



Technology Development and Field Trials of EGS Drilling Systems

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ARRA Funded R&D

- Objective
 - Develop fit-for-purpose EGS drilling solutions for geothermal exploration and production drilling
 - Hard/abrasive/fractured rock, high temperature, deep drilling
- Purpose
 - Improved drilling technologies that reduce costs by drilling faster with improved life, capabilities for improved hard stringer penetration, and are appropriate for deep drilling applications
 - Improved support for economic development of geothermal resources
 - Increase in the number of tools / options available for geothermal well construction
 - Service companies engaged in geothermal drilling market
 - Broad experience base to promote continued geothermal well construction

- Challenges/Barriers addressed on this project
 - Risk Reduction
 - Limitations of Laboratory Testing
 - Service Company Investment
 - Drilling Industry Acceptance
- Impact/Performance
 - Potentially reduce geothermal drilling costs via improved ROP & increased bit life
 - Nominal baseline is sealed roller cone performance in hard abrasive rock (low ROP: 10-20 ft/hr, short life: 40 hrs)
 - PDC Bits drill proportionally faster
 - Derive benefit from O&G/Minerals research in comparable domains
 - Catalyze industry via improved / economical deep hole access
- Innovation
 - Provides pathway for introduction of advanced technology with service company support

Overall Approach

Three Phases over Three Years (ARRA-funded for two of three years)

- Phase 1 - Preliminary field trials to demonstrate potential & highlight deficiencies (Yr 1: ARRA-funded)
- Phase 2 - Service company involvement in performance remediation and custom development (Yr 2: ARRA-funded)
- Secondary/Follow-Up field trials for verification & validation (Yr 3: Non-ARRA funded)
 - Demonstrate technology readiness for geothermal drilling
 - Verify design improvements realized in year two

Highlights

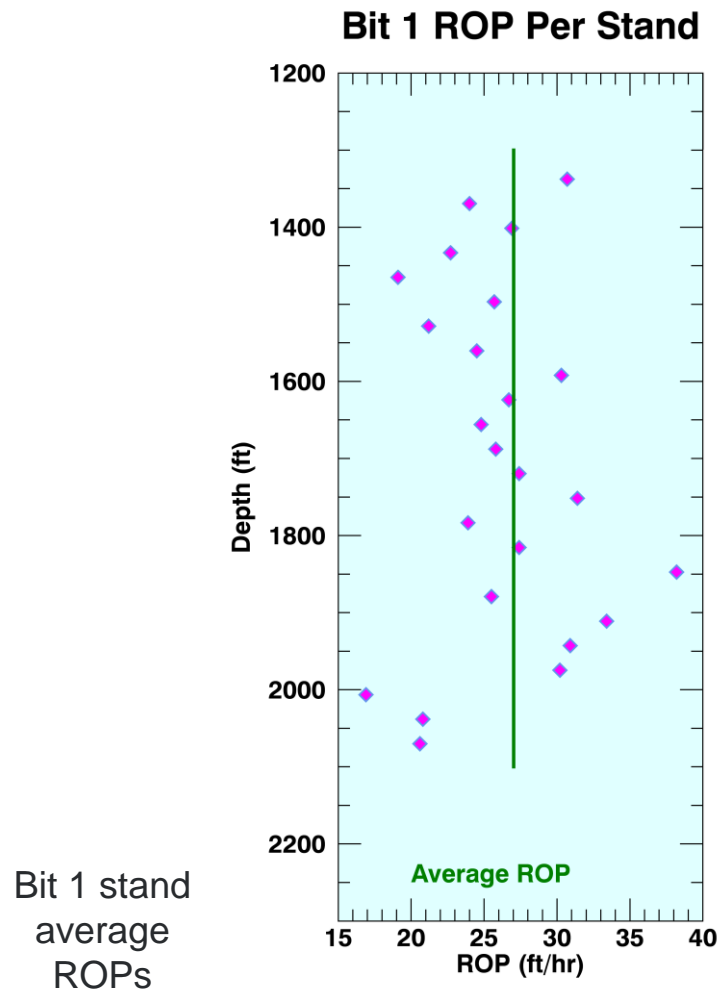
- Direct partnership with geothermal operators/developers
- Service companies directly involved in bit development & testing

Overall approach included the following elements:

- Technical Interchange Meetings with Team
- Develop well-defined drilling plans
- Pre-selection of fit-for-purpose bit solutions
- Data acquisition system development
 - Surface system integration
 - Downhole via service company tools
- Sandia-monitored field drilling deployment with on-going monitoring activities
- Direct involvement of service companies during tool specification and field testing
- Data reduction and analysis
- Post-mortems on bit conditions
- Next generation bit development and testing

Accomplishments, Results and Progress (continued)

Bit 1 Test Results



Bit 1A: Pre-Drill

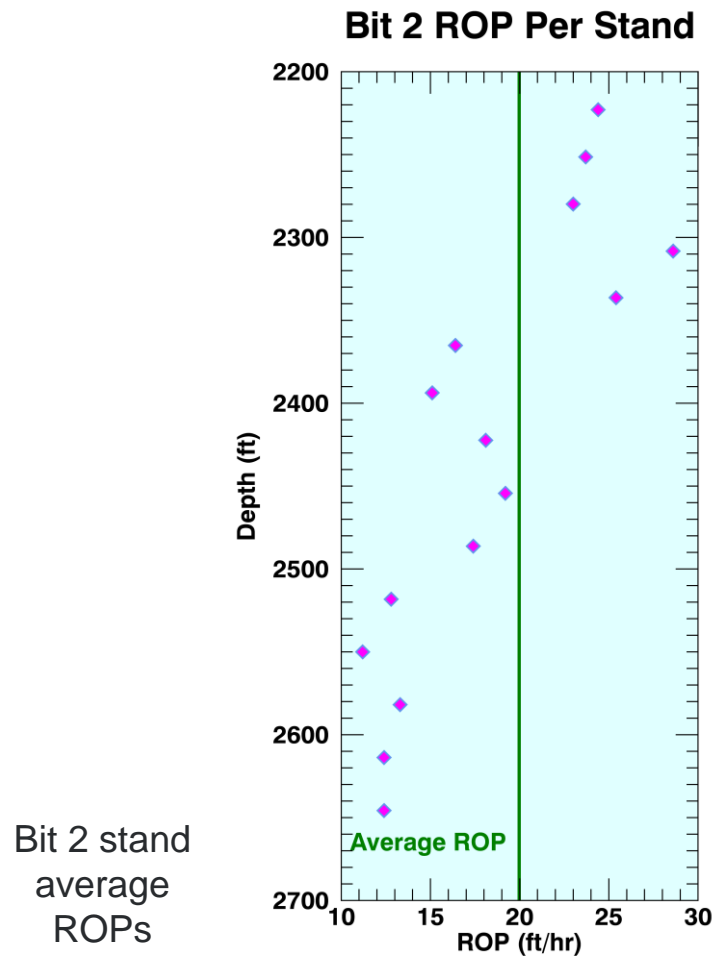


Bit 1A: Post-Drill After 726 ft.



Accomplishments, Results and Progress (continued)

Bit 2 Test Results



Bit 2A: Pre-Drill



Bit 2: Post Drill after 566 ft.



Accomplishments, Results and Progress (continued)

Phase 2 bit is similar to bit 1
Phase 2 bit is denoted bit 3
First run in Sierra White
showed minor cutter
selection problem

Bit 1: Pre-Drill Sharp Condition



3 Bit Pre-drill

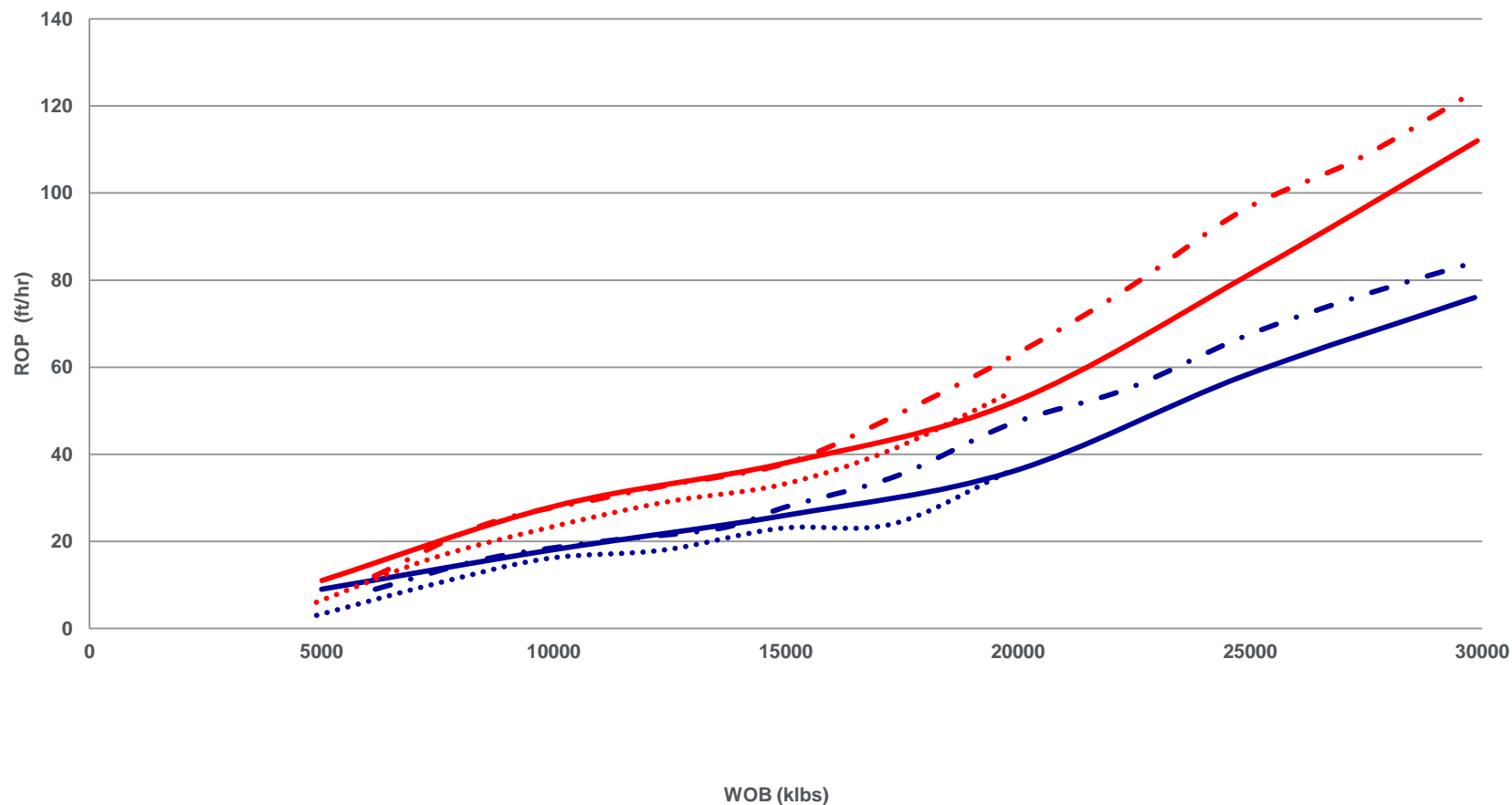


Bit 3 Post drill



Accomplishments, Results and Progress (continued)

E813M ROP - WOB



RPM

— 70-1

— 110-1

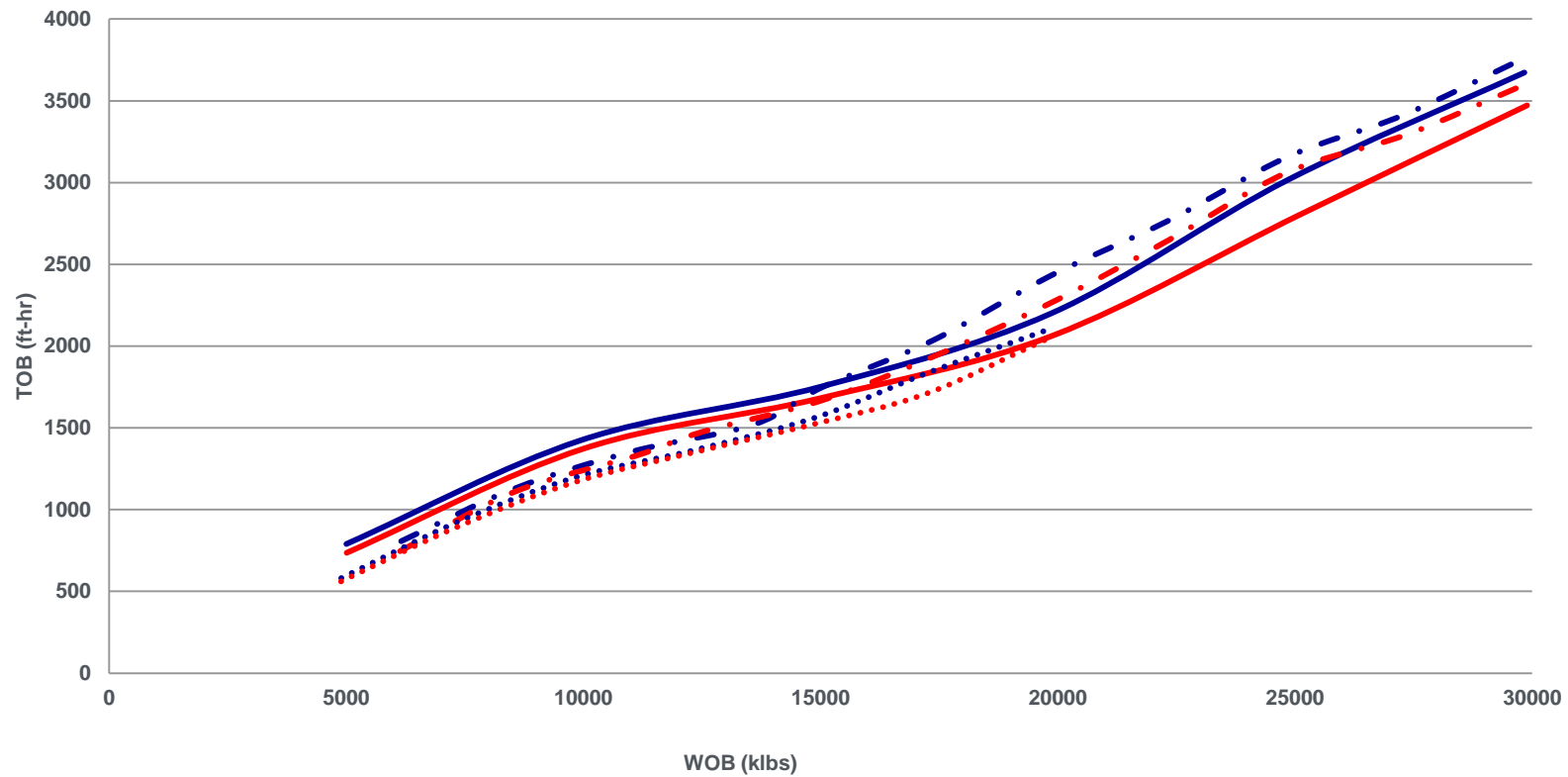
- - 70-2

- - 110-2

... 70-3

... 110-3

E813M TOB - WOB



RPM

— 70-1

— 110-1

- - 70-2

- - 110-2

... 70-3

... 110-3

DEFINING TWO VARIABLES OF INTEREST

$$\text{SPE} = \frac{2 * \text{TOB} * 60 * \text{RPM}}{r^2 * \text{ROP}} \quad \text{psi}$$

$$S = \frac{\text{WOB}}{r * \text{DOC}} \quad \text{psi}$$

WHERE:

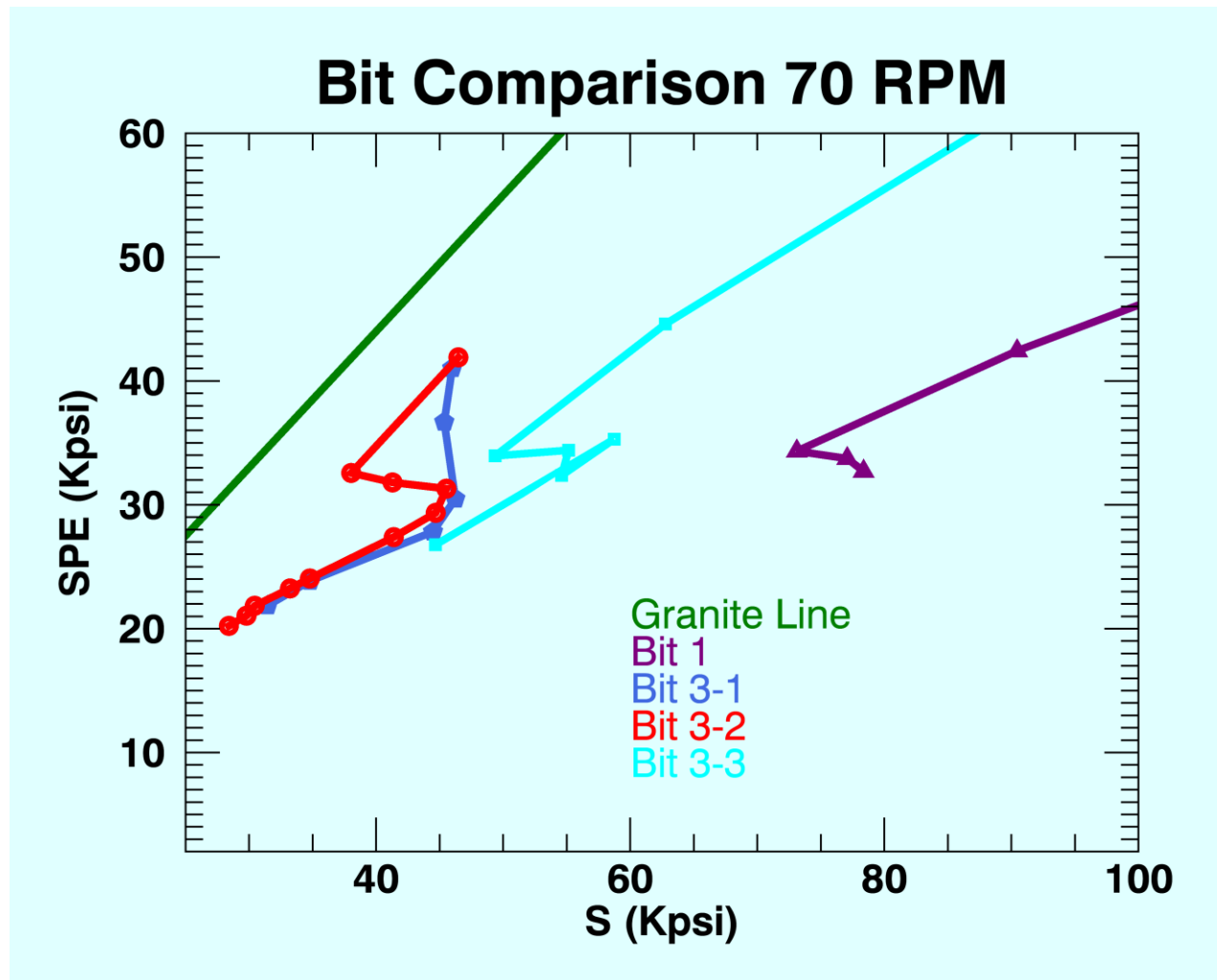
TOB = Torque On Bit

RPM = Bit Revolutions Per Minute

ROP = Rate Of Penetration

DOC = Depth Of Cut

r = Radius of the bit



- Major results from Phase 1 testing
 - 813 didn't have much impact damage
 - 713 had significant impact damage
 - Torque control components are key
 - Abrasion not an issue
 - Rig needs more torque capacity
- Major results from Phase 2 design effort
 - New bit designed building on success of earlier 813 bit
 - TCC type and setback optimized
 - Will result in 2 bits to test

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Phase 1 Field Test	Chocolate Mountain	Dec 2011
Phase 2 Bit Design	Successful Bit 2 Test	Nov 2012

- Rock Reduction Technology
 - Mature for conventional geothermal drilling
 - Present technology (roller cone bits) will inhibit commercially – viable development of EGS resources
 - PDC bits provide improvements that are necessary to access EGS resources
- PDC bits will prove benefit when coupled with capable rig
 - Backed by significant R&D
 - Drilling comparable rocks/depths
- Demonstration project has validated PDC technology for geothermal drilling
- Phase 2 bit follows in the footsteps of the successful phase 1 bit run at Chocolate Mountain drilling site

Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Current End Date
Apr 2010	Sept 2012	Oct 2010	June 2013

Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
\$1,336,565	\$52,500	\$1,297,203	\$841,092*	\$1,177,887	\$80,000

- Management
 - No well of opportunity found for downhole hammer.
 - Considering purchase new hybrid bit and alternate diameter bits to test in Geothermal
 - Integrates well with Sandia's overall effort to lower drilling cost
 - NOV Downhole heavily involved in phase 2
- Scheduling in NOV Downhole facility delayed phase 2 completion into FY-13