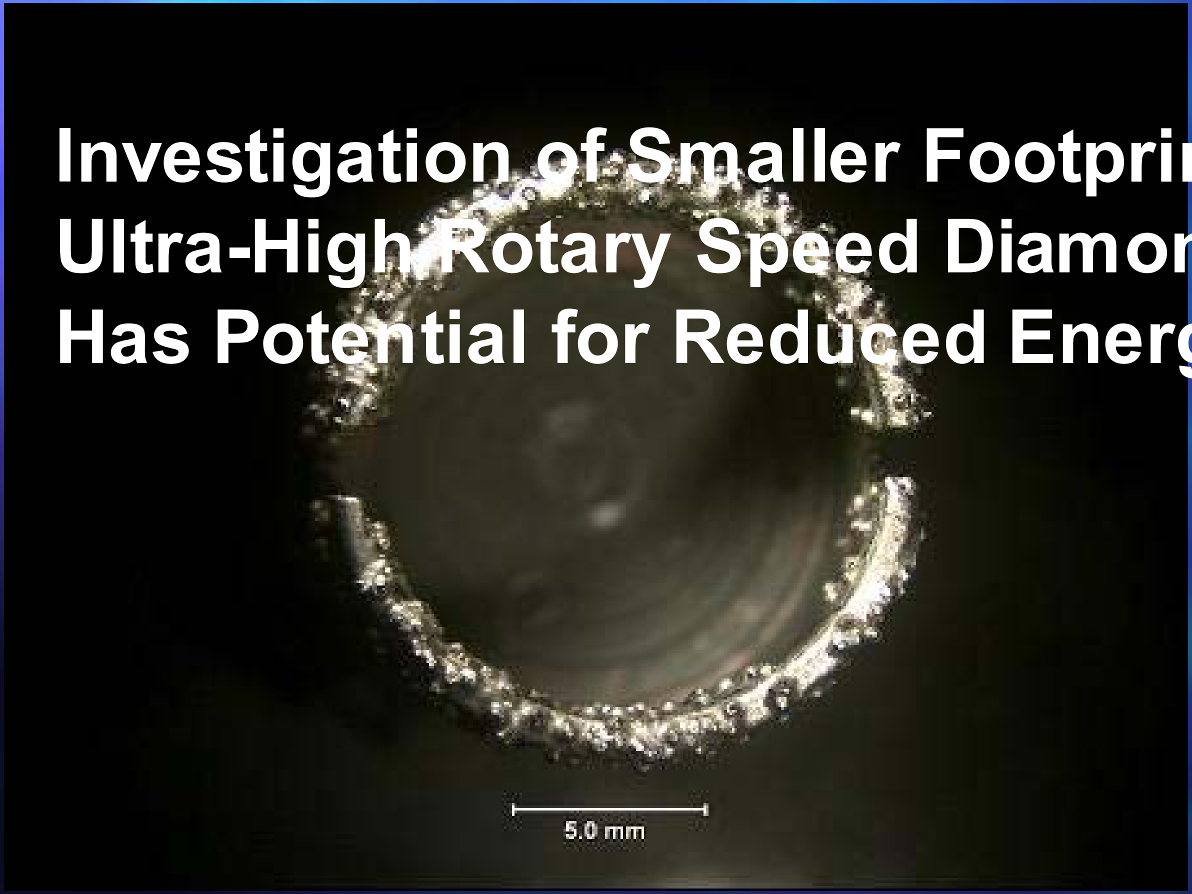
Investigation of Smaller Footprint Drilling System; Ultra-High Rotary Speed Diamond Drilling Has Potential for Reduced Energy Requirements



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TerraTek

Basis of presentation

IADC/SPE 99020

Investigation of Smaller Footprint Drilling System;
Ultra-High Rotary Speed Diamond Drilling Has Potential for Reduced Energy Requirements

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Investigation of Smaller Footprint Drilling System; Ultra-High Rotary Speed Diamond Drilling Has Potential for Reduced Energy Requirements

- Introduction and Business Impact
- Testing
- Future Work
- Conclusions

Acknowledgement to Paul West (Tulsa), DOE's Project Manager for this program

U.S. DEPARTMENT OF ENERGY

The program addresses long-term developments in deep well and hard rock drilling.

The principle focus is on demonstration testing of diamond bits rotating at speeds in excess of 10,000 rpm to achieve high rate of penetration rock cutting with lower inputs of energy and weight-on-bit loads.

Context

Introduction and Business Impact

- **Economic Benefit**
  - Domestic developments in drilling tools and testing
  - Potential for increased activities in oil and gas plays
- **Drilling Performance**
  - Diamond product bit applications for increased rate of penetration
  - Directional drilling applications
  - Potential for both slim and larger hole sizes
- **Target Markets**
  - Gas, deep gas plays
  - Domestic oil, where drilling performance can be improved

Harnessing Dental Drills

Ultra high rpm drilling offers faster penetration rates and reduced environmental footprint.

If oilfield drilling technology cannot be used in dentistry, perhaps the technology behind dental drills can be applied to the oil industry. The US Department of Energy (DOE) thinks so. It envisions that ultra high speed drilling will not only result in faster penetration rates at lower weight-on-bits but also reduce environmental footprints.

Although Chinese and Arabic physicians reputedly drilled teeth long before the middle ages, hand held motor-driven drills only appeared in the Western world in 1864. Powered by elegant 'clock-spring' movements, the speed and power of these drills was limited to 100 rpm and several ft-lb/sec. Soon afterwards pneumatic drills — powered by bellows arrived. With the advent of electromagnetic motors, drills became lighter, cheaper and much more powerful.

Mostly 1/16-in. in size, dental bits are made of tungsten carbide or natural diamond and kept cool by an air/water mist that circulates through the bit. The motors require between 30 psi – 40 psi pressure to operate and can rotate miniature turbines at speeds exceeding 400,000 rpm.

Among several wide ranging technology programs is the DOE 'Ultra High Speed Drilling Program' initiated in July 2003. During a successful Ultra-High Speed Diamond Drilling feasibility analysis, which was spun off from the Jet Propulsion Laboratory 'Drilling on Mars' project, National Aeronautics and Space Administration (NASA) and TerraTek demonstrated that ultra-high speed air drilling could achieve higher rates of penetration with lower weight-on-bit in a variety of rock types — sandstone, limestone and basalt. The DOE hopes to take this technology to the oilfield.

In fact, significantly lower loads at the bit and reduced specific energies were sufficient to improve penetration rates that were considered normal in oil and gas drilling. Reduced energy consumption was considered a key success factor by NASA because of the limitations space missions imposed on logistics and available energy for drilling equipment.

Downhole equipment such as turbines and electrical motors are capable of achieving high rotational speeds. However, these are often lower than 2,000 rpm. During the NASA tests, electric brushless DC motors (1.6-in. diameter) were run at speeds of up to 52,000 rpm using a continuous 2,000 watt power source. In this test a 7/8-in. diameter coring bit was used to drill sandstone. 1,250 watts of power were required to run the motor and torque was calculated at approximately 0.25 ft-lb. Results showed that with 9 pounds weight-on-bit at a rotary speed of 40,000 rpm, a 220 ft/hr penetration rate was achieved. Although, the laboratory sample and bit length were limited to a 1-in. stroke, this has encouraged further studies.

Covering a range of drilling fluids and reproduced 'well-bore' pressures, drilling research will use natural diamond coring bits of less than 1-in. diameter. Once connected to commercially available electric brushless DC motors, these bits will be capable of being run at speeds of over 50,000 rpm. Bits and motors or turbines will be scaled up in two phases. First, test bits will be increased to reach 3-in. slim-hole diameters and ultra high speed motors or turbines will be designed to handle increased velocities. The second step encompasses the design of ultra high speed down-hole components for conventional bit sizes up to 17 1/2-in.

There are plenty of intriguing questions regarding ultra high speed drilling. How will salt, shale or clay based formations react to ultra high speed drilling? How will directional behavior be affected? What characteristics will cutting size and distribution display? Although it is hard to answer these questions without test data, it is fair to say that much will change. An example of this would be the nature and size of cuttings. Cuttings from hard formations (above 20,000 psi compressive strength) are likely to be smaller than 0.5mm as they are ground to a fine powder or dust, rather than being crushed solids. Consequently, this will have implications on the distribution and removal of cuttings within the well-bore and mud return equipment.

At first sight, ultra high rpm drilling seems outlandish, but the concept fits with coiled tubing and under-balanced techniques. If electrical power is required cables can be integrated within the coil, during or after the time of manufacture. Additionally, penetration rates will not be held back by connections. In the case of air driven motors, traditional under-balanced air compressors units should be able to meet the operating pressure requirements while rotating wellheads can provide well control. E&P

Ultra-high speed drilling test at 50,000 rpm in limestone. ***(Photo courtesy of DOE)***

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Started as a NASA project to drill on Mars

DOE Input

- ***Applications and prior art for ultra-high –***

Assess drilling applications requiring improvement

Access information from available sources

- ***Concept development –***

Engineer and evaluate concept with bench scale testing

Review progress and start <u>engineering for slim size</u>

- ***Demonstration of concept –***

Benchmark performance with sizes up to 3” range

Final report ‘Feasibility of Ultra-High Speed Diamond Drilling’

Team

"Feasibility of Ultra-High Speed Diamond Drilling"

Kick-Off Meeting Team Participants:

Department of Energy

TerraTek

ReedHycalog

Shell

Meeting at DOE Tulsa, August, 2003

Ultra High Speed Drilling Program

The Promise of High RPM Drilling

- Experience with high speed turbine drilling
- Incremental benefit larger with smaller hole size
- Long bit & turbine life results in lower cost/ft
- Drilling rate approx. proportional to rpm

Hence, strong interest in exploring higher RPM's

If lower specific energy required, development of suitable high speed motors will follow

Tasks

Phase 1

1. Review technologies / kick-off meeting (done)
2. Design program / concepts for ultra-high rotary speed drilling (done)
3. Conduct small scale performance tests (done . . some additional tests being replicated and experimental gaps analyzed)
4. Analysis and concept evaluation (nearly done)
5. Preliminary planning / engineering for slim size (in progress)
6. Transfer technology (mainly done via SPE/IADC publication, Phase 2 application in April ’06 with DOE progress meeting to follow)

Testing

"A review of industry practices has shown that in general extremely high rotary speeds have not been used in the oil and gas industry"

Typical Drill Bit (~3/4" diameter) used in concept development work

Project Challenges

- Bit Design Problems
  - number of diamonds?
  - size of diamonds?
  - junk slots adequate?
- Bit Balancing Issues
  - dimensional tolerances?
  - balancing of bits not always adequate
  - bit length too long for fixture?
- Motor and Test Fixture Limitations
  - stalling in some rocks
  - fluid sealing adequate?
  - RPM measurement erratic? Maybe not
  - RPM fall off at times
  - Torque limitation precludes high WOB
  - Friction elesewhere

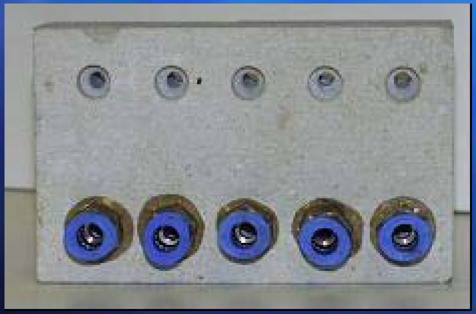
Project Challenges (continued)

- Bit Cleaning
  - Nitrogen flow
  - Pressure drop measured?
  - WOB variable due to pump off forces?
  - Bit junk slots adequate?
  - Large number of small diamonds restrict flow area
  - Fluid flow; same issues?
- Bit Wear
  - Can have big effect on reducing ROP and increasing Specific Energy
  - Need to run repeat tests to access wear effects
  - Started photographing bit after each test
  - Shorten drilling distance

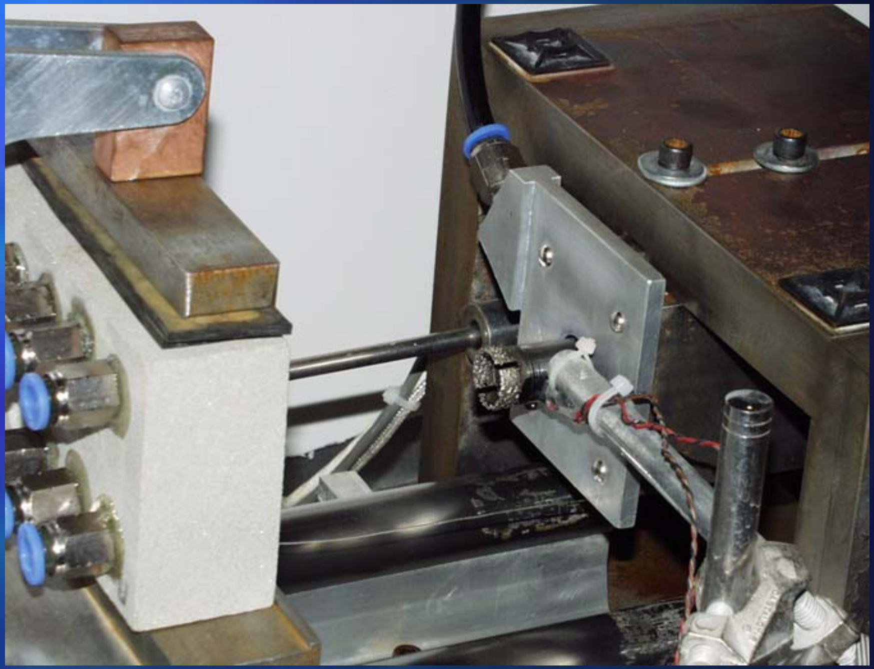
Testing

Front

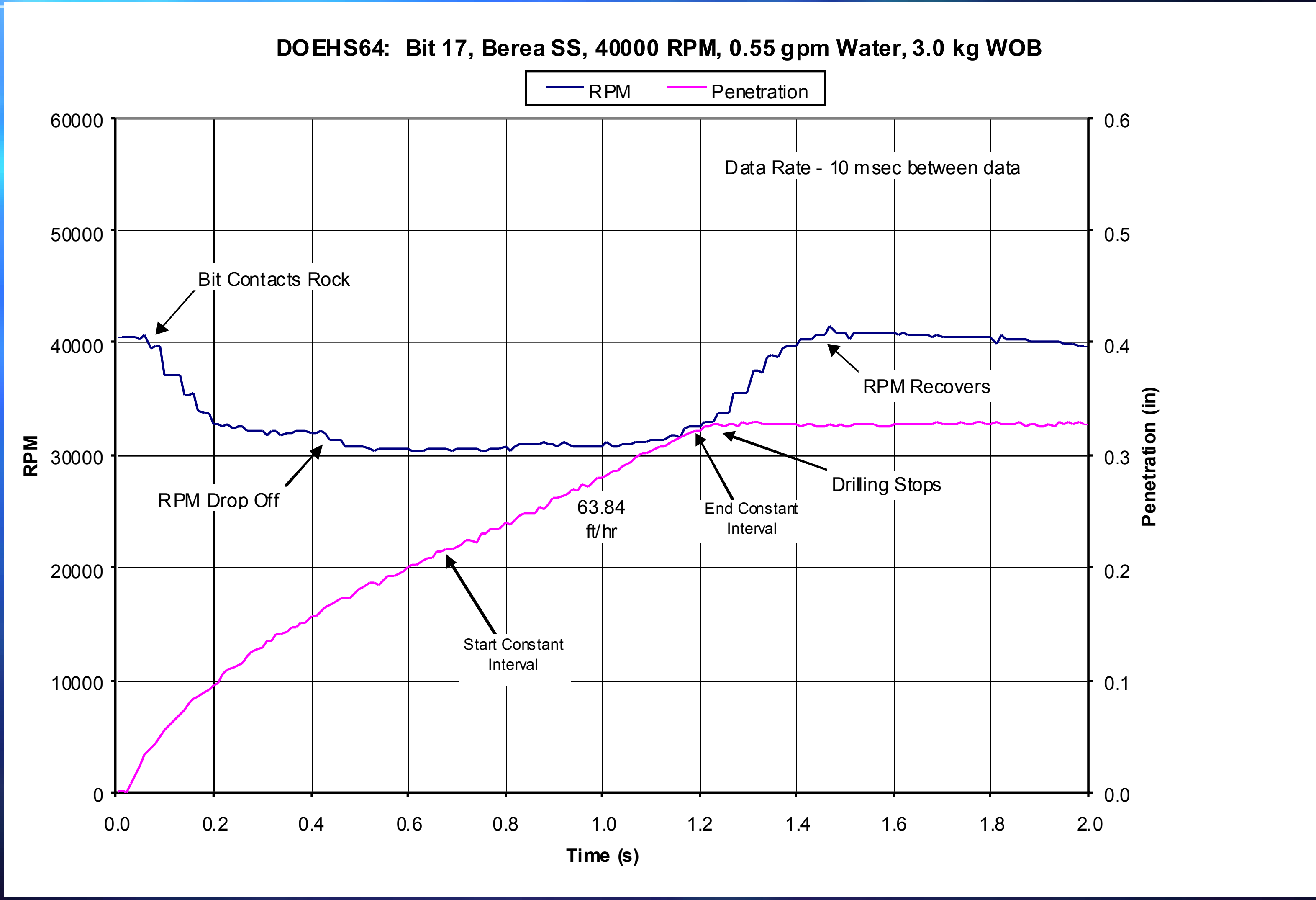
Prepared rock sample



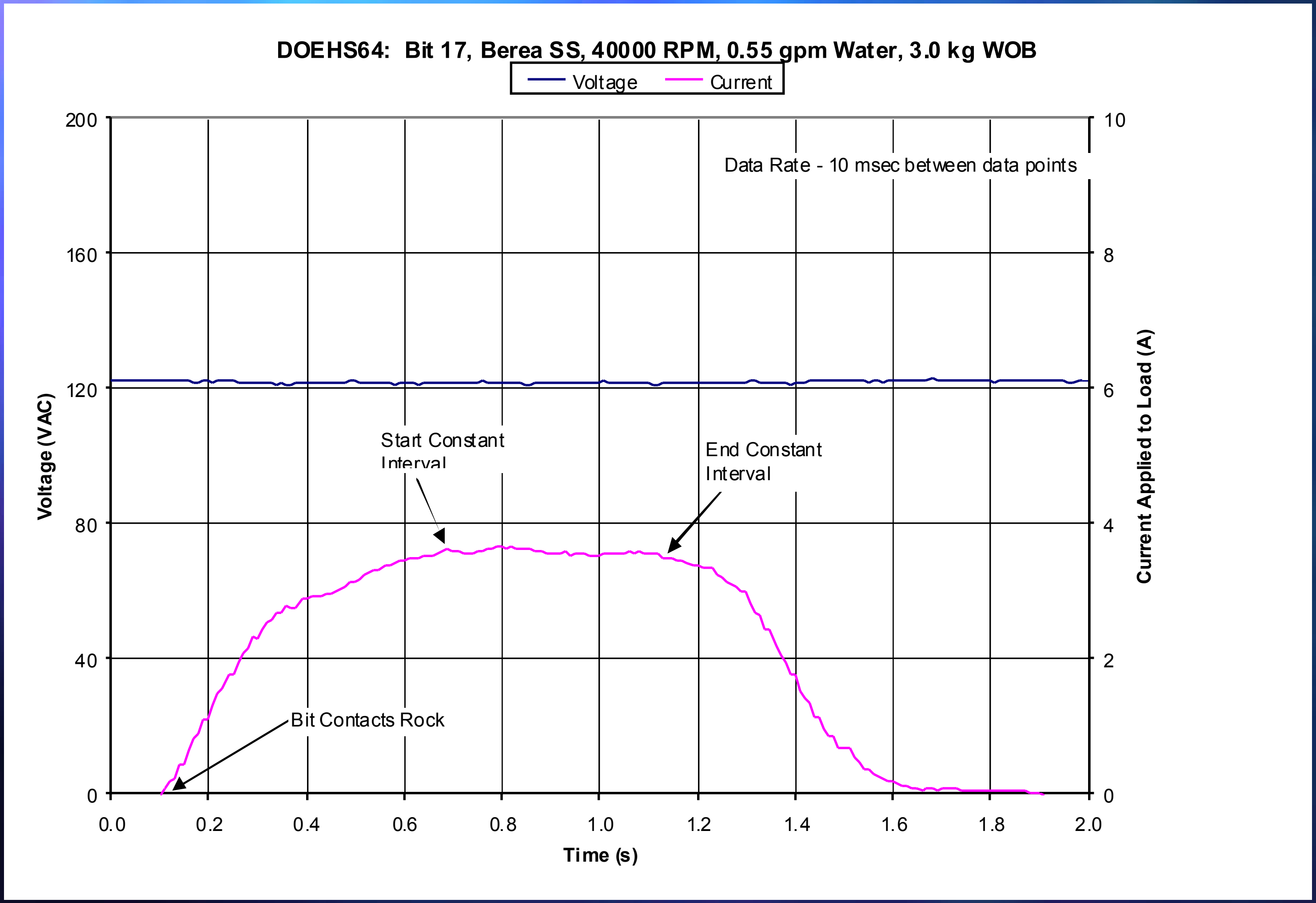
Rear



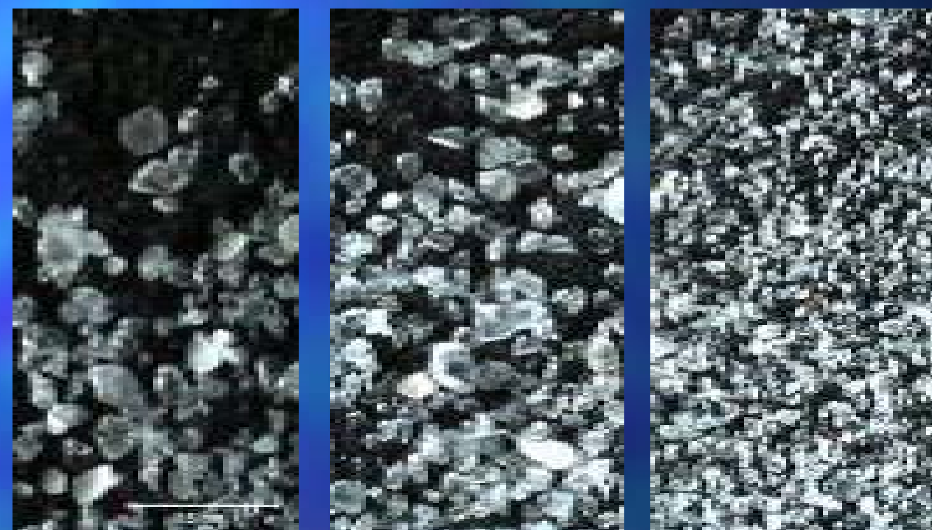
Penetration and RPM versus time showing steady state intervals



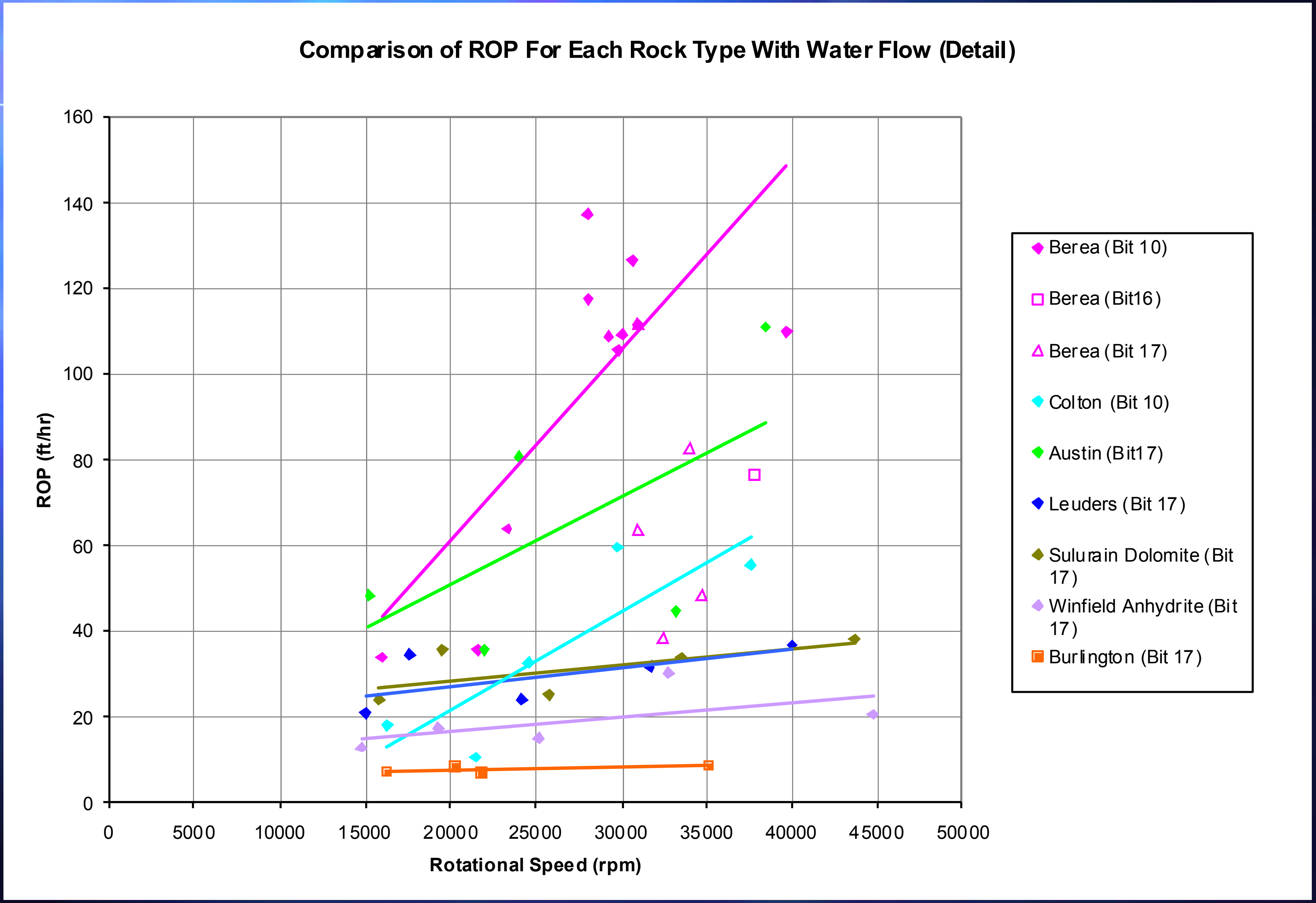
Voltage and current vs. time



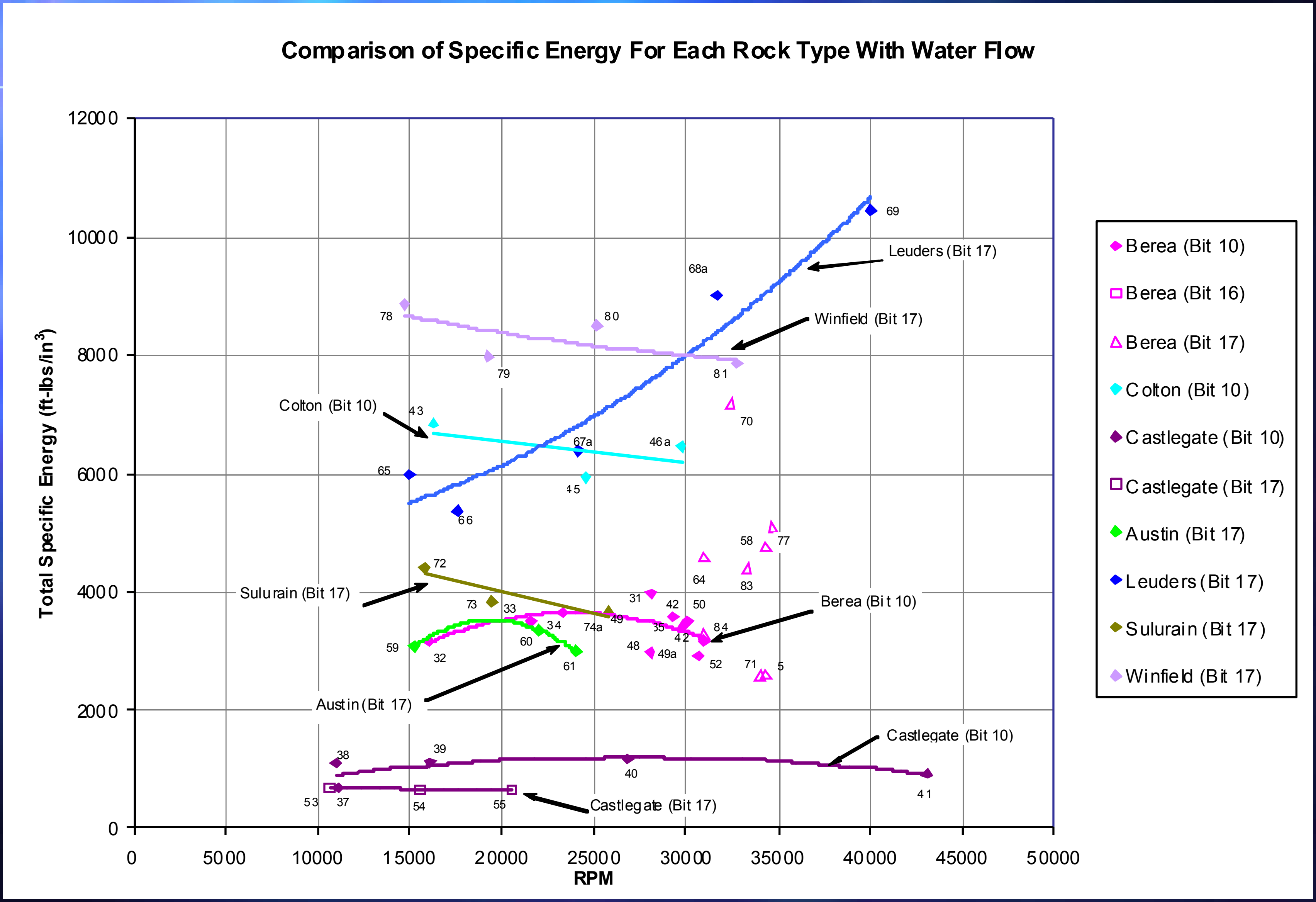
Cuttings obtained from three tests in Berea Sandstone

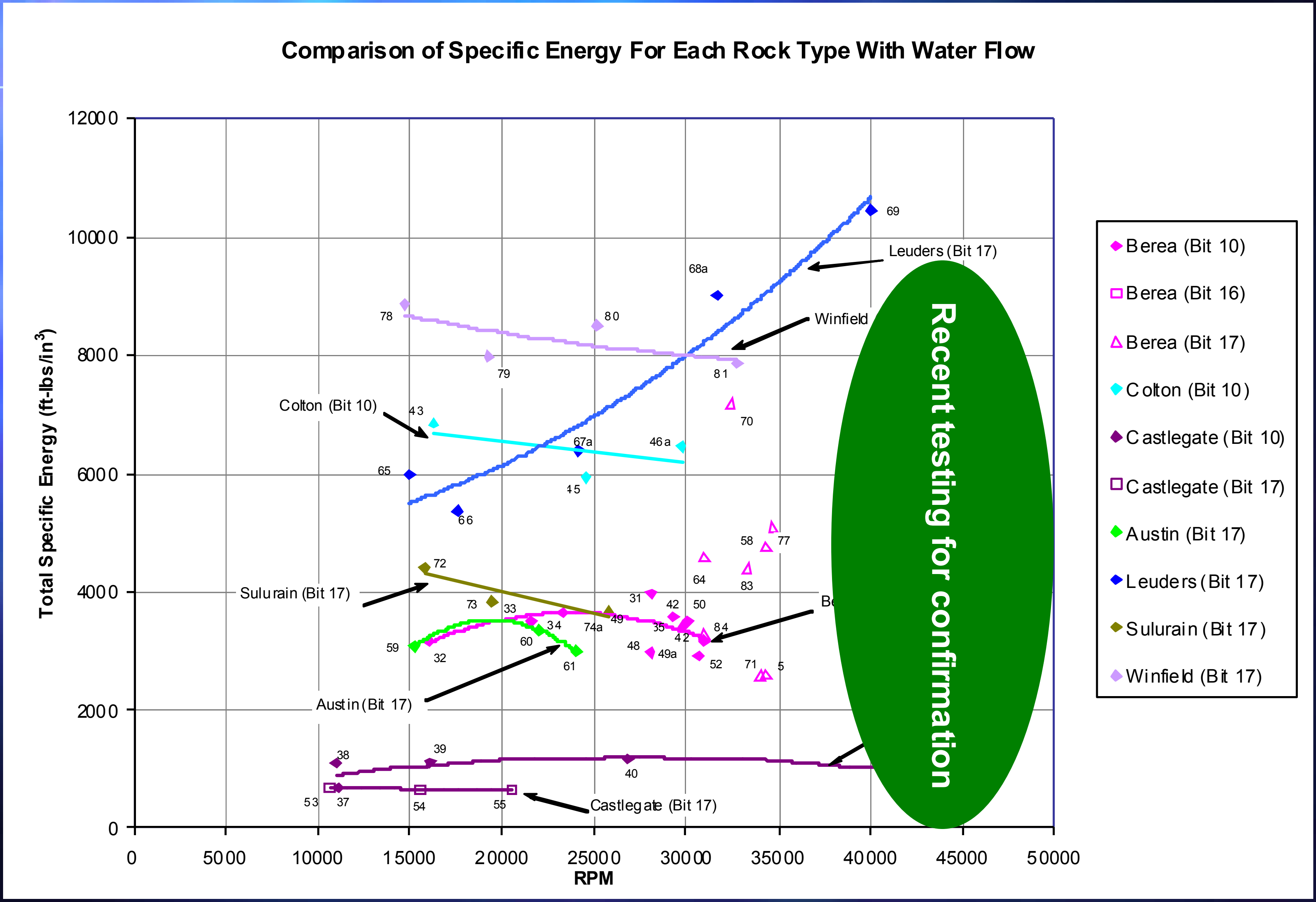


Drilling rotary speed (RPMs) 30 k 40 k 50k



Comparison of ROP For Each Rock Type With Water Flow (Detail)
ROP (ft/hr)
160
140
120
100
80
60
40
20
0
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
Rotational Speed (rpm)
Berea (Bit 10)
Berea (Bit16)
Berea (Bit 17)
Colton (Bit 10)
Austin (Bit17)
Leuders (Bit 17)
Sulurain Dolomite (Bit 17)
Winfield Anhydrite (Bit 17)
Burlington (Bit 17)


Comparison of Specific Energy For Each Rock Type With Water Flow
Total Specific Energy (ft-lbs/in³)
RPM
Leuders (Bit 17)
Winfield (Bit 17)
Colton (Bit 10)
Sulurain (Bit 17)
Berea (Bit 10)
Austin (Bit 17)
Castlegate (Bit 10)
Castlegate (Bit 17)
Berea (Bit 10)
Berea (Bit 16)
Berea (Bit 17)
Colton (Bit 10)
Castlegate (Bit 10)
Castlegate (Bit 17)
Austin (Bit 17)
Leuders (Bit 17)
Sulurain (Bit 17)
Winfield (Bit 17)

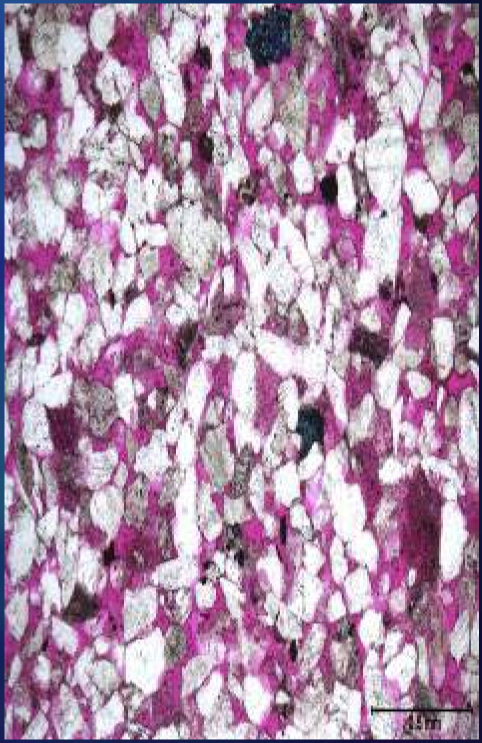


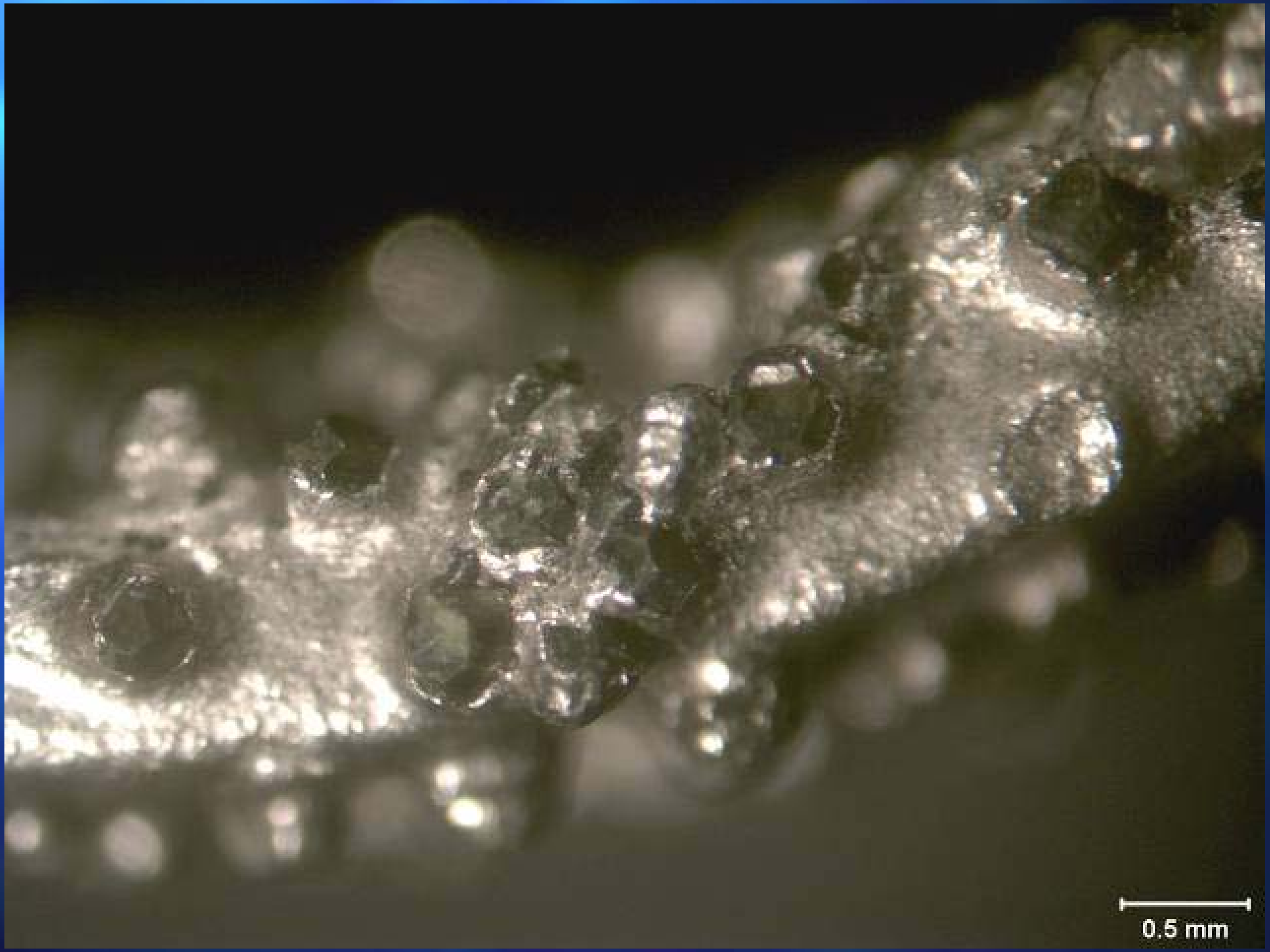
Comparison of Specific Energy For Each Rock Type With Water Flow
Total Specific Energy (ft-lbs/in³)
RPM
Leuders (Bit 17)
Winfield
Colton (Bit 10)
Sulurain (Bit 17)
Austin (Bit 17)
Castlegate (Bit 17)
Recent testing for confirmation
Berea (Bit 10)
Berea (Bit 16)
Berea (Bit 17)
Colton (Bit 10)
Castlegate (Bit 10)
Castlegate (Bit 17)
Austin (Bit 17)
Leuders (Bit 17)
Sulurain (Bit 17)
Winfield (Bit 17)

During the initial tests, the size of the cuttings decreased at increased rotary speeds and the cuttings collected from the highest speeds appeared smaller than the grain size of the sandstone, suggesting a possible change in removal mechanism at higher RPM. This slide shows a photograph of these cuttings compared to a photograph of a thin section of Berea sandstone in which the grains can be seen.

Cuttings when drilling at 50,000 RPM

Thin section

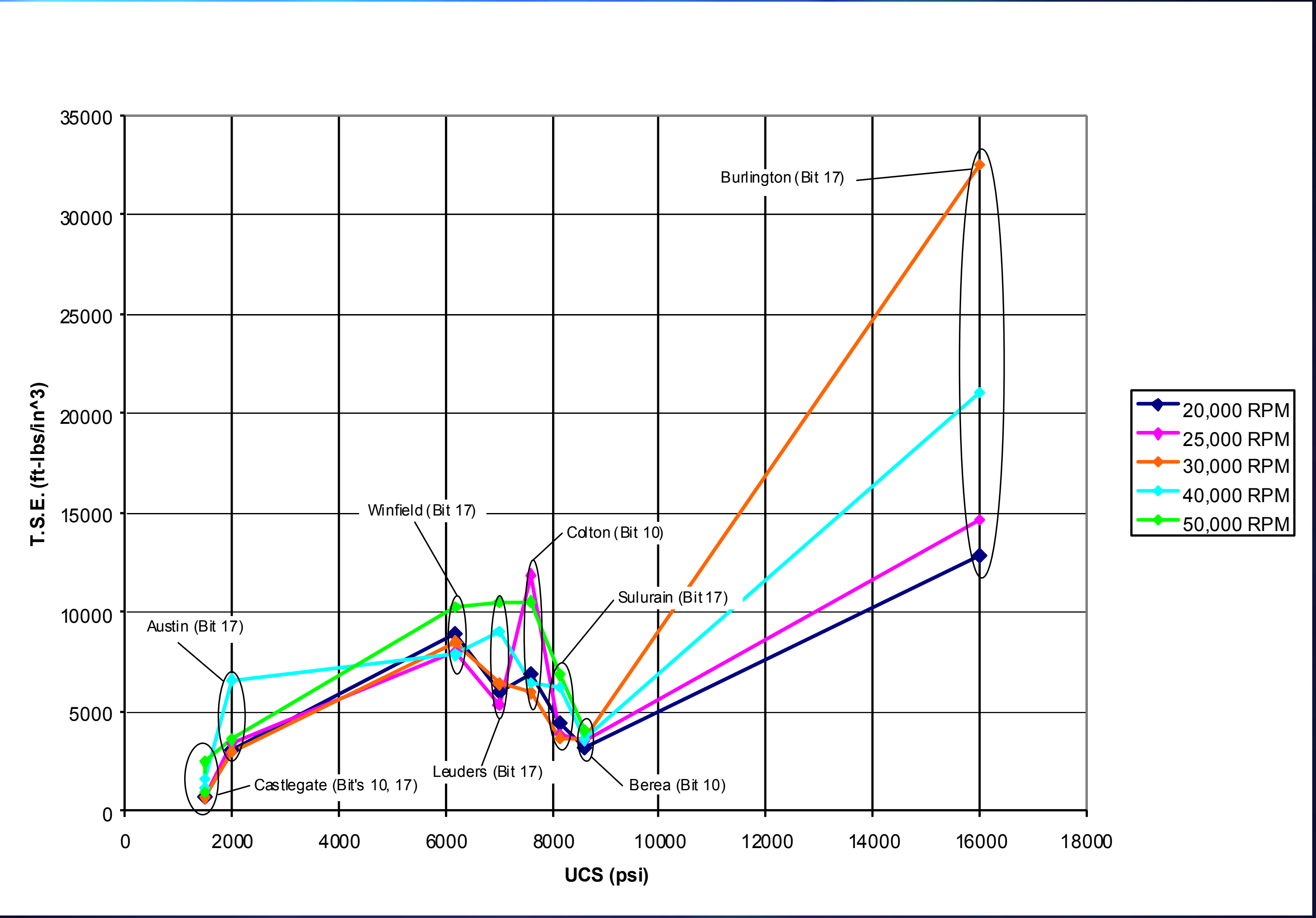



0.5 mm

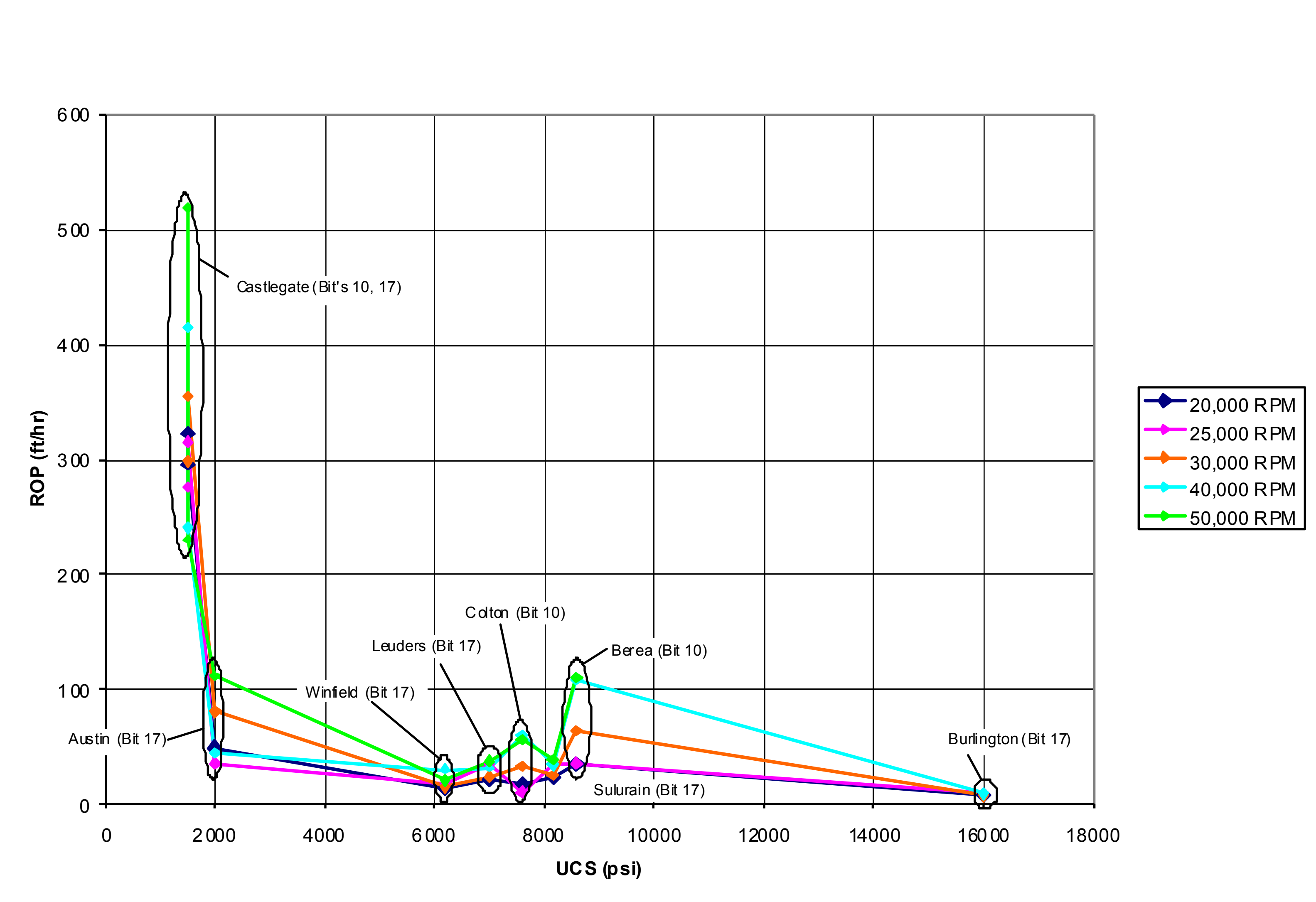
Typical properties . . . . . .

Rock Type	UCS (psi)	Porosity (%)	Bulk Density (gm/cc)
Berea SS	8600	20.0	2.230
Castlegate SS	1500	25.0	1.970
Colton SS	7600	10.9	2.380
Austin Chalk	2000	29.0	1.960
Leuders Limestone	7000	18.9	2.190
Sulurain Dolomite	8150	20.9	2.864
Winfield Anhydrite	6200	1.1	2.925
Burlington Limestone	16000	1.4	2.650

Relationship of specific energy & rock strength



Relationship of penetration rate and rock strength



Ongoing Work

- Evaluation of the collected cuttings is necessary to determine the significance of the change in cutting size at high RPM. If it is actually due to a change in removal mechanism, relationships of particle size distributions at different RPM, when compared and evaluated, should be used to characterize this phenomenon in different formations.
- Final Phase 1 testing is being conducted to ensure that data gaps are not missing and that performance charts get final analysis.
- Continued development of high-speed downhole motors will verify these test results at full (slim) scale and provide the link between this testing and oilfield implementation.
- Phase 2 application April 2006 for slim / microhole scale testing

Conclusions

- Penetration rates increased at higher rotational speeds and specific energy requirements decreased with increasing RPM in some cases.

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- Further evaluation and characterization of this phenomenon could be used as a factor in optimizing drilling parameters to maximize penetration while minimizing expended energy and tool wear.

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Phase 2
‘Demonstration of Concept and Performance Testing’

<u>MOTOR / DRIVE Options</u>

Impact Technologies (Oklahoma) electric drive; prototype lease potential for 9 months

APS fluid drive (larger collar)

Technology International, Inc. TSP – Turbine combination (B. Radtke)

Smith International fluid turbine

TerraTek to provide drive under rig for Phase 2 testing

Questions

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