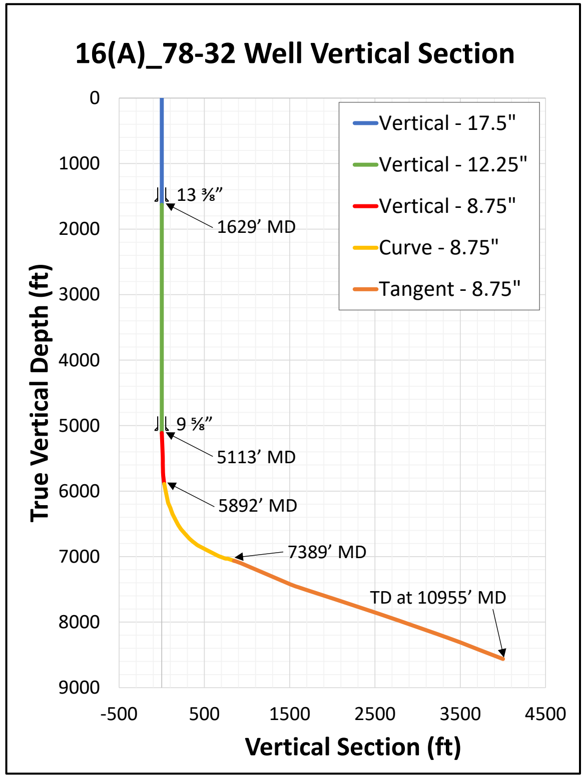
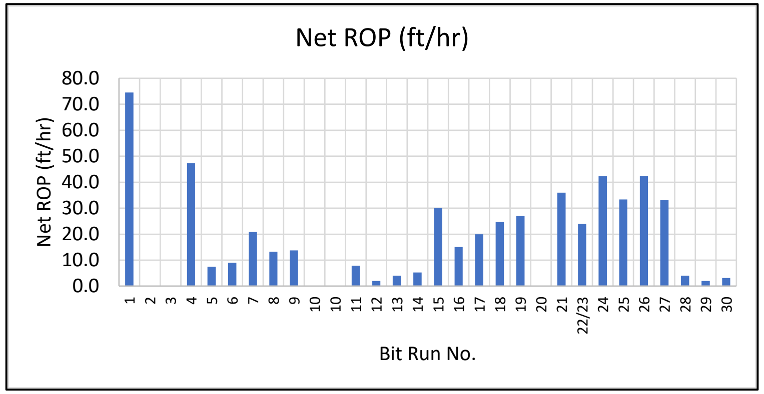
Technical Accomplishments and Progress

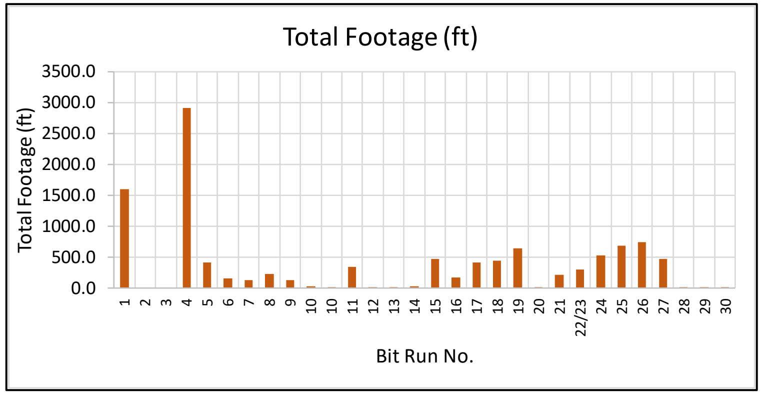
Task: Surface Data Access and Review of Utah FORGE bit performance

- Well 16A(78)-32
  - EDR data accessed and processed
  - Results reported



Bit Run No.	Manufacturer	Type	Serial No.	BHA	Bit Dia. (in)	Depth Start (ft)	Depth End (ft)	Total Footage (ft)	Time on Bottom (hrs)	Net ROP (ft/hr)
1	NOV ReedHycalog	TKC76-C5 PDC	A275580	Surface BHA	17.50	28.0	1629.0	1601.0	21.5	74.5
2	NOV ReedHycalog	TKC66-R1 PDC	E266453	2	12.25	-	-	-	3.0	-
3	Smith	GF 15BODJPS TRI-CONE	RK6139	3	12.25	1629.0	1644.0	-	0.5	-
4	NOV ReedHycalog	TKC66-R1 PDC	E266453	4	12.25	1644.0	4552.0	2908.0	61.5	47.3
5	Smith	MDSi616	JM 7398	5	12.25	4552.0	4964.0	412.0	55.0	7.5
6	Smith	Z713S	JP4755	6	12.25	4964.0	5113.0	149.0	16.5	9.0
7	Ulterra	GTX63	R28DF	-	8.75	4987.0	5112.0	125.0	6.0	20.8
8	Smith	XS616	JV2705	9	8.75	5113.0	5345.0	232.0	17.5	13.3
9	Ulterra	U616M PDC	54132	10	8.75	5345.0	5469.0	124.0	9.0	13.8
10	CCI - Canamera 713	Core	462-06	11	8.75	5469.0	5495.0	26.0	0.0	0.0
10	CCI - Canamera 713	Core	462-06	12	8.75	5495.0	5504.0	9.0	0.0	0.0
11	NOV ReedHycalog	TKC66-P3 PDC	A271699	14	8.75	5504.0	5846.0	342.0	43.5	7.9
12	nine blade core bit	Core	Core	15	8.75	5846.0	5856.0	10.0	5.0	2.0
13	Ulterra	U616M	54131	16	8.75	5856.0	5858.0	2.0	0.5	4.0
14	CCI - Canamera 713	Core	Core	17	8.75	5858.0	5892.0	34.0	6.5	5.2
15	NOV ReedHycalog	TKC63-C7	A255857	18	8.75	5892.0	6360.0	468.0	15.5	30.2
16	NOV ReedHycalog	SKC613M-O1C	A232400	20	8.75	6360.0	6526.0	166.0	11.0	15.1
17	NOV ReedHycalog	SKC513M-O1C	A276122	22	8.75	6526.0	6945.0	419.0	21.0	20.0
18	NOV ReedHycalog	FTKC63-O1	A276121	23	8.75	6945.0	7389.0	444.0	18.0	24.7
19	NOV ReedHycalog	TKC63-C7	A255857	30	8.75	7389.0	8024.0	635.0	23.5	27.0
20	OTHER	Mill	Mill	-	-	8024.0	8025.0	1.0	-	-
21	NOV ReedHycalog	SKC513M-O1C	A276122	34	8.75	8025.0	8241.0	216.0	6.0	36.0
22/23	NOV ReedHycalog	SKC613M-O1C	A230682	35	8.75	8241.0	8535.0	294.0	6.0	24.0
24	NOV Reed Hycalog	TKC63-O1	A270819	38	8.75	8535.0	9064.0	529.0	12.5	42.3
25	NOV Reed Hycalog	TKC63-O1	A270978	39	8.75	9064.0	9748.0	684.0	20.5	33.4
26	NOV Reed Hycalog	TKC63-P1	A271436	41	8.75	9748.0	10490.0	742.0	17.5	42.4
27	NOV Reed Hycalog	TKC63-P1	A271437	42	8.75	10490.0	10955.0	465.0	14.0	33.2
28	CCI - Canamera 713	Core 713	3409-01	47	8.75	10955.0	10971.0	16.0	4.0	4.0
29	Ulterra	PDC U613M	47954	48	8.75	10971.0	10973.0	2.0	1.0	2.0
30	CCI - Canamera 713	Core 713	77302	49	8.75	10973.0	10987.0	14.0	4.5	3.1





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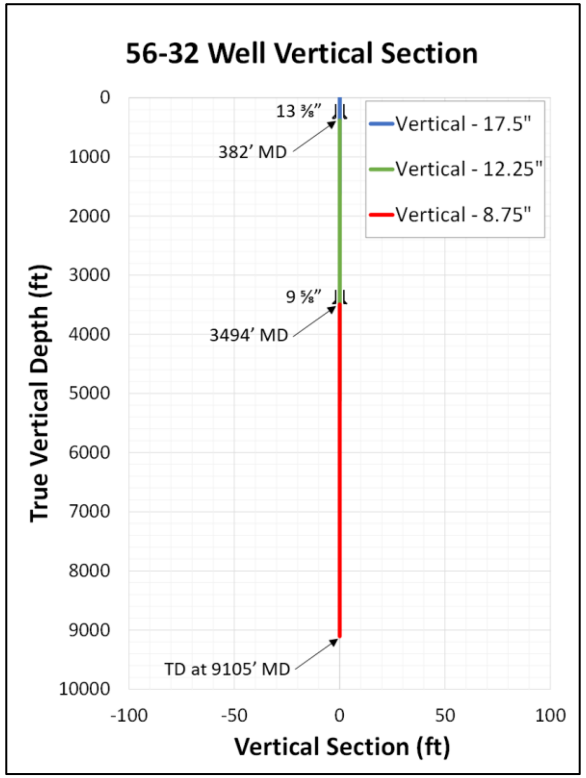
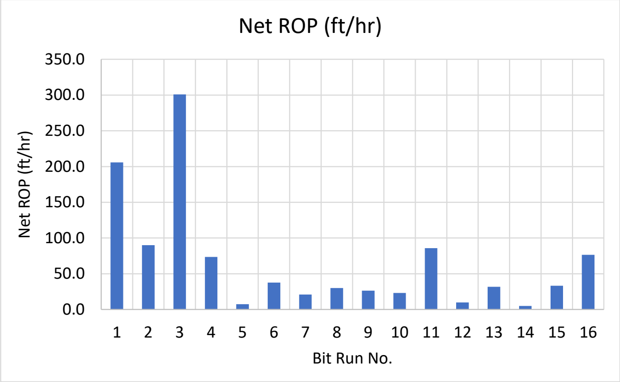
Technical Accomplishments and Progress

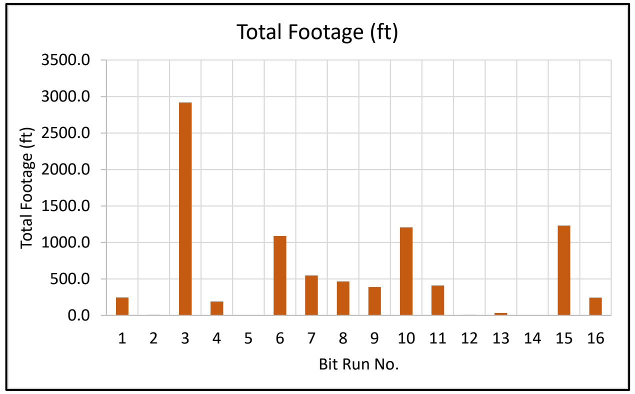
Task: Surface Data Access and Review of Utah FORGE bit performance

- Well 56-32
  - EDR data accessed and processed
  - Results reported



Bit Run No.	Manufacturer	Type	Serial No.	BHA	Bit Dia. (in)	Depth Start (ft)	Depth End (ft)	Total Footage (ft)	Time on Bottom (hrs)	Net ROP (ft/hr)
1	ReedHycalog	TK59-B1	A252419	1	17.50	134.0	381.0	247.0	1.2	205.8
2	-	M-22	-	-	12.25	381.0	390.0	9.0	0.1	90.0
3	ReedHycalog	TKC66-R1	A266974	2	12.25	390.0	3309.0	2919.0	9.7	300.9
4	ReedHycalog	TK63-A1A	A268226	3	12.25	3309.0	3500.0	191.0	2.6	73.5
5	-	GX-177	-	4	8.75	3500.0	3506.0	6.0	0.8	7.5
6	ReedHycalog	TKC73-H1	A275660	4	8.75	3506.0	4595.0	1089.0	28.9	37.7
7	-	EP5475	5042714	5	8.75	4595.0	5143.0	548.0	26.2	20.9
8	ReedHycalog	TKC63-P1	A277166	6	8.75	5143.0	5610.0	467.0	15.5	30.1
9	ReedHycalog	TKC63-P1	A271436	7	8.75	5610.0	5999.0	389.0	14.8	26.3
10	ReedHycalog	FTKC73-A1	A275803	8	8.75	5999.0	7208.0	1209.0	52.1	23.2
11	ReedHycalog	FTKC73-A1	A276121	9	8.75	7208.0	7620.0	412.0	4.8	85.8
12	E6	Hammer	-	-	8.75	7620.0	7628.0	8.0	0.8	10.0
13	ReedHycalog	FTKC63-A1	A276121	-	8.75	7628.0	7663.0	35.0	1.1	31.8
14	E6	Hammer	-	-	8.75	7663.0	7667.0	4.0	0.8	5.0
15	ReedHycalog	TKC63-P1	A271437	10	8.75	7667.0	8900.0	1233.0	37.0	33.3
16	ReedHycalog	FTKC83-A3	A276071	11	8.75	8900.0	9145.0	245.0	3.2	76.6





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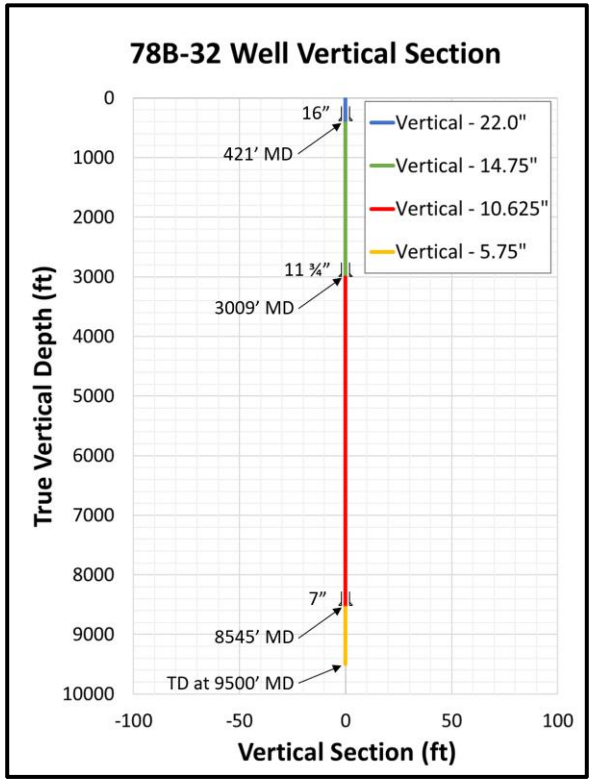
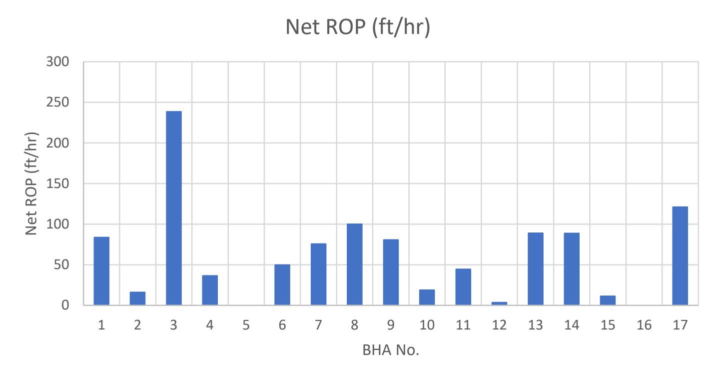
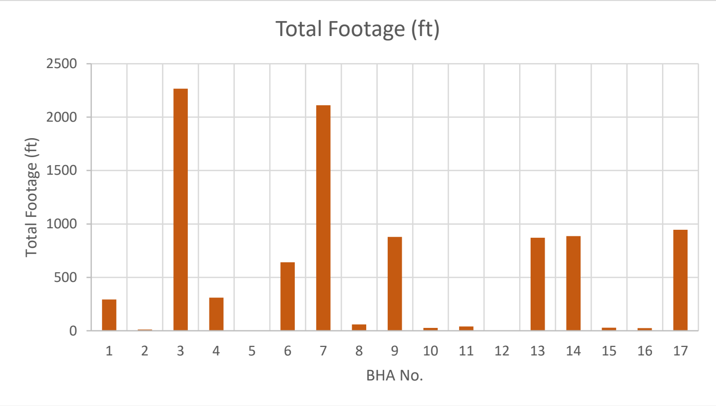
Technical Accomplishments and Progress
Task: Surface Data Access and Review of Utah FORGE bit performance

- Well 78B-32
  - EDR data accessed and processed
  - Results reported



Bit Run No.	Manufacturer	Type	Serial No	BHA	Bit Dia.	Depth Start (ft)	Depth End (ft)	Total Footage (ft)	Time on Bottom (hrs)	Net ROP (ft/hr)
1	Smith	XR-C	-	1	22	128	421	293	4	84
2	BAKER	GT-C1	-	2	14.75	421	433	12	1	16
3	NOV	TKC66	A279635	3	14.75	433	2699	2266	10	239
4	NOV	TKC63	A279636	4	14.75	2699	3009	310	9	36
5	VAREL	VM-1	-	5	10.625	3009	3009	0	2	0
6	NOV	TKC83	A279637	6	10.625	3009	3651	642	13	50
7	NOV	TKC83	A279639	7	10.625	3651	5761	2110	28	76
8	NOV	TKC83	A279690	8	10.625	5761	5821	60	1	100
9	NOV	TKC83	A279692	9	10.625	5821	6700	879	11	81
10	HALLBTN	FC3843	13340636	10	8.75	6700	6728	28	2	19
11	HALLBTN	FC3843	12958459	11	8.75	6700	6740	40	1	44
12	BAKER	MYR547	1116990	12	10.625	6740	6742	2	1	3
13	NOV	TKC83	A279638	13	10.625	6742	7613	871	10	89
14	NOV	TKC83	A279691	14	10.625	7613	8500	887	10	89
15	HALLBTN	FC3843	13206404	15	10.625	8500	8530	30	3	11
16	-	Various	-	16	5.75	8530	8555	25	-	-
17	NOV REED	TKC63	A279641	17	5.75	8555	9500	945	8	121





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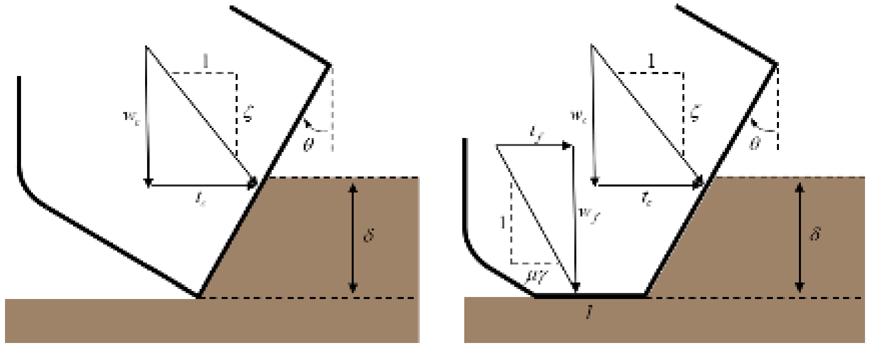
Methods/Approach

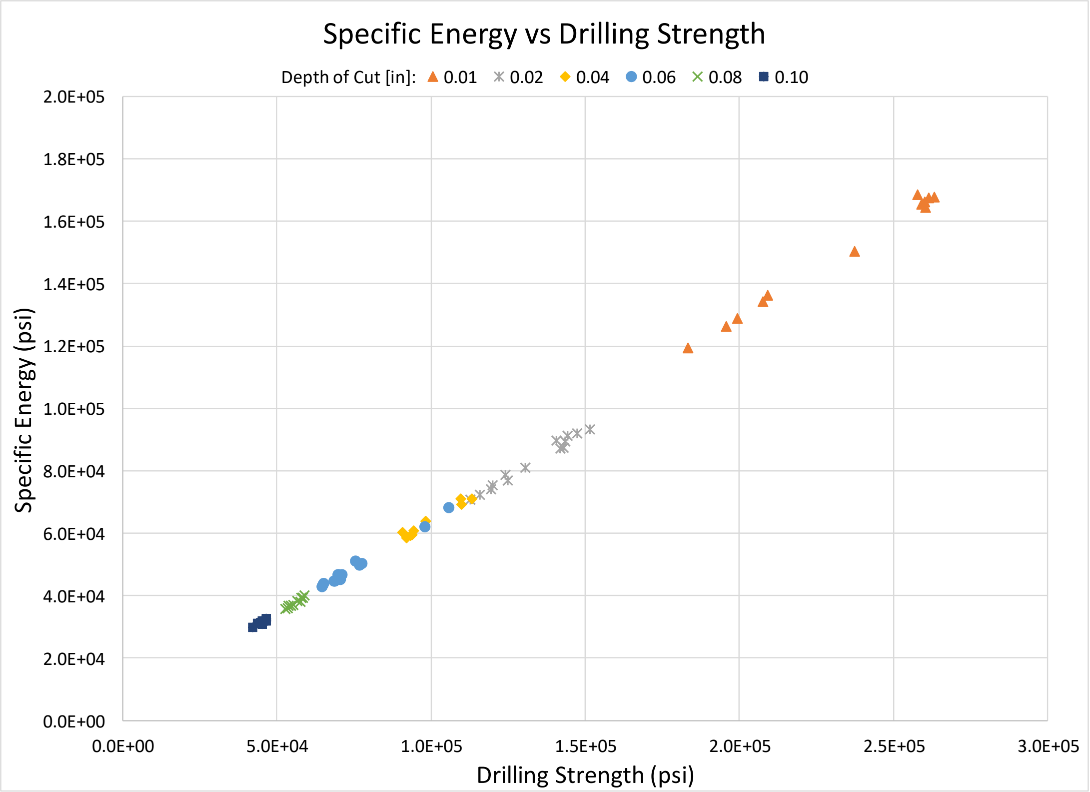
Task: Surface Data Access and Review of Utah FORGE bit performance

- Rock Reduction Model Constraint (Detournay and Defourny, 1992)



ε intrinsic specific energy ζ cutting force ratio
μ friction coefficient
F_n vertical cutter force
F_s horizontal cutter force
A frontal area of cut
E Specific Energy
S Drilling Strength

- $E = \frac{F_s}{A}$ (1) Specific Energy
- $S = \frac{F_n}{A}$ (2) Drilling Strength
- $E = \varepsilon$ $S = \zeta\varepsilon$ (3) Sharp Cutter
- $E = E_0 + \mu S$ (4) Blunt Cutter
- $E_0 = (1 - \mu\zeta)\varepsilon$ (5) Intercept



Single Cutter Data (Glowka, 1987)

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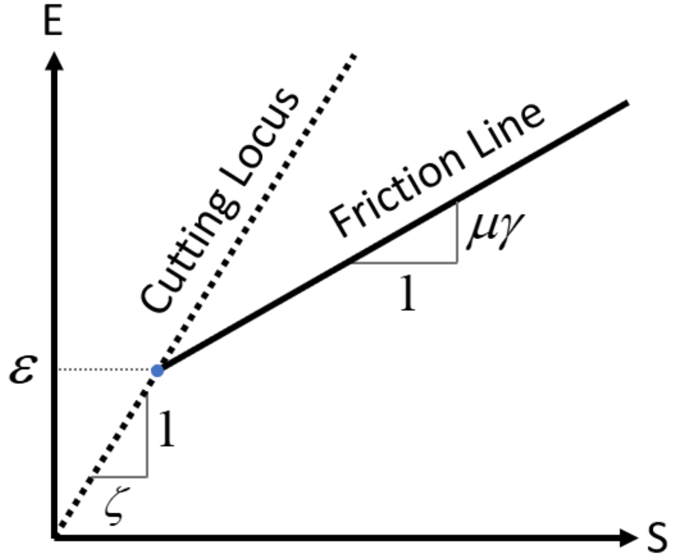
Methods/Approach

Task: Surface Data Access and Review of Utah FORGE bit performance

- Full Bit Model (Detournay and Defourny, 1992)

r bit radius
δ depth of cut per revolution
W Weight on Bit
T Torque
γ unitless bit constant



- $\frac{2T}{r} = (1 - \mu\gamma\zeta)\varepsilon\delta r + \mu\gamma W$ (6) Torque constraint
- $E = \frac{2T}{r^2\delta}$ (7) Bit Specific Energy
- $S = \frac{W}{r\delta}$ (8) Bit Drilling Strength
- $E = E_0 + \mu\gamma S$ (9) Friction Line
- $E_0 = (1 - \beta)\varepsilon$ (10) Intercept
- $\beta = \gamma\mu\zeta$ (11) $\mu\,\gamma$ Friction Line Slope

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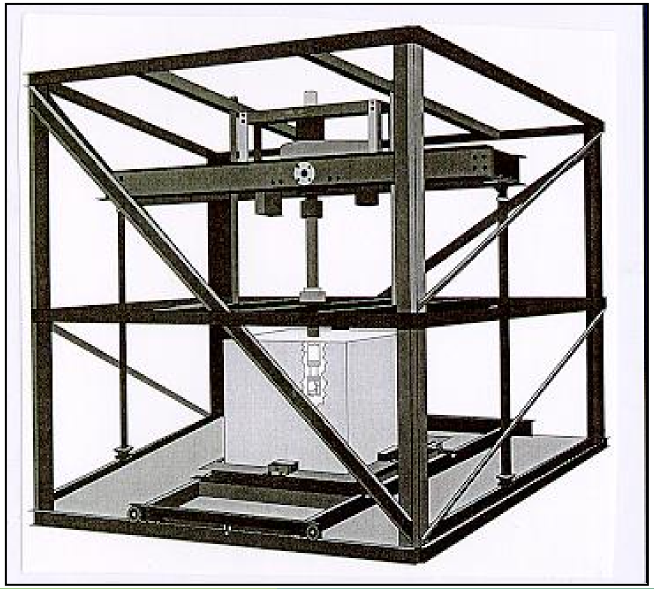
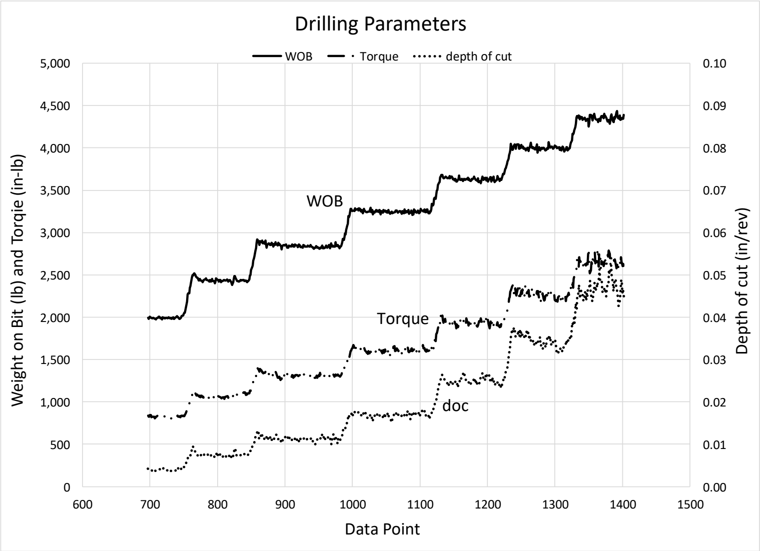
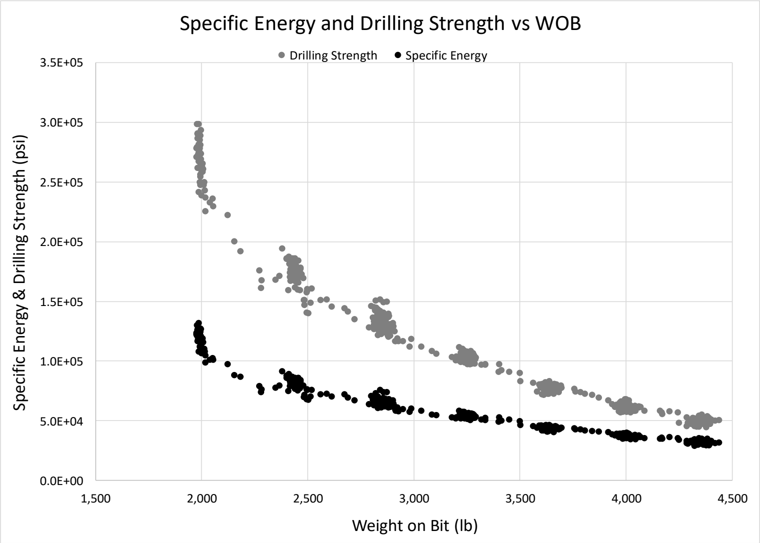
Methods/Approach

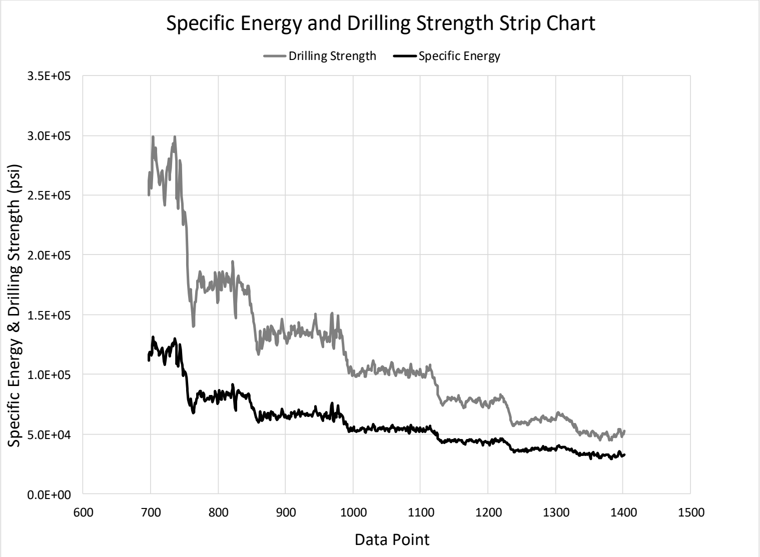
Task: Surface Data Access and Review of Utah FORGE bit performance

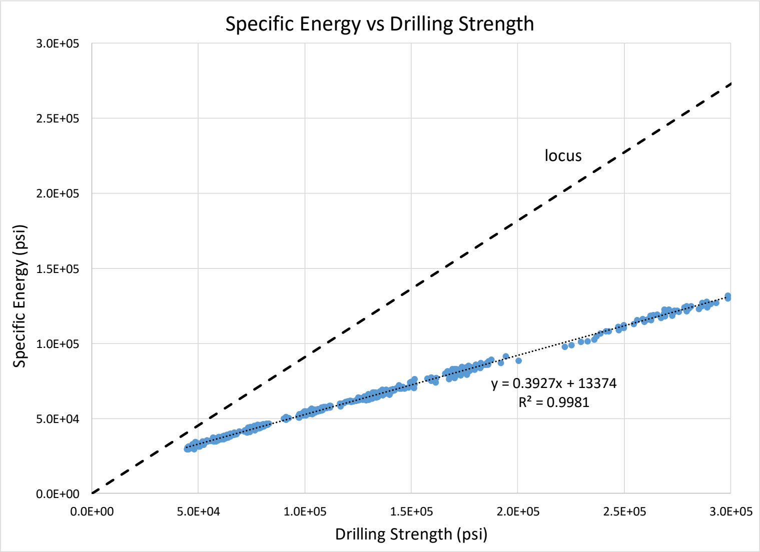
- Model Validation in Laboratory











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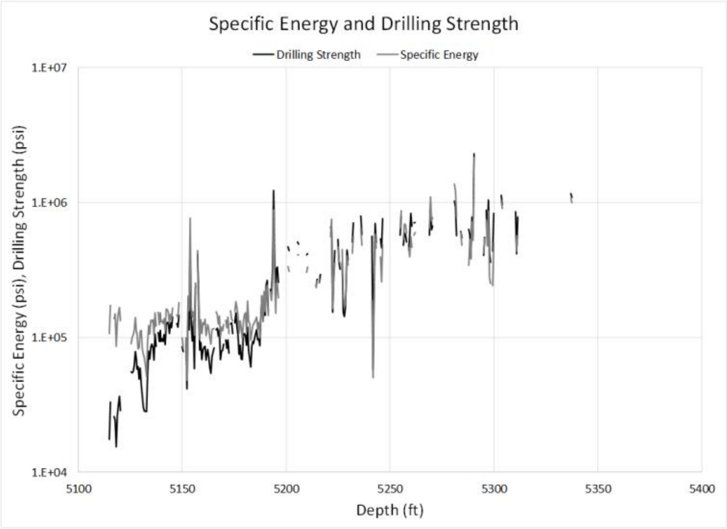
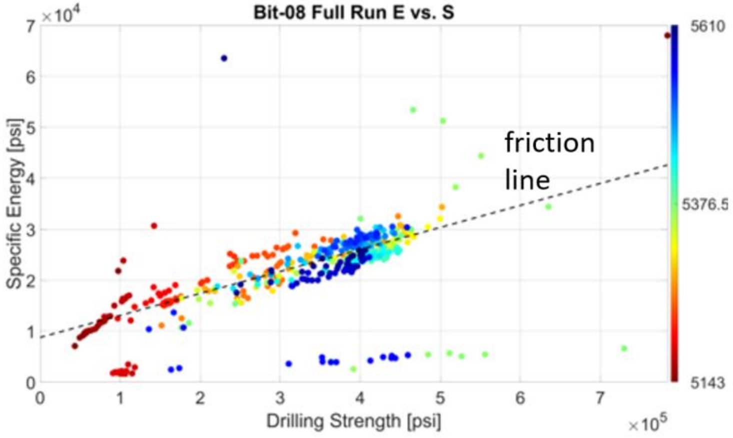
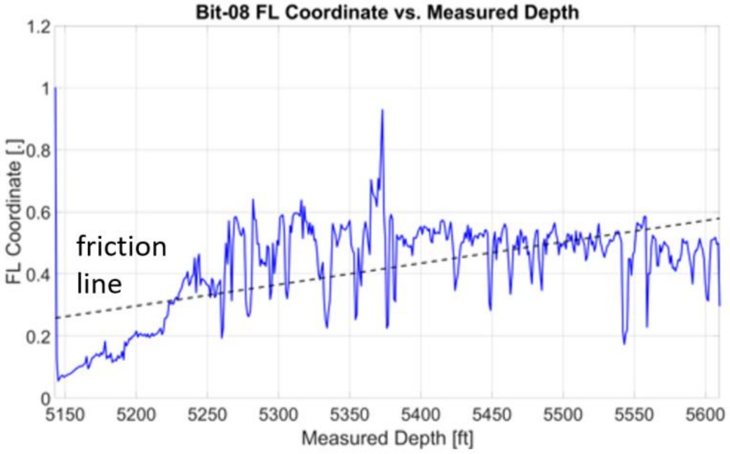
Technical Accomplishments and Progress
Task: Surface Data Access and Review of Utah FORGE bit performance

- Detournay model has been applied to Utah FORGE bit evaluations
  - 1 ft data from EDR
  - Monitor proportionality between E and S for stable drilling
  - E vs S plane shows friction line
  - Points color-contoured with depth across interval to track wear state
  - Bit response comparisons to cutter response allows objective evaluation of response with respect to performance standard







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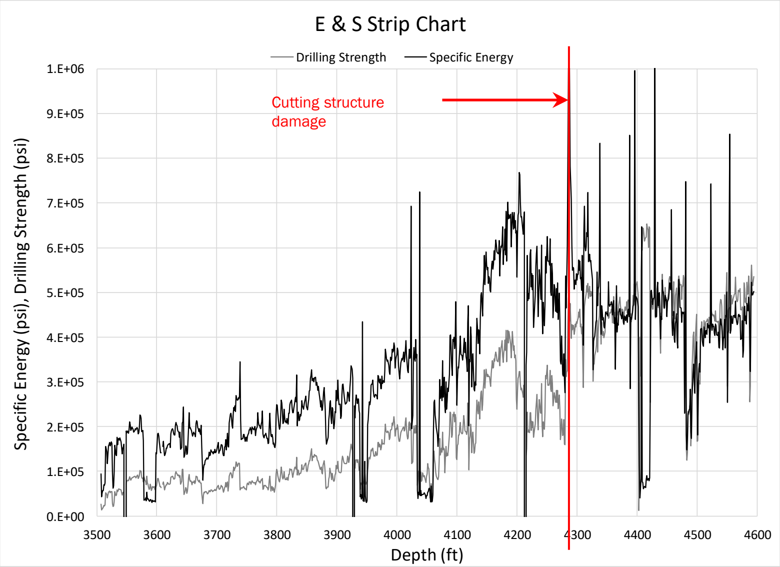
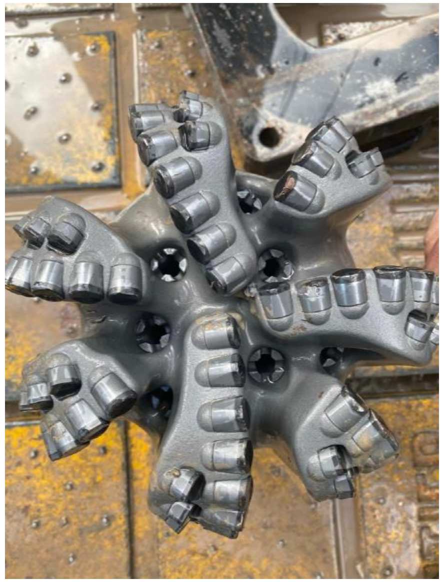
Technical Accomplishments and Progress

Task: Surface Data Access and Review of Utah FORGE bit performance

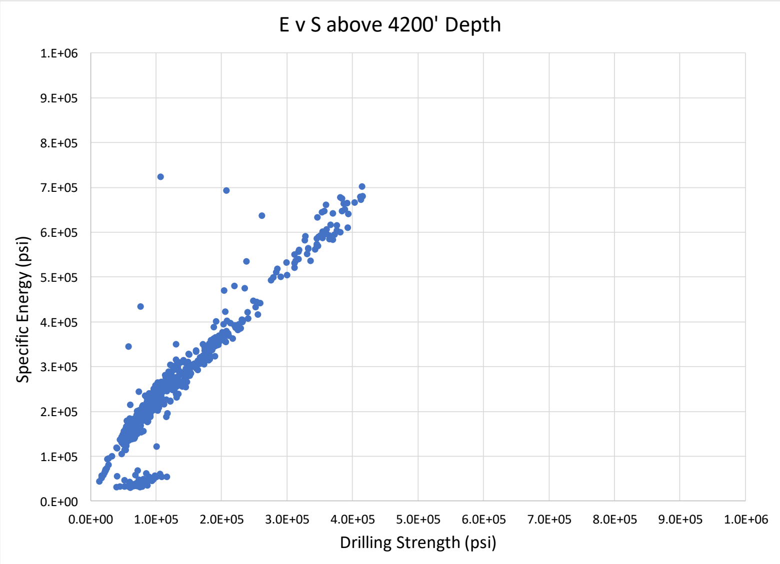
- Constraint model has been further applied to Utah FORGE bit evaluations
  - Detect off-normal conditions
  - Downhole dynamics
  - Cutting structure damage
- Further research is needed to address range of conditions

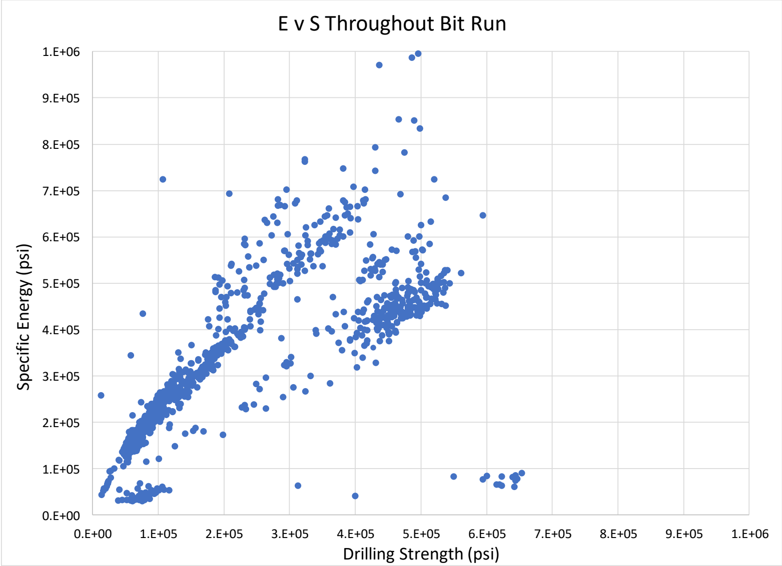




Cutting structure damage identification on 56-32/Bit 6 using E & S monitoring (left to right, top to bottom):

a) E & S strip chart
b) post-drilling image
c) ES plane response above 4200 ft
d) ES plane response for entire bit run





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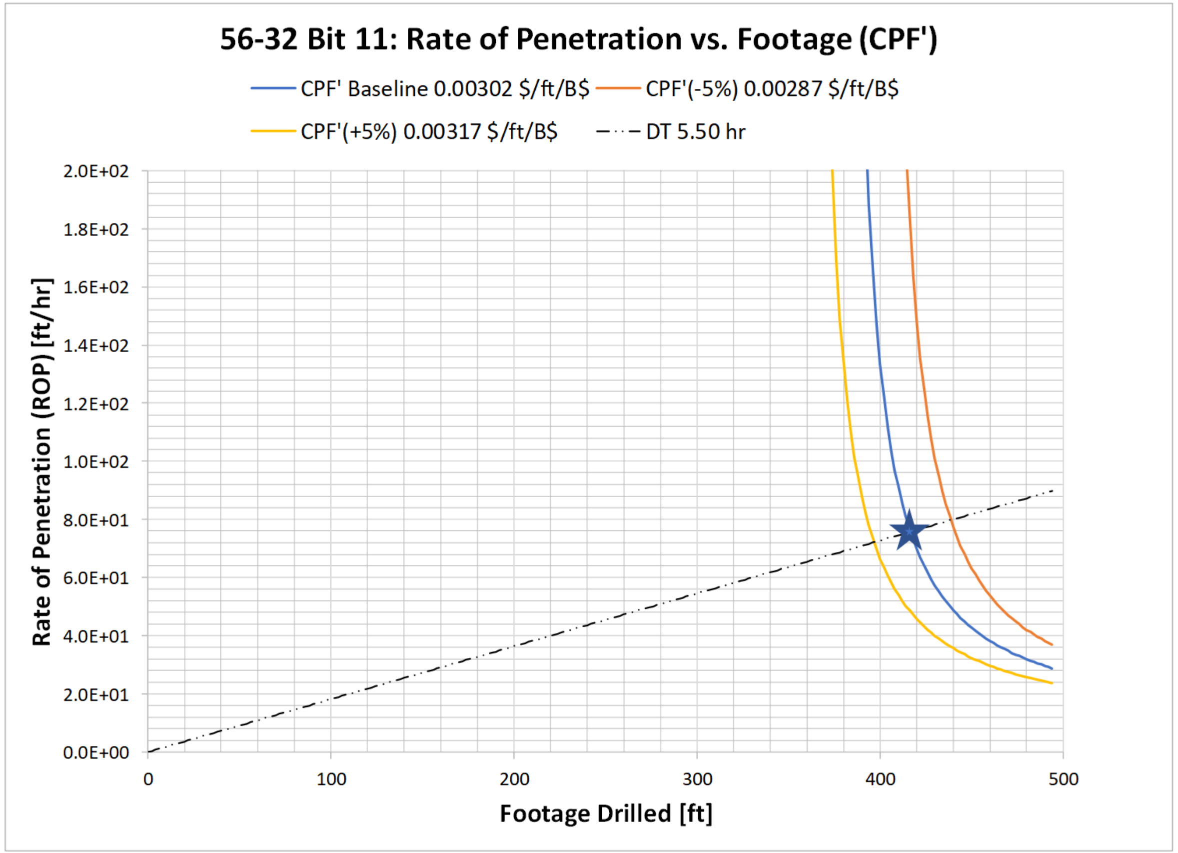
Methods/Approach
Task: Surface Data Access and Review of Utah FORGE bit performance

- ROP vs Footage constraint evaluations
  - Closed form constraint allows objective evaluation of trade-off between ROP and Footage



- $CPF = \frac{BC + RR(DT + TT)}{L}$ (A – 1)
- $DT = \frac{L}{ROP}$ (A – 2)
- $\bar{D} = D_0 + \frac{L}{2}$ (A – 3)
- $TT = \frac{\bar{D}}{TR} = \frac{D_0}{TR} + \frac{L}{2TR}$ (A – 4)
- $k_1 = \frac{RR}{BC}$ (A – 9)
- $k_2 = \frac{\left(\frac{RR}{BC}\right)}{2TR} = \frac{k_1}{2TR}$ (A – 10)
- $CPF' = \frac{1}{L} + \frac{k_1}{ROP} + k_2\left(1 + \frac{2D_0}{L}\right)$ (A – 11)
- $CPF = CPF' \times BC$ (A – 12)

CPF = cost per foot [$/ft]
BC = bit cost [$]
RR = rig rate [$/hr]
DT = drilling time [hr]
TT = tripping time [hr]
L = footage drilled [ft]
D_0 initial interval depth [ft]
$\bar{D}$ average interval depth [ft]
CPF' Contour in ROP-Footage plane

Mandatory- may utilize multiple slides

Technical Accomplishments and Progress

Task: Surface Data Access and Review of Utah FORGE bit performance

2022 PROJECT PEER REVIEW
U.S. DEPARTMENT OF ENERGY
GEOTHERMAL TECHNOLOGIES OFFICE

- ROP vs Footage Evaluation Results
  - Interval CPF’ drilling costs bits used on the three wells assuming a rig rate (RR) of \$1000/hr, individual bit costs (BC) of \$50,000, and round-trip trip rates (TR) of 1000 ft/hr corresponding to respective constants of k_1=0.02 [1/hr] and k_2 = 0.00001 [1/ft].
  - Method can be used to evaluate technology improvements to improve ROP and/or Bit Life

Well	Bit No.	Bit Diameter	Start Depth	Footage Drilled	End Depth	Dbar	ROP	CPF'
16A_78-32	7	8.75	4987.00	125.00	5112.00	5049.50	20.80	0.009769
16A_78-32	8	8.75	5113.00	232.00	5345.00	5229.00	13.30	0.006265
16A_78-32	15	8.75	5892.00	468.00	6360.00	6126.00	30.20	0.003061
16A_78-32	16	8.75	6360.00	166.00	6526.00	6443.00	15.10	0.008125
16A_78-32	17	8.75	6526.00	419.00	6945.00	6735.50	20.00	0.003708
16A_78-32	18	8.75	6945.00	444.00	7389.00	7167.00	24.70	0.003385
16A_78-32	19	8.75	7389.00	635.00	8024.00	7706.50	27.00	0.002558
16A_78-32	21	8.75	8025.00	216.00	8241.00	8133.00	36.00	0.005938
16A_78-32	22	8.75	8241.00	150.00	8391.00	8316.00	25.00	0.008575
16A_78-32	23	8.75	8391.00	144.00	8535.00	8463.00	24.00	0.008953
16A_78-32	24	8.75	8535.00	529.00	9064.00	8799.50	42.30	0.002696
16A_78-32	25	8.75	9064.00	684.00	9748.00	9406.00	33.40	0.002336
16A_78-32	26	8.75	9748.00	742.00	10490.00	10119.00	42.40	0.002092
16A_78-32	27	8.75	10490.00	465.00	10955.00	10722.50	33.20	0.003214
56-32	6	8.75	3506.00	1089.00	4595.00	4050.50	37.70	0.001523
56-32	7	8.75	4595.00	548.00	5143.00	4869.00	20.90	0.002959
56-32	8	8.75	5143.00	467.00	5610.00	5376.50	30.10	0.003036
56-32	9	8.75	5610.00	389.00	5999.00	5804.50	26.30	0.003630
56-32	10	8.75	5999.00	1209.00	7208.00	6603.50	23.20	0.001798
56-32	11	8.75	7208.00	412.00	7620.00	7414.00	85.80	0.003020
56-32	15	8.75	7667.00	1233.00	8900.00	8283.50	33.30	0.001546
56-32	16	8.75	8900.00	245.00	9145.00	9022.50	76.60	0.005079
78B-32	6	10.625	3009.00	642.00	3651.00	3330.00	49.80	0.002063
78B-32	7	10.625	3651.00	2110.00	5761.00	4706.00	75.60	0.000783
78B-32	8	10.625	5761.00	60.00	5821.00	5791.00	100.00	0.018797
78B-32	9	10.625	5821.00	879.00	6700.00	6260.50	80.60	0.001528
78B-32	10	8.75	6700.00	28.00	6728.00	6714.00	18.70	0.041580
78B-32	11	8.75	6700.00	40.00	6740.00	6720.00	44.40	0.028810
78B-32	12	10.625	6740.00	2.00	6742.00	6741.00	3.30	0.573471
78B-32	13	10.625	6742.00	871.00	7613.00	7177.50	88.90	0.001538
78B-32	14	10.625	7613.00	887.00	8500.00	8056.50	88.70	0.001535
78B-32	15	10.625	8500.00	30.00	8530.00	8515.00	10.70	0.040879
78B-32	17	5.75	8555.00	945.00	9500.00	9027.50	121.20	0.001414

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Methods/Approach

Task: Collaboration with bit industry SMEs on FORGE bit performance

- Approach
  - FY21/OSU Collaborations
    - Act as liaison with researchers at Oklahoma State University (OSU) to collaborate on the DOE EDGE-funded Real-Time Drilling Optimization project using Utah FORGE data
    - Focus is on prediction of preferred operating conditions subject to bit design, penetration rate predictions, specific energy monitoring, and drillstring dynamics modeling
    - Use of FORGE drilling plans, bit designs and drillstring properties, and surface data measurements will benefit these collaborations; may enable real-time optimizations on future Utah FORGE well.
  - FY22/SME Collaborations
    - Collaborate with bit industry subject matter experts (SMEs) on FORGE bit performance
- Status
  - OSU Proposal submitted to DOE for acceptance/approval; Sandia/OSU contract executed
  - FY21 Collaborations with Geir Hareland and Mohammed Aldushaishi via raw data transmittal
  - FY22 Technical Interchange Meeting (TIM) with bit industry subject matter experts pending

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Technical Accomplishments and Progress

Task: Collaboration with bit industry SMEs on FORGE bit performance

2022 PROJECT PEER REVIEW
U.S. DEPARTMENT OF ENERGY
GEOTHERMAL TECHNOLOGIES OFFICE

- Collaboration with Subject Matter Experts via Technical Interchange Meeting

Utah FORGE Drilling Technology Evaluation
Technical Interchange Meeting (TIM) Agenda

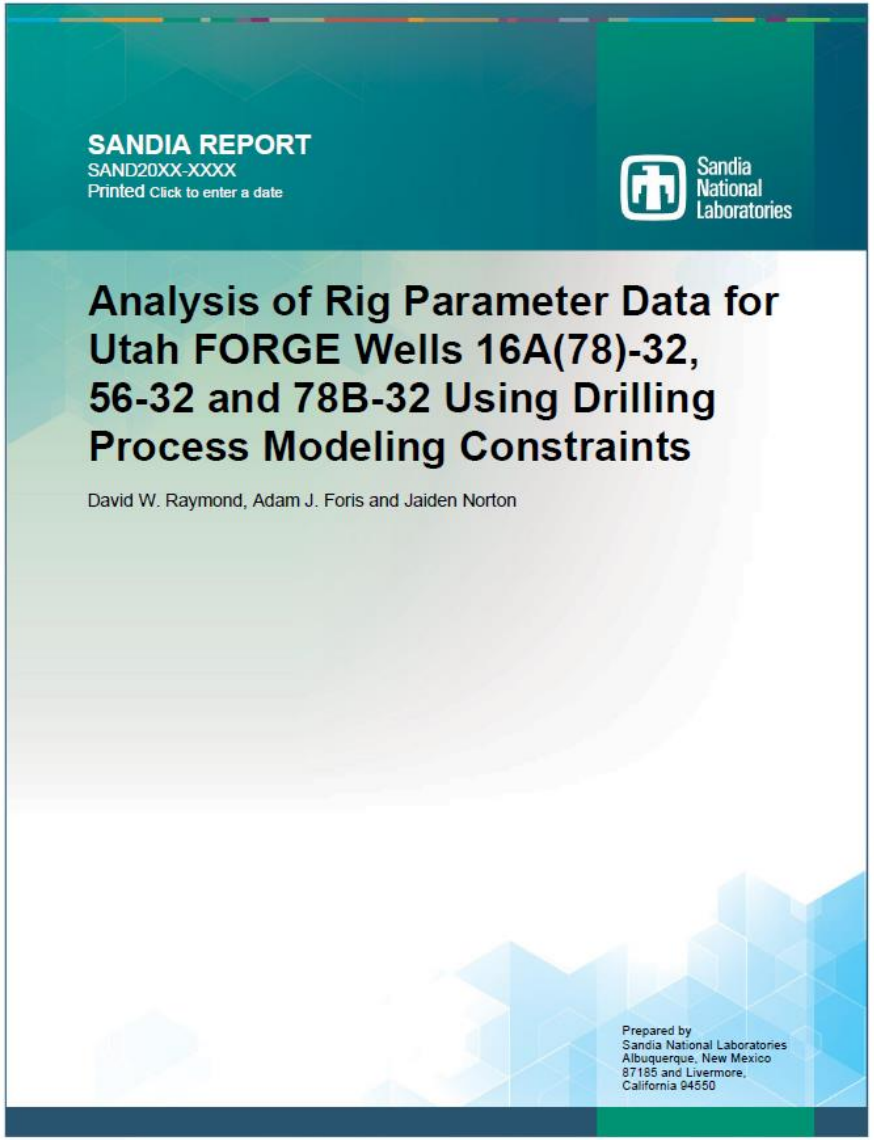
Day 1 - 04/20/2022						Start Time			
Session/Topic	Description	Org	Speaker	Duration (h:m)	Total Time (h:m)	PDT	MDT	CDT	EDT
Opening	Welcome/Telecon Guidance	Sandia	Bettin	0:05	0:05	10:30 AM	11:30 AM	12:30 PM	1:30 PM
DOE Remarks	Objectives & Expected Outcomes	DOE	Nieto/GTO	0:05	0:10	10:35 AM	11:35 AM	12:35 PM	1:35 PM
Utah FORGE	Utah FORGE Overview	EGI	Moore	0:20	0:30	10:40 AM	11:40 AM	12:40 PM	1:40 PM
FORGE 16A(78)-32	Bit Run Overview	NOV	Self, Stevenson	0:15	0:45	11:00 AM	12:00 PM	1:00 PM	2:00 PM
Break				0:10	0:55	11:15 AM	12:15 PM	1:15 PM	2:15 PM
FORGE 56B-32	Bit Run Overview	NOV	Self, Stevenson	0:15	1:10	11:25 AM	12:25 PM	1:25 PM	2:25 PM
FORGE 78B-32	Bit Run Overview	NOV	Self, Stevenson	0:15	1:25	11:40 AM	12:40 PM	1:40 PM	2:40 PM
Speaker	Limiter-Redesign Workflow on 16A & 78B	TAMU	Dupriest, Noynaert	0:20	1:45	11:55 AM	12:55 PM	1:55 PM	2:55 PM
Break				0:10	1:55	12:15 PM	1:15 PM	2:15 PM	3:15 PM
Open Discussion	Utah FORGE drilling program and information presented	All	GTO / Moderator	0:25	2:20	12:25 PM	1:25 PM	2:25 PM	3:25 PM
Closing	Wrap Up	Sandia	Bettin	0:10	2:30	12:50 PM	1:50 PM	2:50 PM	3:50 PM

Day 2 - 04/21/2022						Start Time			
Session/Topic	Description	Org	Speaker	Duration (h:m)	Total Time (h:m)	PDT	MDT	CDT	EDT
Opening	Welcome/Telecon Guidance	Sandia	Bettin	0:05	0:05	10:30 AM	11:30 AM	12:30 PM	1:30 PM
Speaker	Lessons Learned from Utah FORGE	EGI	McLennan	0:15	0:20	10:35 AM	11:35 AM	12:35 PM	1:35 PM
Speaker	Advanced Analytics of Rig Parameter Data	Sandia	Raymond	0:20	0:40	10:50 AM	11:50 AM	12:50 PM	1:50 PM
Speaker	Analysis of Bit Wear on FORGE 56-32	OSU	Aldushaishi	0:20	1:00	11:10 AM	12:10 PM	1:10 PM	2:10 PM
Break				0:10	1:10	11:30 AM	12:30 PM	1:30 PM	2:30 PM
Speaker	Sandia Drilling Tech Eval - Report Overview	Sandia	Raymond	0:10	1:20	11:40 AM	12:40 PM	1:40 PM	2:40 PM
Open Discussion 1	Utah FORGE drilling systems performance	All	GTO / Moderator	0:25	1:45	11:50 AM	12:50 PM	1:50 PM	2:50 PM
Break				0:10	1:55	12:15 PM	1:15 PM	2:15 PM	3:15 PM
Open Discussion 2	Geothermal Drilling Needs and Recommendations going forward	All	GTO / Moderator	0:20	2:15	12:25 PM	1:25 PM	2:25 PM	3:25 PM
Closing	Wrap Up	DOE	Nieto/GTO	0:10	2:25	12:45 PM	1:45 PM	2:45 PM	3:45 PM

Original Planned Milestone / Technical Accomplishment	Actual Milestone / Technical Accomplishment	Date Completed
Collaboration with bit industry subject matter experts on FORGE bit performance.	Technical Interchange Meeting with SMEs	April 20-21, 2022 (planned date)

Technological Advancement and Data Dissemination

- Project has technically advanced this research area
  - Largest assemblage of PDC bit field data in geothermal hard-rock drilling
- Project team disseminated data for future public use
  - GRC Transactions Paper & Presentation
    - "Advanced Analytics of Rig Parameter Data Using Rock Reduction Model Constraints for Improved Drilling Performance," *GRC Transactions*, October 2021.
  - ECN Post/Transmittal to OSU for data evaluations
  - SAND Report Pending
    - "Analysis of Rig Parameter Data for FORGE Wells 16A(78)-32, 56-32 and 78B-32 Using Drilling Process Modeling Constraints." SAND2022-xxxx.
    - Analysis Overview (Matlab script description, filtering, etc.)
    - Appendix A: 16A(78)-32 Bit EDR with Daily Drilling Reports
    - Appendix B: 56 -32 Bit EDR with Daily Drilling Reports
    - Appendix C: 78B-32 Bit EDR with Daily Drilling Reports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Sandia National Laboratories

Analysis of Rig Parameter Data for Utah FORGE Wells 16A(78)-32, 56-32 and 78B-32 Using Drilling Process Modeling Constraints

David W. Raymond, Adam J. Foris and Jaiden Norton

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico
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California 94550

Future Directions

- Future funding would provide opportunity to:
  - Develop real-time application of rock reduction constraint models
    - Detournay rock reduction constraint model for improved bit performance
    - Drilling Cost Constraints for improved cost per foot performance
  - Demonstrate on future well of opportunity

Milestones	Status and Expected Completion Date
Real-time Advanced Analytics using rig EDR data	TBD

Summary

- Advanced Analytics methods have been developed and demonstrated
  - Bit performance metrics for Utah FORGE Well 16A(78)-32, Well 56-32 and Well 78B-32 have been evaluated and reported
  - A rock reduction model has been presented that enables objective interpretation of bit response
    - Validated in laboratory
    - Model may be used to provide insight into field drilling performance
    - Model has been applied to the drilling response of bits from the FORGE drilling campaigns
  - Examples presented can allow insight into methods used to evaluate bit response, formation hardness, wear rate, cutting structure damage, and drilling dynamic dysfunction conditions
- Analyses have been conducted post drilling yet may be applied to real-time evaluations for improved drilling performance
- Relative cost-benefit of improving penetration rate response and bit durability has been evaluated

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