Smaller Footprint Drilling System for Deep and Hard Rock Environments; Feasibility of Ultra-High-Speed Diamond Drilling

Technical Progress Report

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ABSTRACT

The two phase program addresses long-term developments in deep well and hard rock drilling. TerraTek believes that significant improvements in drilling deep hard rock will be obtained by applying ultra-high rotational speeds (greater than 10,000 rpm). The work includes a feasibility of concept research effort aimed at development that will ultimately result in the ability to reliably drill 'faster and deeper' possibly with smaller, more mobile rigs. 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 (ROP) rock cutting with substantially lower inputs of energy and loads.

The significance of the 'ultra-high rotary speed drilling system' is the ability to drill into rock at very low weights on bit and possibly lower energy levels. The drilling and coring industry today does not practice this technology. The highest rotary speed systems in oil field and mining drilling and coring today run less than 10,000 rpm—usually well below 5,000 rpm.

This document details the progress to date on the program entitled "Smaller Footprint Drilling System for Deep and Hard Rock Environments: Feasibility of Ultra-High-Speed Diamond Drilling" for the period starting 1 October 2004 through 30 September 2005. Additionally, research activity from 1 October 2005 through 28 February 2006 is included in this report.

- TerraTek reviewed applicable literature and documentation and convened a project kick-off meeting with Industry Advisors in attendance (see Black).
- TerraTek designed and planned Phase I bench scale experiments (See Black). Some difficulties continue in obtaining ultra-high speed motors. Improvements have been made to the loading mechanism and the rotational speed monitoring instrumentation. New drill bit designs have been provided to vendors for production. A more consistent product is required to minimize the differences in bit performance. A test matrix for the final core bit testing program has been completed.
- TerraTek is progressing through Task 3 "Small-scale cutting performance tests."
    - Significant testing has been performed on nine different rocks.
    - Bit balling has been observed on some rock and seems to be more pronounces at higher rotational speeds.
- Preliminary analysis of data has been completed and indicates that decreased specific energy is required as the rotational speed increases (Task 4). This data analysis has been used to direct the efforts of the final testing for Phase I (Task 5).
- Technology transfer (Task 6) has begun with technical presentations to the industry (see Judzis).

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EXECUTIVE SUMMARY

Background

The "Smaller Footprint Drilling System for Deep and Hard Rock Environments; Feasibility of Ultra-High-Speed Diamond Drilling" tests are being conducted to explore specific energy requirements while drilling at ultra high rotational speeds. Also, to determine trends in penetration rates as related to specific energy and rotation speed and investigate any evidence of changes in rock removal mechanisms at such speeds.

Accomplishments

The following was accomplished reported during previous reporting period (see Black):

- TerraTek reviewed applicable literature and documentation and has convened a project kick-off meeting with Industry Advisors in attendance.
- TerraTek has designed and planned Phase I bench scale experiments. Some difficulties in obtaining ultra-high speed motors for this feasibility work were encountered though they were sourced mid 2004.
- TerraTek made progress in small-scale cutting performance tests.
- Some improvements over early NASA experiments have been identified.

The following has been accomplished during the past 17 months:

- Quarter 4 2004—Six preliminary drilling tests were run in Berea sandstone at various rotational speeds using nitrogen as a drilling fluid.
- Quarter 2 2005—Ran 24 tests on Berea and Colton sandstones at various rotational speeds to determine the best drilling fluid (nitrogen or water) and flow rate. Water was selected for the drilling fluid and the optimum flow rate of 0.55 gal/min determined. Bit wear seemed to decrease with the use of water for a drilling fluid.
- Quarter 4 2005—Ran 71 tests using Berea sandstone, Castlegate sandstone, Colton sandstone, Nugget sandstone, Austin chalk, Leuders Limestone, Burlington Limestone, Sulurian dolomite, and Winfield anhydrite. These tests were run at various rotational speeds using water as a drilling fluid.
- January and February 2006—Ten tests were run on Berea sandstone, Burlington limestone, and Nugget sandstone at various rotational speeds and with water as a drilling fluid.
- Design improvements have been made in the loading mechanism and the sensor for monitoring rotational speed.
- A paper titled "Investigation of Smaller Footprint Drilling System; Ultra-High Rotary Speed Diamond Drilling Has Potential for Reduced Energy Requirements," authored by Arnis Judzis, et al. (see Judzis), was prepared and

presented at the IADC/SPE Drilling Conference in February 2006. This paper outlined accomplishments to date on the Ultra-High Speed Diamond Drilling project.

- Preliminary engineering and assessment of high speed motors has begun. Contact has been made with four parties regarding high speed motors for Phase 2 testing.

Current Activity

TerraTek is proceeding with Tasks 3, 4, 5, and 6 with continued testing and analysis of data, preliminary engineering to scale-up for Phase 2, and transferring the technology to industry. Using the preliminary results from the tests, a test matrix has been completed to complete the core bit tests.

Drill bit design improvements and manufacturing process enhancements will provide better, more consistent core drilling bits for the final phase of testing.

Presentations are scheduled with industry associations to discuss test findings and explore future possibilities for high rotational speed drilling.

INTRODUCTION

Objective

The objective of this test program is to explore specific energy requirements while drilling at ultra high rotational speeds. Also, to determine trends in penetration rates as related to specific energy and rotation speed and investigate any evidence of changes in rock removal mechanisms at such speeds.

Scope

The two phase program addresses long-term developments in deep well and hard rock drilling. TerraTek believes that significant improvements in drilling deep hard rock will be obtained by applying ultra-high rotational speeds (greater than 10,000 rpm). The work includes a feasibility of concept research effort aimed at development that will ultimately result in the ability to drill ‘faster and deeper’ with smaller, more mobile rigs. The principle focus is on demonstration testing of diamond bits rotating at speeds in excess of 10,000 rpm to achieve high ROP rock cutting with substantially lower energy and load.

This document details the progress to date on the program entitled “Smaller Footprint Drilling System for Deep and Hard Rock Environments: Feasibility of Ultra-High-Speed Diamond Drilling” for the period starting 1 October 2004 through 28 February 2006.

Plan

The plan of this program is to develop equipment necessary (on a small scale) to test the high rotational speed drilling concept to determine if less specific energy is required to drill at higher rotational speeds. The test apparatus and instrumentation have been developed and testing is ongoing. Once the concept has been proven, additional work will be required to develop scaled up equipment and test in a more field-like atmosphere.

METHODS and PROCEDURES

Theory

Specific Energy refers to the amount of energy required to remove a volume of rock while drilling. The total specific energy for rotary drilling is the sum of the rotational component and axial components (Equation 1). The rotational specific energy was calculated using the voltage across the motor, the current used by the motor, the ROP, and the area of rock removed (Equation 2). The axial component was determined using the weight on bit and the area of the rock removed (Equation 3). Reported units for specific energy are ft-lb/in^3.

$$SE_{Tot} = SE_{Rot} + SE_{Ax} \qquad (1)$$

$$SE_{Rot} = \frac{1.726(VI)}{ROP(D_o^2 - D_i^2)} \qquad (2)$$

$$SE = \frac{0.00043WOB}{D_o^2 - D_i^2} \qquad (3)$$

Where:

D_i = inside diameter, inches
D_0 = outside diameter, inches
I = current, i, amperes
SE_{Tot} = total specific energy, ft-lbs/in^3
SE_{Rot} = rotational specific energy, ft-lbs/in^3
SE_{Ax} = axial specific energy, ft-lbs/in^3
ROP = rate of penetration, inches/sec
V = voltage, volts
WOB = weight on bit, g

For applications of high rotary speeds and low weight on bit, the rotational component is significantly greater than the axial component.

Test Apparatus

Rock Samples. Samples of 9 different lithologies were tested. Berea sandstone was used as a baseline rock and repeat tests in Berea sandstone were run to detect any performance changes due to bit wear. The rock types selected for this study and the rock properties are listed in Table 1. Rock samples 3” x 5” x 1.5” were prepared by first cutting the rocks such that the bedding planes ran parallel to the largest face, the face where the rocks were to be drilled. Ten holes, 3/16 inch in diameter, were drilled through each rock (two rows of five holes) for the introduction of fluid to assist in cooling and cleaning the bits. The back of the samples were counter bored and fittings attached with adhesive.

Table 1. Properties of the rock used for Ultra-High Speed Diamond Drilling tests.

Rock Type	Compressive Strength, Unconfined (psi)	Porosity (%)	Bulk Density (g/cm^3)
Berea Sandstone	8,600	20.0	2.230
Castlegate Sandstone	1,500	25.0	1.970
Colton Sandstone	7,600	10.9	2.380
Nugget Sandstone	18,500	9.7	2.393
Austin Chalk	2,000	29.0	1.960
Leuders Limestone	7,000	18.9	2.190
Sulurain Dolomite	8,150	20.9	2.864
Winfield Anhydrite	6,200	1.1	2.925
Burlington Limestone	16,000	1.4	2.650

Coring Bits and Drive Motor. Diamond coring bits (Figure 1), nominally 0.82" outside diameter x 0.51" inside diameter x 0.5" drilling length with a kerf area of about 0.324 in^2, were sized to allow drilling with a commercially available "Hall Effect" ultra-high speed motor. Natural diamonds (20/25 mesh) were applied to the core bit head using an electrolysis coating technique. The bits used in these tests typically had about 60 diamonds on the cutting kerf. Of these 60 diamonds, only a small number were in contact with the formation due to variability in diamond height. The bits were dynamically balanced at several 1000 rpm. Future bits are being manufactured with fewer diamonds and with more controlled spacing and height to improve consistency and increase drilling performance.

Figure 1. A core drilling bit used for the high speed drilling tests.

The Hall effect drive motor is no load rated for 51,000 rpm. The drill bit is mounted directly to the motor shaft.

Drilling Apparatus and Instrumentation Setup. The sample was clamped to a low friction table moving on Thompson rods. A steel cable was attached to the front of the table, passed over a pulley, and then attached to a hanging rod of known mass. The rod was restricted only to axial

translation by Thompson bearings. The motor and bit were rigidly mounted such that the weight pulled the table and rock sample into the stationary bit during drilling. Pins were set up as stops to control the travel of the table and sample to 0.375" distance. Figure 2 is a photograph of the test apparatus setup.

Displacement was measured by means of a linear variable displacement transducer (LVDT) mounted to the table and the frame of the apparatus. An optical tachometer measured revolutions of the bit by recording the number of times a black strip on a white background painted on the bit passed the sensor. The setup included the sample, fluid lines, and instruments. Measurements of the current and voltage supplied to the motor were taken.

Test Parameters. The test parameters included:

- Rotational speeds (at the start of each test) were 20,000 rpm, 25,000 rpm, 30,000 rpm, 40,000 rpm, and 50,000 rpm.
- The weight on bit was limited to 3000 grams to operate within the motor's torque limit.
- Drilling fluids included nitrogen and water. Water was used as the drilling fluid for most of the tests.

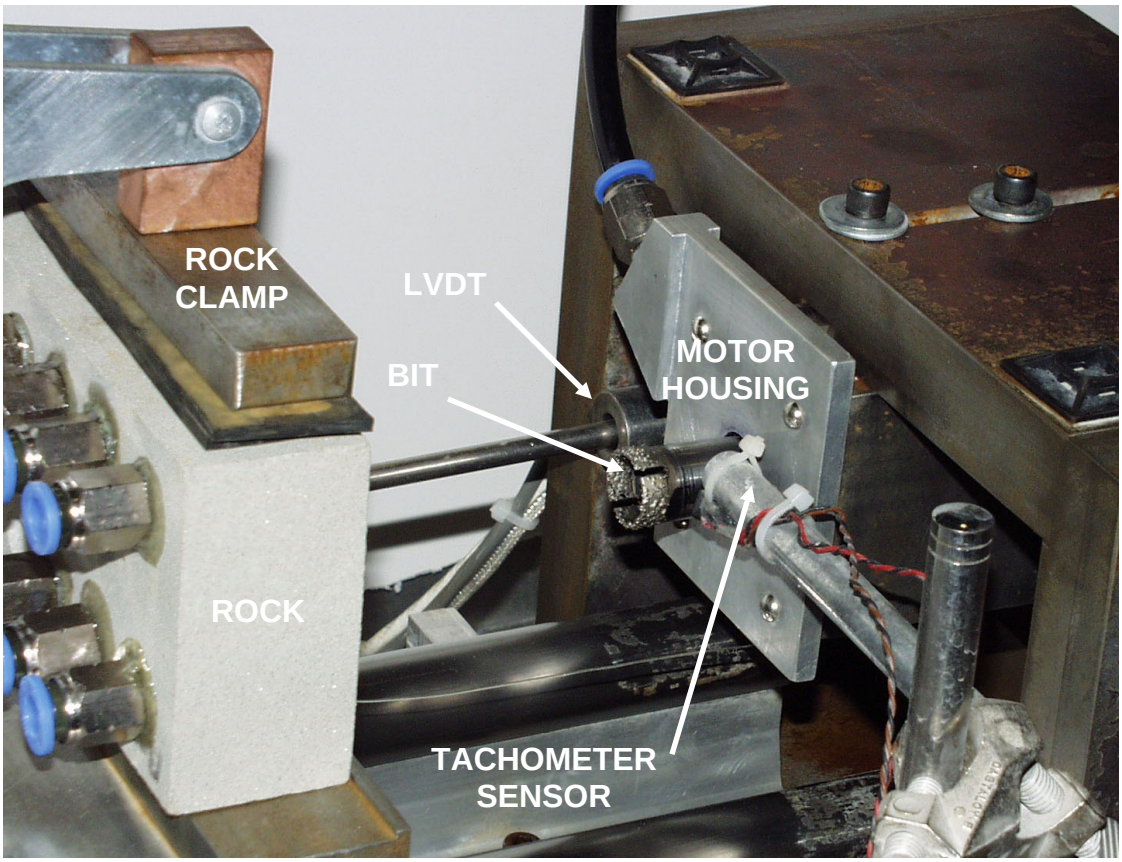

Figure 2. Photograph of the high speed drilling test setup.

Test Procedure

The motor was initially brought up to the nominal rotary speed with the rock sample very near but not in contact with the bit. The low friction table was then released allowing the sample to be forced into the bit at a constant weight on bit by means of gravitational forces on the attached mass. Samples of the cuttings were collected during each test for later analysis.

The detailed procedure included the following steps:

1. Measure no load amps to detect pending motor failure.
2. Install bit on motor shaft.
3. Clamp rock sample to table, aligning hole to the bit.
4. Set start pin to space the bit off the rock 0.002 inch.
5. Move bit forward to engage start pin.
6. Attach water line to back of sample making sure that the ball valve is closed and the needle valve is set.
7. Check the optical tachometer alignment.
8. Place an aluminum tray, to catch cuttings, on the table under the bit.
9. Zero Instruments.
10. Setup x-y-y' recorder.
11. Open ball valve to start water flow at 0.55 gpm.
12. Rotate drill bit to specified rotational speed.
13. Start the high rate data acquisition.
14. Pull start pin.
15. When stop pin is reached, or if ROP is less than slope line on x-y-y' (20 ft/hr), or if motor stalls, lift weight to stop drilling.
16. Bring rotational speed to zero.
17. Stop water flow.
18. Remove cuttings in aluminum tray, label and dry.
19. Label hole drilled and measure inside diameter and outside diameter of the hole.
20. Photograph bit.
21. Examine cuttings under microscope and photograph.
22. Calculate ROP (in/rev), average voltage, average amperage change (subtract initial amps), rotational speed, pressure, and perform specific energy calculations.
23. Generate plots and add test data and calculated specific energy to a table.

Statistics and Data Reduction

After each test the data were plotted and analyzed. Several key plots were used to analyze the test, including: penetration and rotational speed versus time and current and voltage versus time. The slope of the penetration curve was examined and areas of steady penetration rate identified. The slope of this line over the steady interval was used to calculate the penetration rate and also average values of rotational speed, current and voltage over the same interval were used in the specific energy calculations. Figures 3 and 4 are penetration/rotational speed and current/voltage plots for a test in Berea Sandstone. Intervals of steady penetration rates are indicated on the penetration plot. For each test, the dimensions of the annulus cut in the rock were also measured and used in the calculation of specific energy. Plots for tests DEAHS22 through DEAHS102 are in

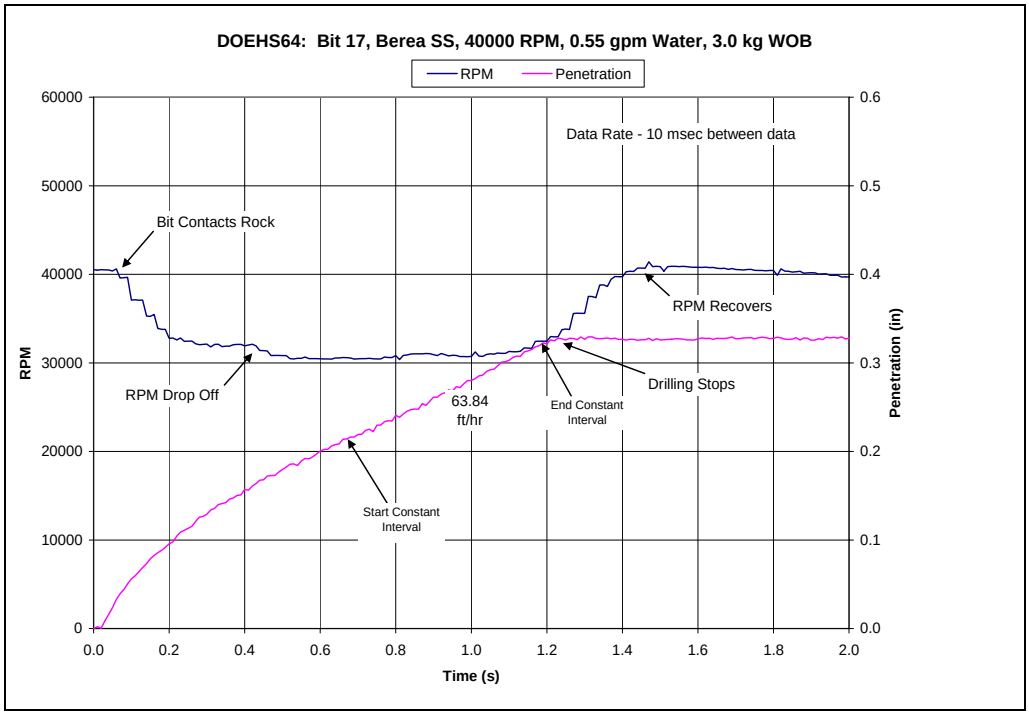

Figure 3. Rotational speed and penetration plot.

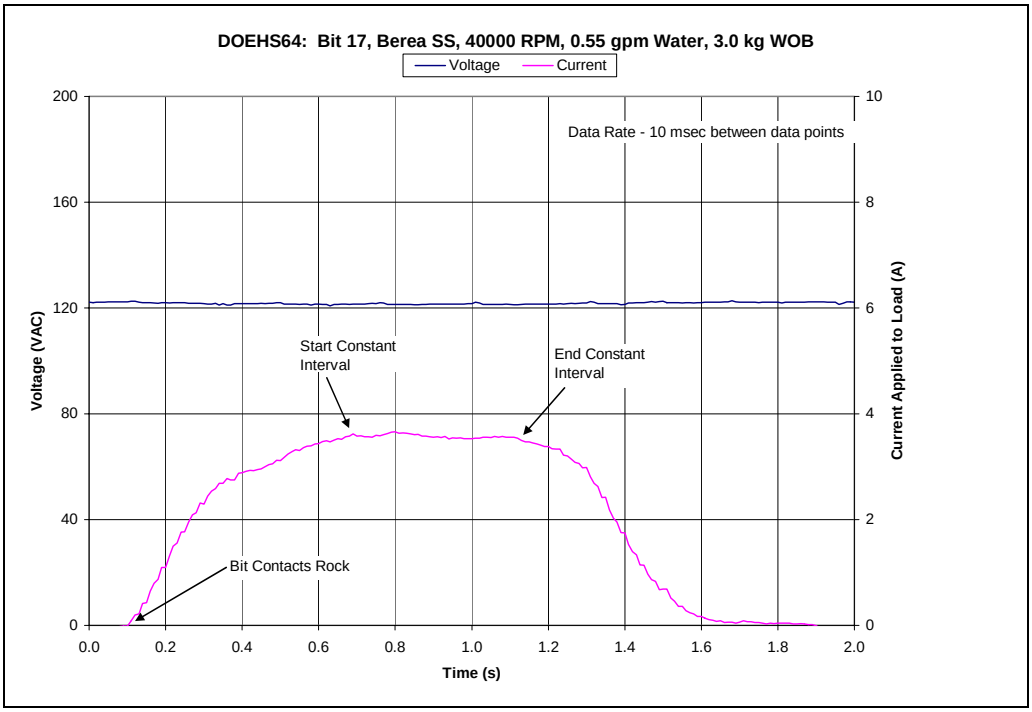

Figure 4. Current and voltage plot during a test.

Appendix B. Photographs of drill bits and drill cuttings collected are also provided in this appendix. This information will be used as a basis for more thorough analysis.

TASK ACCOMPLISHMENTS

The following is a summary of the accomplishments for each of the Phase I tasks.

Task 1.0 – Assessment of deep and hard rock drilling environments requiring novel technologies and tools. This work was completed and reported previously (see Black).

Task 2.0 – Design, engineer, and plan ultra-high speed drilling program concepts. This task was addressed in the previous report. However, some improvements have been made to improve the test operation data collection and quality. Changed made during this reporting period included:

- The loading system was improved by replacing the unstable weight apparatus with a steel cable and a restrained weight system described above.
- The rotary speed instrumentation was improved and protected from the liquid drilling fluid.
- Drill bits were redesigned and methods of manufacture developed to produce a consistent core bit configuration.

Task 3.0 – Small-scale cutting performance tests. Extensive tests were run with various rock, bits, fluids, and loads. The preliminary data has been summarized and is presented in table form in Appendix A.

Task 4.0 – Analysis of data and concept evaluation. Preliminary data analysis was performed after each series of tests to evaluate the trends in specific energy for each rock. A summary plot of the trends in specific energy is provided in Figure 5. Figure 6 provides plots of the ROP for the same rock. Plots of the specific energy for each of the rock types tested. Plots of the penetration and rotary speed and the current and voltage for each test run are provided in Appendix B. This appendix also provides photographs of the drill bits and collected drill cuttings for further analysis.

Task 5.0 – Engineering design. Preliminary engineering for the demonstration of the ultra-high speed drilling concept at mining bit size has begun. Four companies have been contacted regarding high speed motors.

Task 6.0 – Transfer of technology. A paper titled “Investigation of Smaller Footprint Drilling System; Ultra-High Rotary Speed Diamond Drilling Has Potential for Reduced Energy Requirements,” (see Judzis) authored by Arnis Judzis, et al., was prepared and presented at the IADC/SPE Drilling Conference held in Miami, Florida on 23 February 2006. This paper outlined accomplishments to date on the Ultra-High Speed Diamond Drilling project. Additonal technology transfer presentations are scheduled.

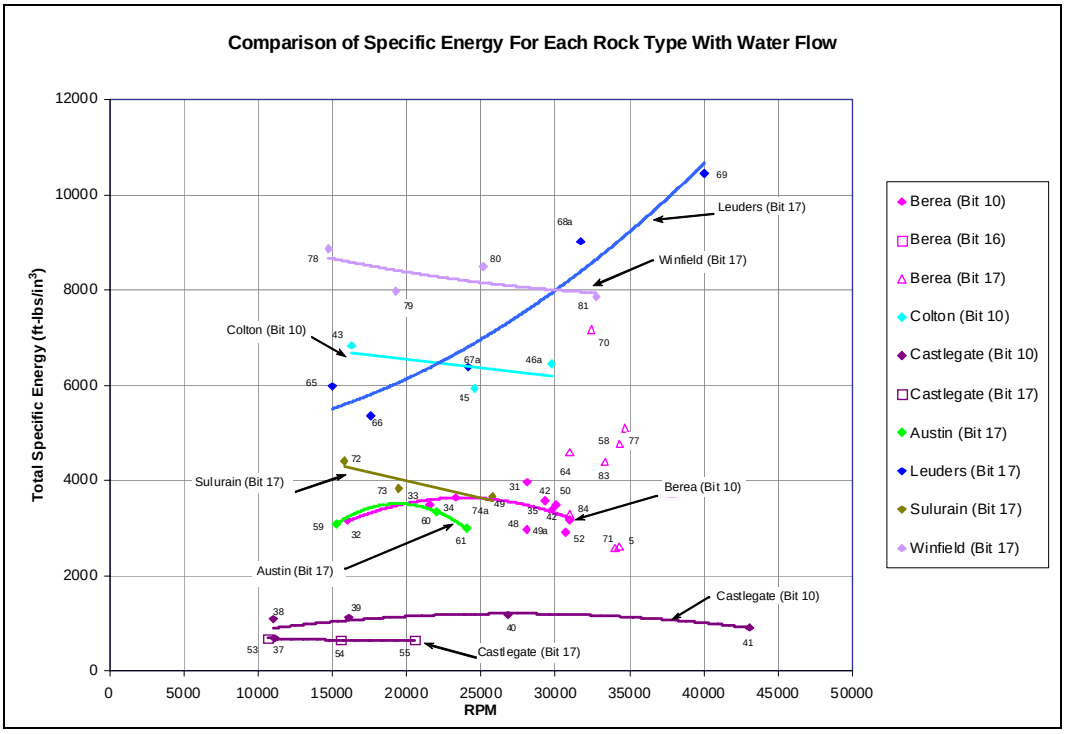

Figure 5. Specific energy of ultra-high speed drilling was determined for various rocks.

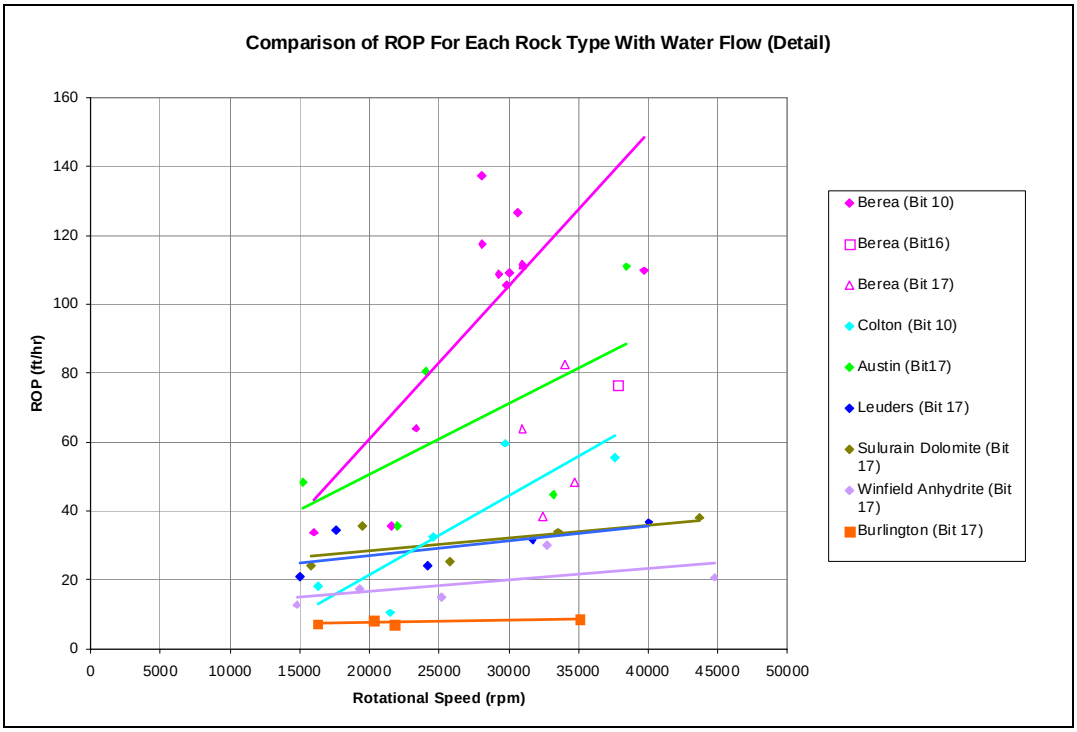

Figure 6. Rate of penetration of various rocks at various speeds.

EXPERIMENTAL ACTIVITY

Through September 2004

Activities completed through 30 September 2004 were reported previously (see Black). Significant accomplishments through that period are summarized and include:

1. TerraTek reviewed applicable literature and documentation and convened a project kick-off meeting with Industry Advisors in attendance.
2. The ultra-high speed equipment was modified and samples of selected rocks were prepared for the tests.
3. Initial checkout tests were run.
4. New motors and bits were obtained.
5. Problems with penetration rates, motor failures and bit balancing were addressed.

October 2004 through September 2005

Quarter 4 2004—Preliminary drilling test was run during this quarter. This test was run on Berea sandstone using a heavy set bit.

Quarter 2 2005—Twenty-six tests were run on Berea and Colton sandstones at various rotational speeds to determine the best drilling fluid (nitrogen or water) and flow rates to use. Water was selected as the drilling fluid because there appeared to be less bit wear with this fluid. A flow rate of 0.55 gal/min determined to be optimum.

October 2004 through February 2006

Quarter 4 2005—Ran 71 tests on Berea sandstone, Castlegate sandstone, Colton sandstone, Nugget sandstone, Austin chalk, Leuders Limestone, Burlington Limestone, Sulurian dolomite, and Winfield anhydrite. These tests were run at various rotational speeds using water as a drilling fluid. The optical tachometer and associated instrumentation malfunctioned at times. This problem was corrected by isolating the circuitry from the drilling fluid. The problem of inconsistent loading of the bit was encountered in the bit loading system. A new design using a cable and a linear bearing was implemented which alleviated the problem. Details of the current configurations are provided in the Methods, Assumptions, and Procedures section above.

January and February 2006—Ten tests were run on Berea sandstone, Burlington limestone, and Nugget sandstone at various rotational speeds and with water as a drilling fluid. The program continues to encounter motor failure problems. Additional motors were ordered to allow testing to be concluded. New coring bits were designed and details provided to the manufacturer. Full-faced drilling bits were designed.

A paper titled “Investigation of Smaller Footprint Drilling System; Ultra-High Rotary Speed Diamond Drilling Has Potential for Reduced Energy Requirements,” authored by Arnis Judzis, et al., was prepared and presented at the IADC/SPE Drilling Conference held in Miami, Florida on 23 February 2006. This paper outlined accomplishments to date on the Ultra-High Speed Diamond Drilling project.

Future Activities

1. Complete statistical design of experiment for the final trials.
2. Modify the motor housing to improve cooling and support of the motor.
3. Obtain new core bits.
4. Work with the vendor to obtain full-face drill bits.
5. Evaluate bit wear.
6. Evaluate rock failure mechanism.
7. Complete a through statistical analysis of all data and make conclusions.
8. Complete preliminary engineering equipment scale up.
9. Transfer technology and hold a “lesson’s learned” meeting.
10. Write the final report and make recommendations for Phase 2 continuation.

RESULTS AND DISCUSSION

Initial tests were conducted in Berea Sandstone to determine specific energy trends and to evaluate the relative effectiveness of drilling fluids and flow rates. Nitrogen and water were both evaluated as drilling fluids.

Though the general trends in specific energy and ROP were consistent with the expectations, both of these values are somewhat unstable from test to test. Inconsistencies in strength and composition within a single rock sample account for some of the ROP variation observed. Additionally, bit wear is a factor in the performance that creates variations in the data. Also, the placement of diamonds on each bit and the number of diamonds on each bit varies from bit to bit. While the general trends of the data are valid and are consistent with theory, the variation in each test can be attributed to these inconsistencies.

As expected, ROP increased with higher rotational speed. As a general trend, specific energy decreased with increasing rotational speed. The ROP trend is consistent with existing theory and the trend in specific energy, while a departure from existing theory is consistent with the expectations of this testing program. The ROP was not as high as expected at the highest rotational speed while using nitrogen as the drilling fluid. Inspection of the bit following this test showed high levels of bit wear. While using water at the drilling fluid, ROP continued to increase at high rotational speed without the bit wear observed using nitrogen.

There is a trend, with some rock types, indicating a general decrease in specific energy at higher rotational speeds for values up to 40,000. Above 40,000 rpm, there was a slowing in ROP and an increase in specific energy. The data suggest that at rotational speed values greater that 40,000 significant balling occurred (particularly in limestone rocks) and invalidated the tests. Figure7 shows “balled” rock material on the bit. At rotational speed values greater than 40,000 the penetration rates did not increase as expected. This fact and examination of the bits after testing indicate that significant balling occurred.

Though balling to the extent seen in the tests at rotational speed values greater than 40,000 was not seen in the slower rotational speed tests, some balling may have occurred at speeds near but lower than 40,000 rpm. Such partial balling would have an effect on the decline in specific energy at these speeds. Also, increased vibrations occurred at rotational values greater than 40,000 rpm. Such vibrations would also tend to increase the kerf size and specific energy requirements. Specific energy values at these speeds may actually be lower than the values calculated from the data obtained.

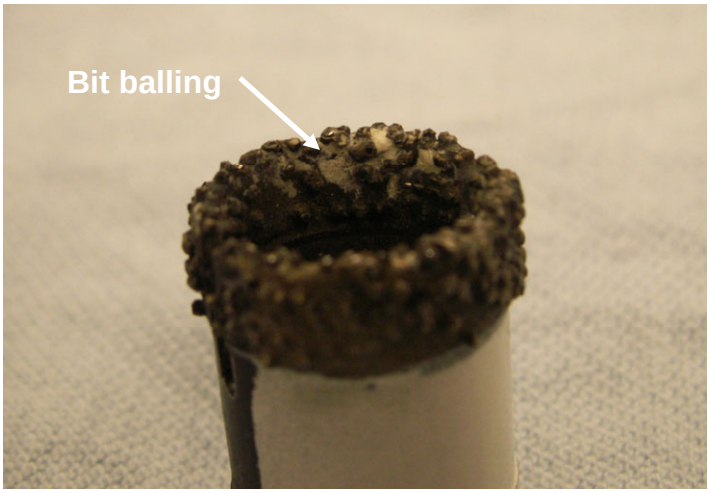

Figure 7. Rock material "balled" between the diamond cutters.

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Black, Alan, Judzis, Arnis, "Smaller Footprint Drilling System for Deep and Hard Rock Environments; Feasibility of Ultra-High Speed Diamond Drilling," October 2004, Technical Progress Report for the Department of Energy, DOE Award Number: DE-FC26-03NT15401.

Judzis, Arnis, Boucher, Marcel, McCammon, Jason, Black, Alan, 2006, "Investigation of Smaller Footprint Drilling System; Ultra-High Rotary Speed Diamond Drilling has Potential for Reduced Energy Requirements," IADC/SPE 99020, presented at the IADC/SPE Drilling Conference, Miami, Florida, U.S.A., 21-23 February 2006.

APPENDIX A.
Summary of Test Data

Table A1. Test data summary for Ultra-Rotary Speed Diamond Drilling

Table A1. Test data summary for Ultra-High-Speed Rotary Diamond Drilling.

Test	Test Date	Rock Type	Bit	Rotary Speed		Drilling Fluid	Rate of Penetration (in/sec)	Specific Energy (ft-lb/in^3)	Comments
				Target (rpm)	Actual (r/min)				
DOE1a	1/12/2004	Berea SS[1]	Mars	10,000	5,452	Nitrogen	0.0829	6,116	
DOE2a	1/12/2004	Berea SS	Mars	30,000	22,927	Nitrogen	0.1806	4,311	
DOE2c	1/14/2004	Berea SS	Mars	40,000	41,728	Nitrogen	0.0713	1,629	
DOE3a	1/14/2004	Berea SS	Mars	20,000	14,566	Nitrogen	0.0982	5,545	
DOE3b	1/14/2004	Berea SS	Mars	40,000	33,890	Nitrogen	0.1908	3,960	
DOE3c	1/14/2004	Berea SS	Mars	43,000	41,915	Nitrogen	0.0453	2,744	
DOE3d	1/14/2004	Berea SS	Mars	15,000	11,272	Nitrogen	0.0777	5,633	
Pre1	9/16/2004	Berea SS	1	25,000	17,465	Nitrogen	0.2899	3,145	15 psi N_2-evaluate flow
Pre2	9/16/2004	Berea SS	1	25,000	19,628	Nitrogen	0.1955	3,284	50 psi N_2-evaluate flow
Pre3	9/16/2004	Berea SS	1	25,000	19,363	Nitrogen	0.2507	2,909	100 psi N_2-evaluate flow
Pre4	9/16/2004	Berea SS	4	30,000	27,850	Nitrogen	0.1129	1,334	100 psi N_2-evaluate flow
Pre5	9/16/2004	Berea SS	4	40,000	39,886	Nitrogen	0.0412	982	100 psi N_2-evaluate flow
HS1A	10/19/2004	Berea SS	2	30,000	24,853	Nitrogen	0.2823	2,753	Heavy set bit
DEAHS01	4/29/2005	Berea SS	8	30,000	24,454	Nitrogen	0.3819	2,515	150 psi N_2-evaluate flow
DEAHS02	4/29/2005	Berea SS	8	40,000	30,338	Nitrogen	0.5906	2,236	150 psi N_2-evaluate flow
DEAHS03	4/29/2005	Berea SS	8	50,000	45,634	Nitrogen	0.4230	2,081	150 psi N_2-evaluate flow
DEAHS04	5/5/2005	Colton SS	8	30,000	27,554	Nitrogen	0.0294	15,993	150 psi N_2-evaluate flow
DEAHS05	5/5/2005	Colton SS	8	40,000	37,790	Nitrogen	0.0199	21,487	150 psi N_2-evaluate flow
DEAHS06	5/5/2005	Colton SS	8	50,000	46,763	Nitrogen	0.0098	63,783	150 psi N_2-evaluate flow
DEAHS07	5/5/2005	Berea SS	8	40,000	34,430	Nitrogen	0.3219	2,609	150 psi N_2-evaluate flow
DEAHS08	5/5/2005	Berea SS	9	30,000	28,947	Water	0.3455	1,199	Evaluate water flow-too high
DEAHS09	5/5/2005	Berea SS	9	40,000	35,346	Water	0.2916	1,305	Evaluate water flow-too high
DEAHS10	5/5/2005	Berea SS	9	50,000	47,590	Water	0.2618	944	Evaluate water flow-too high
DEAHS10A	5/16/2005	Berea SS	9	25,000	22,927	Water	0.0500	4,281	Evaluate water flow-too high
DEAHS10B	5/16/2005	Berea SS	9	20,000	17,900	Water	0.0972	2,646	Evaluate water flow-too high
DEAHS10C	5/16/2005	Berea SS	9	20,000	18,364	Water	0.1443	2,565	Evaluate water flow-too high
DEAHS10D	5/16/2005	Berea SS	9	25,000	23,460	Water	0.0741	3,670	Evaluate water flow-too high
DEAHS10E	5/16/2005	Berea SS	9	30,000	27,143	Water	0.0663	4,644	Evaluate water flow-too high
DEAHS10F	5/16/2005	Berea SS	9	40,000	34,934	Water	0.1500	3,291	Evaluate water flow-too high
DEAHS10G	5/16/2005	Berea SS	9	50,000	45,982	Water	0.1157	2,693	Evaluate water flow-too high

Table A1. Test data summary for Ultra-High-Speed Rotary Diamond Drilling.

Test	Test Date	Rock Type	Bit	Rotary Speed		Drilling Fluid	Rate of Penetration (in/sec)	Specific Energy (ft-lb/in^3)	Comments
				Target (rpm)	Actual (r/min)				
DEAHS11	5/18/2005	Colton SS	9	30,000		Water	0.0950	NC[3]	Evaluate water flow-2.2 gpm
DEAHS12	5/23/2005	Colton SS[1]	9	40,000		Water	0.1030	NC[3]	Evaluate water flow-2.2 gpm
DEAHS13	5/23/2005	Colton SS	9	50,000		Water	0.0537	NC	Evaluate water flow-2.2 gpm
DEAHS14	5/23/2005	Berea SS	9	40,000		Water	0.2643	NC	Evaluate water flow-2.2 gpm
DEAHS15	5/23/2005	Berea SS	9	50,000		Water	0.0827	NC	Evaluate water flow-2.2 gpm
DEAHS16	6/1/2005	Berea SS	9	50,000		Water	0.1889	NC	Evaluate water flow-2.2 gpm
DEAHS17	6/1/2005	Berea SS	9	40,000		Water	0.3905	NC	Evaluate water flow-1.1 gpm
DEAHS18	6/1/2005	Berea SS	9	40,000		Water	0.3580	NC	Evaluate flow-0.55 gpm
DEAHS19	6/1/2005	Berea SS	9	40,000		Water	0.1211	NC	Evaluate water flow-2.2 gpm
DOEHS20	10/6/2005	Berea SS	10	20,000	10,214	Water	0.1772	4,644	RPM[4] probe problem
DOEHS21	10/11/2005	Berea SS	10	25,000	15,798	Water	0.2781	2,422	RPM probe problem
DOEHS22	10/11/2005	Berea SS	10	30,000	23,262	Water	0.2392	2,604	RPM probe problem
DOEHS23	10/11/2005	Berea SS	10	40,000	32,345	Water	0.2656	3,023	RPM probe problem
DOEHS24	10/11/2005	Berea SS	10	50,000	41,834	Water	0.2852	4,351	RPM probe problem
DOEHS25	10/11/2005	Castlegate SS	16	20,000	13,409	Water	0.7724	107	RPM probe problem
DOEHS26	10/11/2005	Castlegate SS	16	25,000	24,604	Water	0.3187	497	RPM probe problem
DOEHS27	10/11/2005	Castlegate SS	16	30,000	23,221	Water	1.2838	24	RPM probe problem
DOEHS28	10/11/2005	Castlegate SS	16	40,000	36,960	Water	2.3158	3	RPM probe problem
DOEHS29	10/11/2005	Castlegate SS	16	50,000	43,210	Water	3.0876	16	RPM probe problem
DOEHS30	10/11/2005	Berea SS	16	40,000	29,670	Water	0.3967	2,332	RPM probe problem
DOEHS31	11/7/2005	Berea SS	10	40,000	30,050	Water	0.3640	3,491	RPM reading consistent
DOEHS32	11/7/2005	Berea SS	10	20,000	15,993	Water	0.1129	3,174	
DOEHS33	11/7/2005	Berea SS	10	25,000	21,589	Water	0.1193	3,488	
DOEHS34	11/7/2005	Berea SS	10	30,000	23,340	Water	0.2136	3,643	
DOEHS35	11/7/2005	Berea SS	10	40,000	29,296	Water	0.3628	3,569	Calibration Replicate
DOEHS36	11/7/2005	Berea SS	10	50,000	39,705	Water	0.3660	4,011	
DOEHS37	11/8/2005	Castlegate SS	10	20,000	11,118	Water	1.0752	681	
DOEHS38	11/8/2005	Castlegate SS	10	25,000	11,054	Water	0.9179	1,084	
DOEHS39	11/8/2005	Castlegate SS	10	30,000	16,110	Water	0.9945	1,115	
DOEHS40	11/8/2005	Castlegate SS	10	40,000	26,848	Water	1.3812	1,173	
DOEHS41	11/8/2005	Castlegate SS	10	50,000	43,063	Water	1.7268	907	

Table A1. Test data summary for Ultra-High-Speed Rotary Diamond Drilling.

Test	Test Date	Rock Type	Bit	Rotary Speed		Drilling Fluid	Rate of Penetration (in/sec)	Specific Energy (ft-lb/in^3)	Comments
				Target (rpm)	Actual (r/min)				
DOEHS42	11/8/2005	Berea SS	10	40,000	29,832	Water	0.3520	3,395	Calibration Replicate
DOEHS43	11/8/2005	Colton SS	10	20,000	16,318	Water	0.0603	6,836	ROP[5] slow
DOEHS44	11/8/2005	Colton SS[1]	10	25,000	21,485	Water	0.0350	11,858	ROP slow
DOEHS45	11/8/2005	Colton SS	10	30,000	24,572	Water	0.1082	5,930	
DOEHS46a	11/8/2005	Colton SS	10	40,000	29,735	Water	0.1989	6,448	
DOEHS47	11/8/2005	Colton SS	10	50,000	37,628	Water	0.1850	10,524	
DOEHS48	11/8/2005	Berea SS	10	40,000	28,102	Water	0.3921	3,965	Evaluate load system
DOEHS49	11/8/2005	Berea SS	10	40,000	28,068	Water	0.4582	2,975	Evaluate load system
DOEHS49a	11/8/2005	Berea SS	10	40,000	30,676	Water	0.4218	2,920	Evaluate load system
DOEHS50	11/10/2005	Berea SS	10	40,000	30,983	Water	0.3721	3,175	New load system installed
DOEHS51	11/10/2005	Berea SS	16	40,000	37,831	Water	0.2552	3,773	
DOEHS52	11/10/2005	Berea SS	17	40,000	30,983	Water	0.3721	3,286	
DOEHS53	11/17/2005	Castlegate SS	17	20,000	10,683	Water	0.9859	683	
DOEHS54	11/17/2005	Castlegate SS	17	25,000	15,572	Water	1.0489	646	
DOEHS55	11/17/2005	Castlegate SS	17	30,000	20,535	Water	1.1819	650	
DOEHS56	11/17/2005	Castlegate SS	17	40,000	28,275	Water	0.8009	1,582	
DOEHS57	11/17/2005	Castlegate SS	17	50,000	33,782	Water	0.7665	2,442	
DOEHS58	11/21/2005	Berea SS	17	40,000	34,718	Water	0.1611	5,104	Calibration Replicate
DOEHS59	11/21/2005	Austin Chalk	17	20,000	15,256	Water	0.1610	3,083	
DOEHS60	11/21/2005	Austin Chalk	17	25,000	22,020	Water	0.1189	3,345	
DOEHS61	11/21/2005	Austin Chalk	17	30,000	24,033	Water	0.2690	2,988	
DOEHS62	11/21/2005	Austin Chalk	17	40,000	33,189	Water	0.1497	6,591	
DOEHS63	11/21/2005	Austin Chalk	17	50,000	38,465	Water	0.3700	3,576	
DOEHS64	11/21/2005	Berea SS	17	40,000	30,978	Water	0.2128	4,593	Calibration Replicate
DOEHS65	11/22/2005	Leuders LS[2]	17	20,000	15,012	Water	0.0698	5,975	ROP varying, uneven rock
DOEHS66	11/22/2005	Leuders LS	17	25,000	17,593	Water	0.1148	5,354	ROP varying, uneven rock
DOEHS67a	11/22/2005	Leuders LS	17	30,000	24,150	Water	0.0801	6,380	ROP varying, uneven rock
DOEHS68a	11/22/2005	Leuders LS	17	40,000	31,696	Water	0.1054	9,022	ROP varying, uneven rock
DOEHS69	11/22/2005	Leuders LS	17	50,000	40,049	Water	0.1223	10,451	ROP varying, uneven rock
DOEHS70	11/22/2005	Berea SS	17	40,000	32,415	Water	0.1286	7,164	Calibration Replicate
DOEHS71	11/22/2005	Berea SS	17	40,000	34,045	Water	0.2753	2,582	Calibration Replicate
DOEHS72	11/22/2005	Sulurain Dolomite	17	20,000	15,795	Water	0.0807	4,411	

Table A1. Test data summary for Ultra-High-Speed Rotary Diamond Drilling.

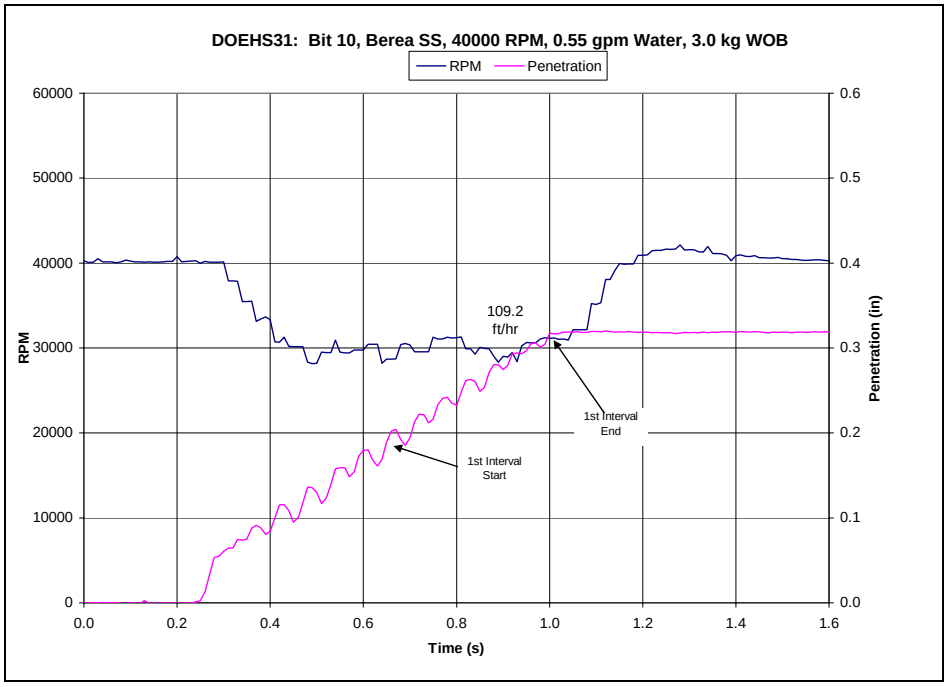
Test	Test Date	Rock Type	Bit	Rotary Speed		Drilling Fluid	Rate of Penetration (in/sec)	Specific Energy (ft-lb/in^3)	Comments
				Target (rpm)	Actual (r/min)				
DOEHS73	11/22/2005	Sulurain Dolomite	17	25,000	19,473	Water	0.1190	3,827	
DOEHS74a	11/22/2005	Sulurain Dolomite	17	30,000	25,770	Water	0.0845	3,654	
DOEHS75	11/22/2005	Sulurain Dolomite	17	40,000	33,511	Water	0.1131	6,226	
DOEHS76	11/22/2005	Sulurain Dolomite	17	50,000	43,707	Water	0.1275	6,845	
DOEHS77	11/29/2005	Berea SS[1]	17	40,000	34,285	Water	0.2438	2,609	Calibration Replicate
DOEHS78	11/29/2005	Winfield Anhydrite	17	20,000	14,767	Water	0.0427	8,861	ROP[5] slow, test ended early
DOEHS79	11/29/2005	Winfield Anhydrite	17	25,000	19,279	Water	0.0583	7,983	ROP slow, test ended early
DOEHS80	11/29/2005	Winfield Anhydrite	17	30,000	25,146	Water	0.0499	8,486	ROP slow, test ended early
DOEHS81	11/29/2005	Winfield Anhydrite	17	40,000	32,766	Water	0.1004	7,857	
DOEHS82	11/29/2005	Winfield Anhydrite	17	50,000	44,748	Water	0.0691	10,238	
DOEHS83	11/29/2005	Berea SS	17	40,000	34,340	Water	0.1341	4,770	Calibration Replicate
DOEHS84	11/29/2005	Berea SS	17	40,000	33,342	Water	0.1549	4,395	Calibration Replicate
DOEHS85	11/29/2005	Burlington LS[2]	17	20,000	16,266	Water	0.0242	12,868	ROP slow, test ended early
DOEHS86	11/29/2005	Burlington LS	17	25,000	20,284	Water	0.0276	14,671	ROP slow, test ended early
DOEHS87	11/29/2005	Burlington LS	17	30,000	21,805	Water	0.0233	32,504	ROP slow, test ended early
DOEHS88	11/29/2005	Burlington LS	17	40,000	35,070	Water	0.0290	21,056	ROP slow, test ended early
DOEHS89	11/29/2005	Burlington LS	17	50,000		Water		NC[3]	Motor Failed-repeat as DEAHS92
DOEHS90	2/10/2006	Berea SS	17	40,000	36,564	Water	0.1123	6,034	Calibration Replicate
DOEHS91	2/10/2006	Berea SS	17	40,000	35,367	Water	0.0162	5,619	Calibration Replicate
DOEHS92	2/10/2006	Burlington LS	17	50,000	44,596	Water	0.0862	41,857	Repeat of DEAHS89
DOEHS93	2/11/2006	Berea SS	17	40,000	35,868	Water	0.0349	7,097	Calibration Replicate
DOEHS94	2/12/2006	Nugget SS	17	20,000	17,334	Water	0.0212	7,016	ROP slow
DOEHS95	2/12/2006	Nugget SS	17	25,000	23,559	Water	0.0273	12,089	ROP slow
DOEHS96a	2/13/2006	Nugget SS	17	30,000	22,066	Water	0.0438	17,488	ROP slow, RPM[4] sensor failed
DOEHS100	2/15/2006	Nugget SS	17	40,000	36,318	Water	0.0160	20,648	ROP slow
DOEHS101a	2/15/2006	Nugget SS	17	50,000	46,107	Water	0.0522	55,969	ROP slow
DOEHS102	2/15/2006	Berea SS	17	40,000	37,188	Water	0.0520	7,362	Calibration Replicate

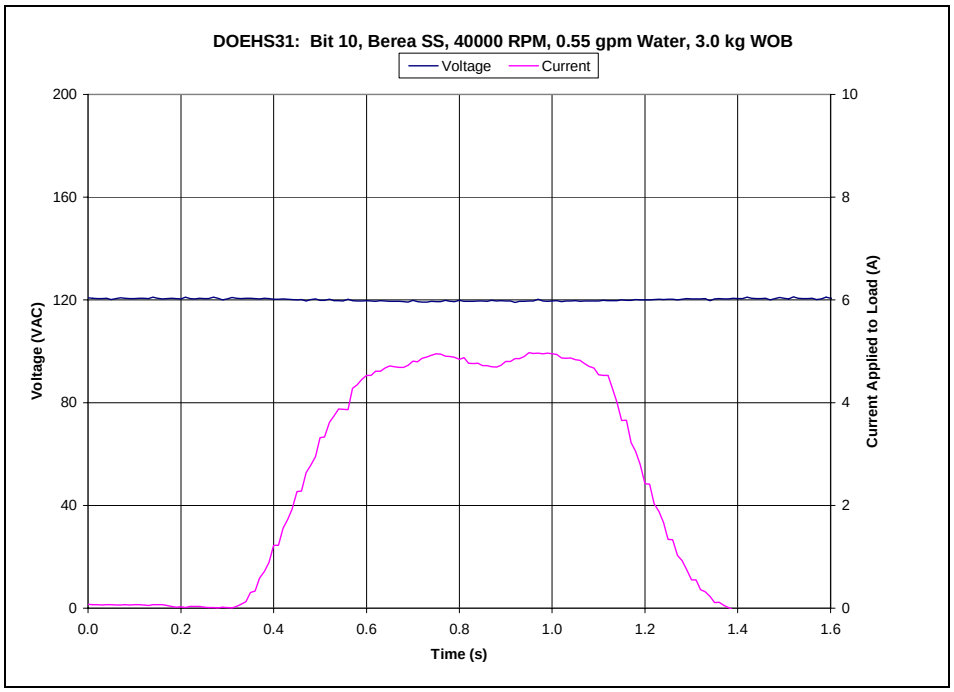
[1] SS – sandstone
[2] LS – limestone
[3] NC – no calculation
[4] RPM – rotational speed
[5] ROP – rate of penetration

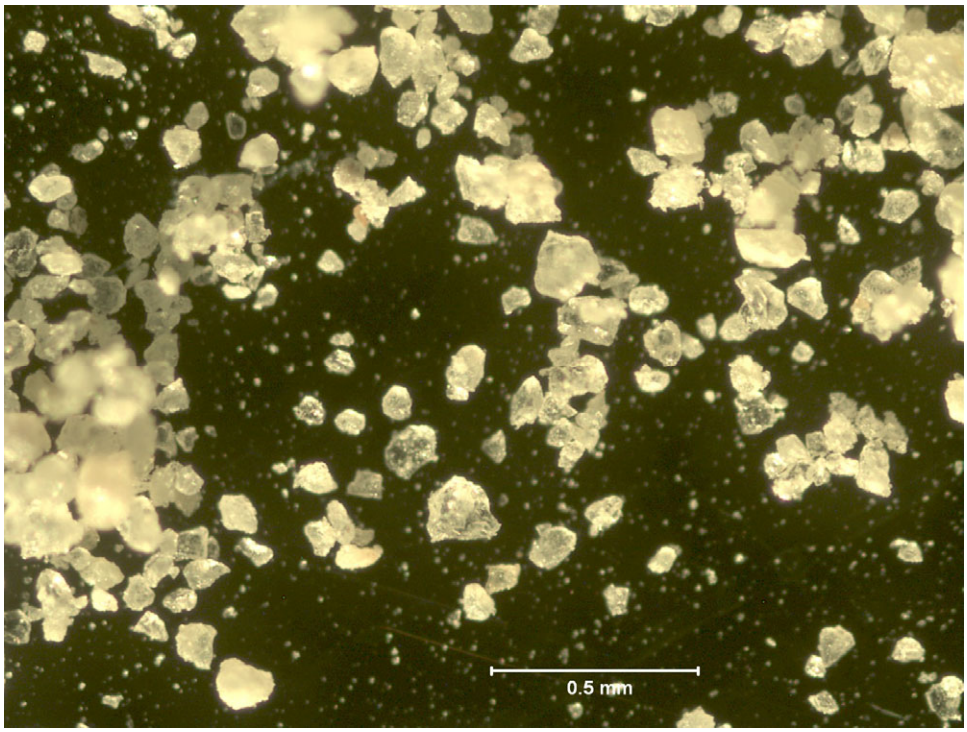
APPENDIX B.
Data Summaries, Graphs, and Photographs of Tests DOEHS31 Through DOEHS102

DEAHS31: Summary data and plots and cuttings photographs.

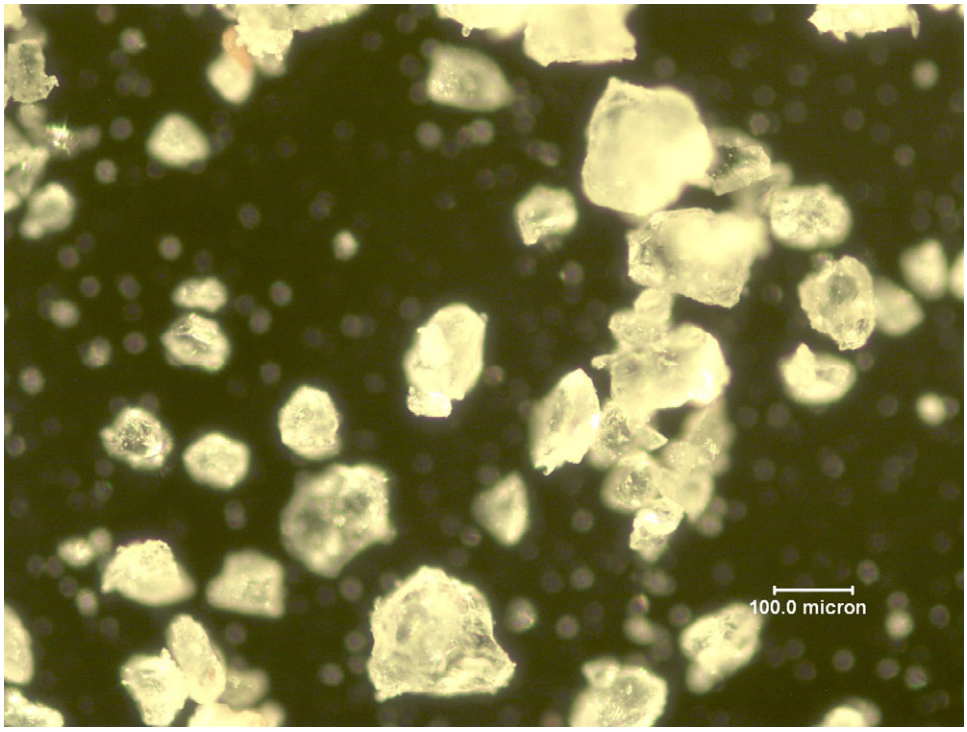
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/7/2005	0.835	0.520	119.5	4.8300	30050	2969	0.1220	0.3640	3489.08	1.63	3490.70	2.89E+08	109.20	0.00073







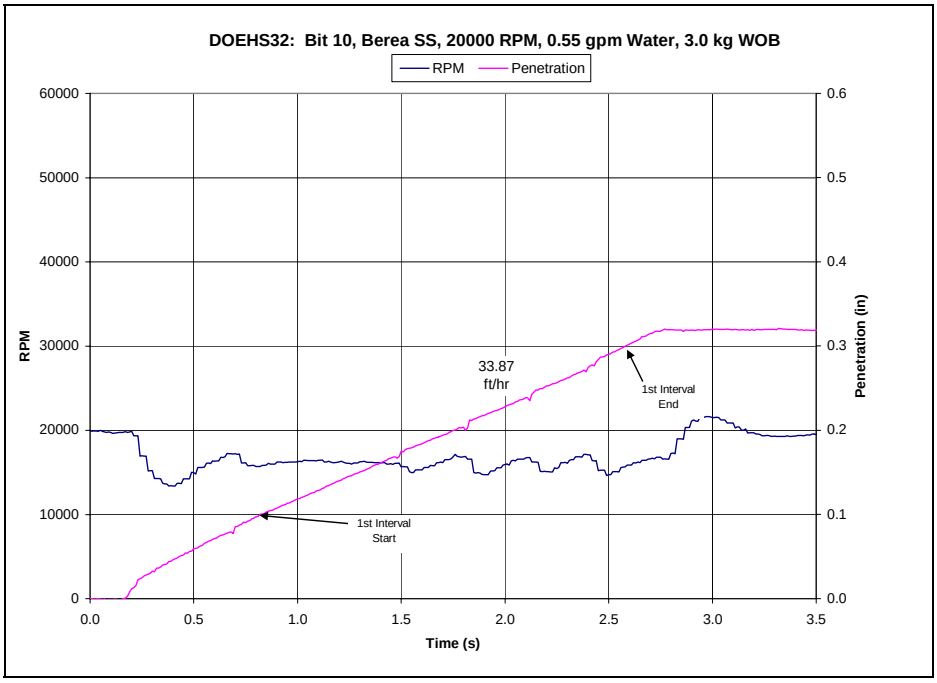
DOEH31 Berea cuttings 40,000 rpm.

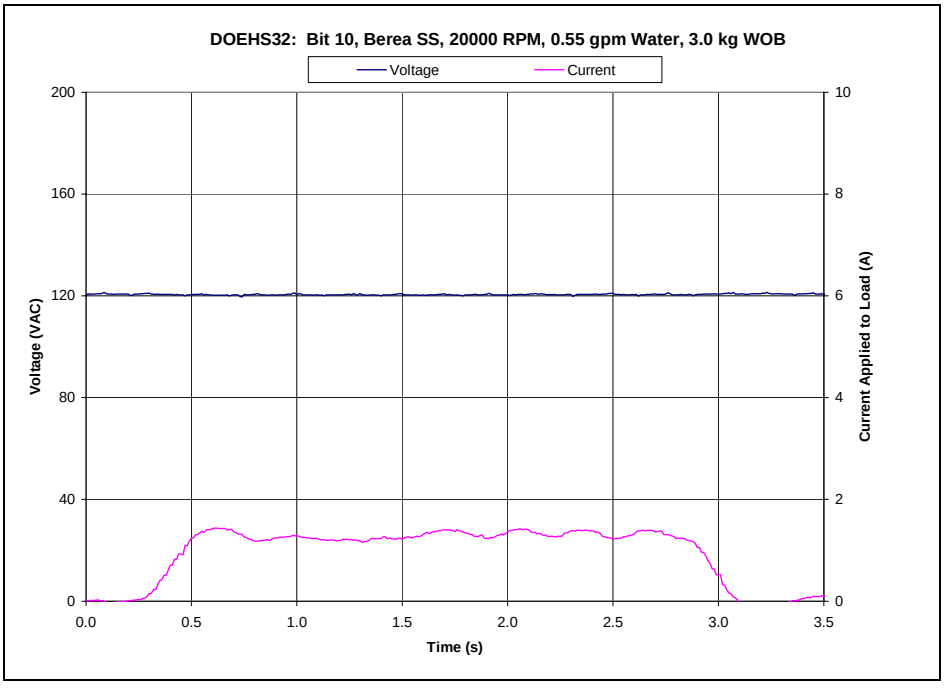


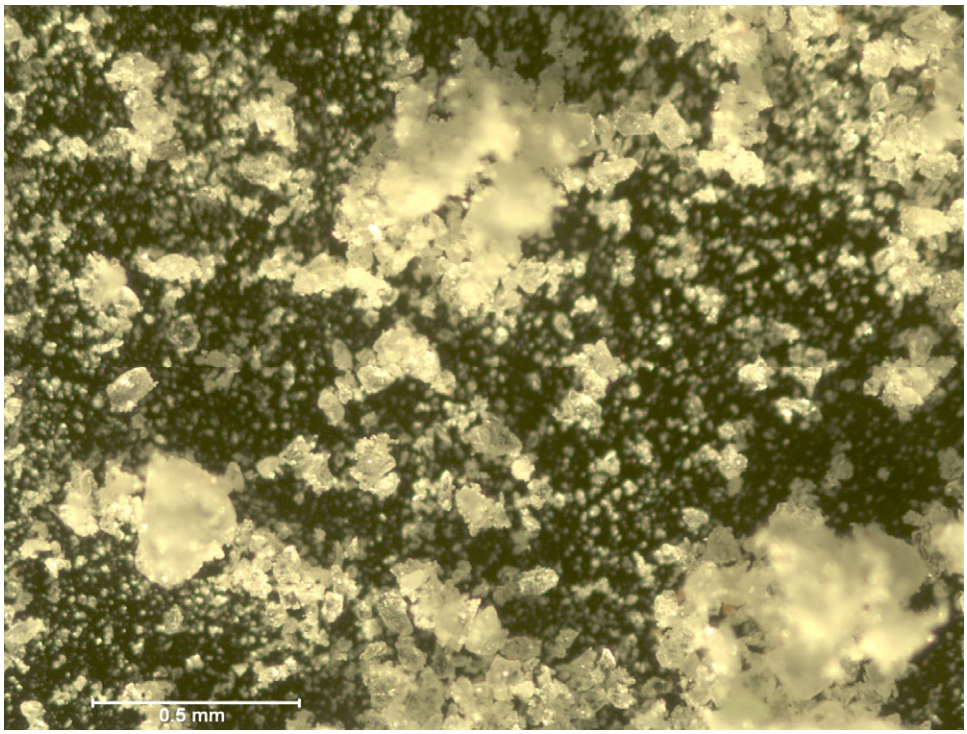
DEAHS31, Berea sandstone at 40,000 rpm.

DEAHS32: Summary data and plots and cuttings photographs.

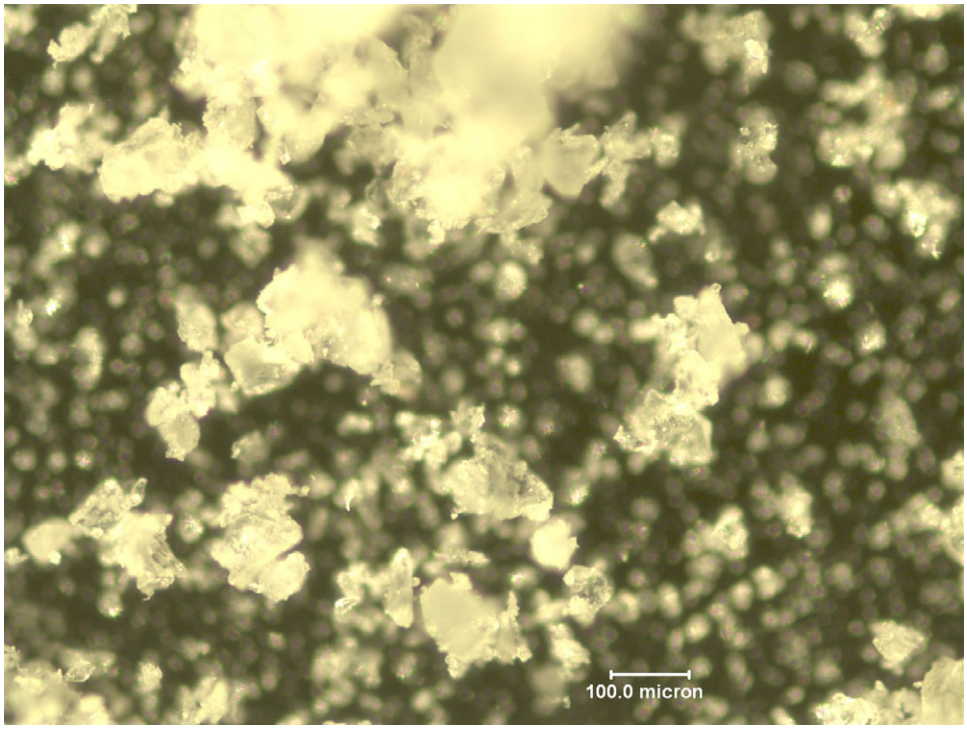
Test	Hole OD	Hole ID	Volts	Amps	RPM	WOB	Volume Removal	ROP	S. E. Rotation	S. E. WOB	Total S. E.	Total S. E.	ROP	
Date	(in)	(In)	(v)	(a)	(rpm)	(gms)	(in3/sec)	(in/sec)	(ft-lbs/in3)	(ft-lbs/in3)	(ft-lbs/in3)	(Joules/m3)	(ft/hr)	(in/rev)
11/7/2005	0.842	0.549	120.5	1.2900	15993	3003	0.0361	0.1129	3172.74	1.72	3174.46	2.62E+08	33.87	0.00042







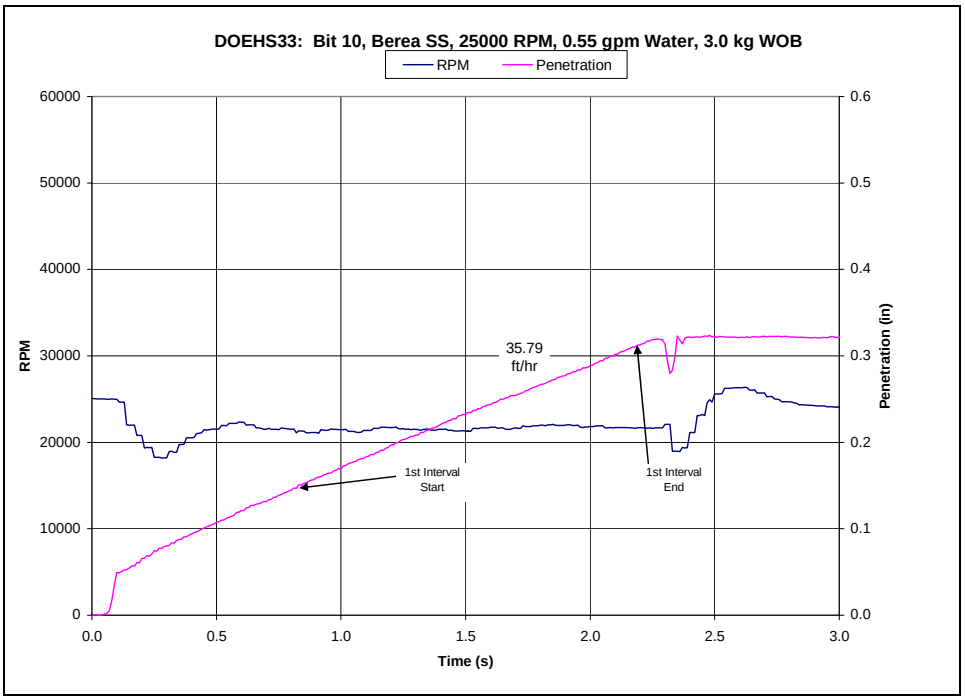
DOEH32 Berea cuttings 20,000 rpm.

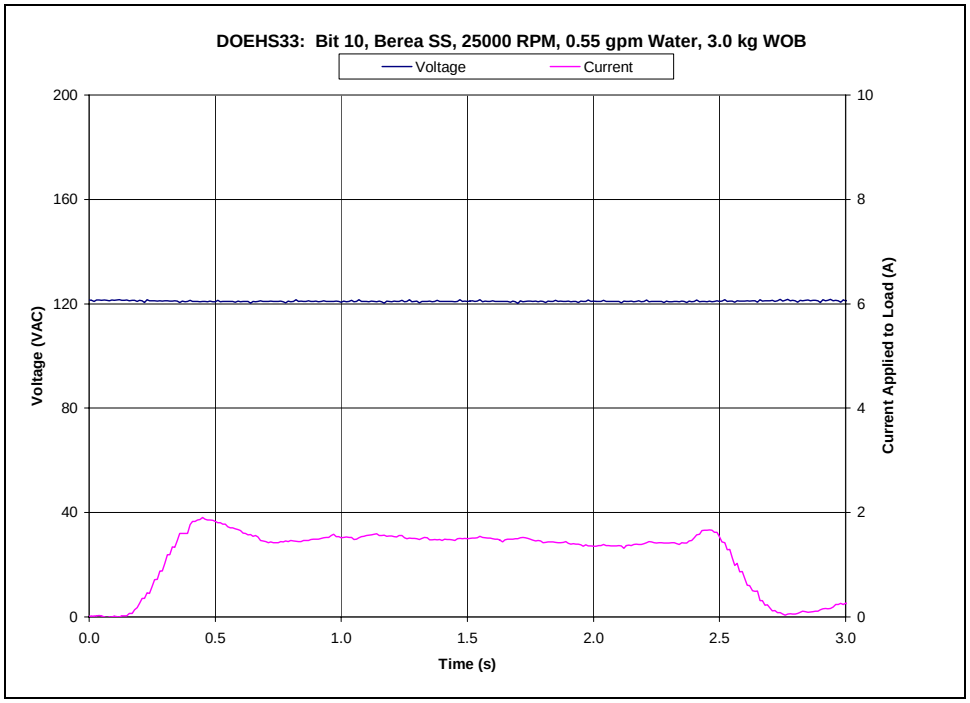


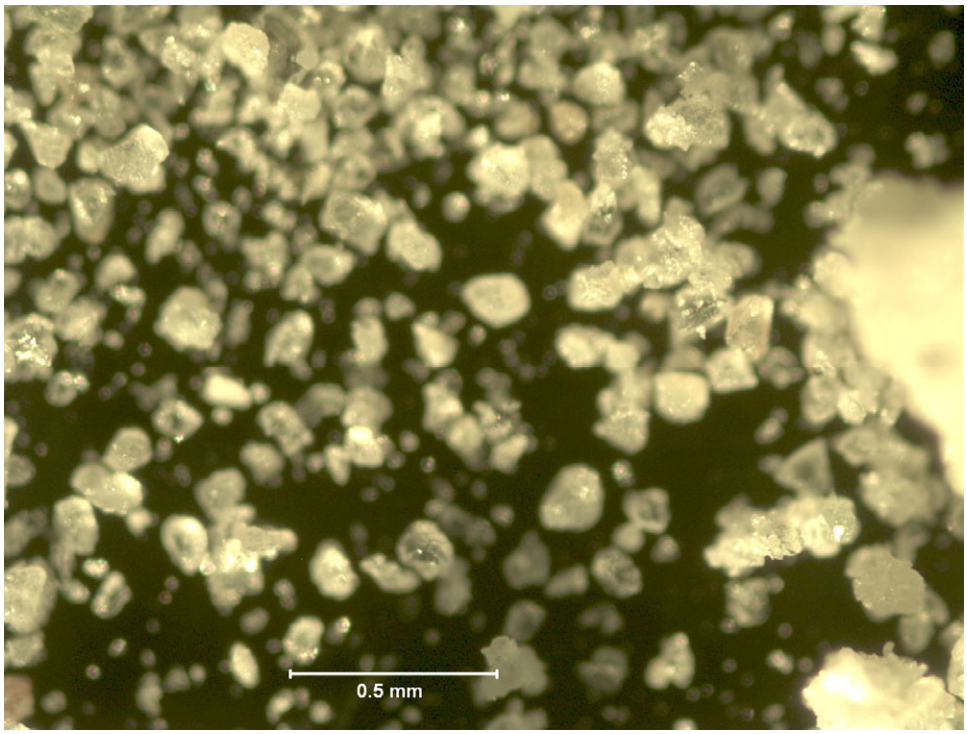
DOEH32 Berea cuttings 20,000 rpm.

DEAHS33: Summary data and plots and cuttings photographs.

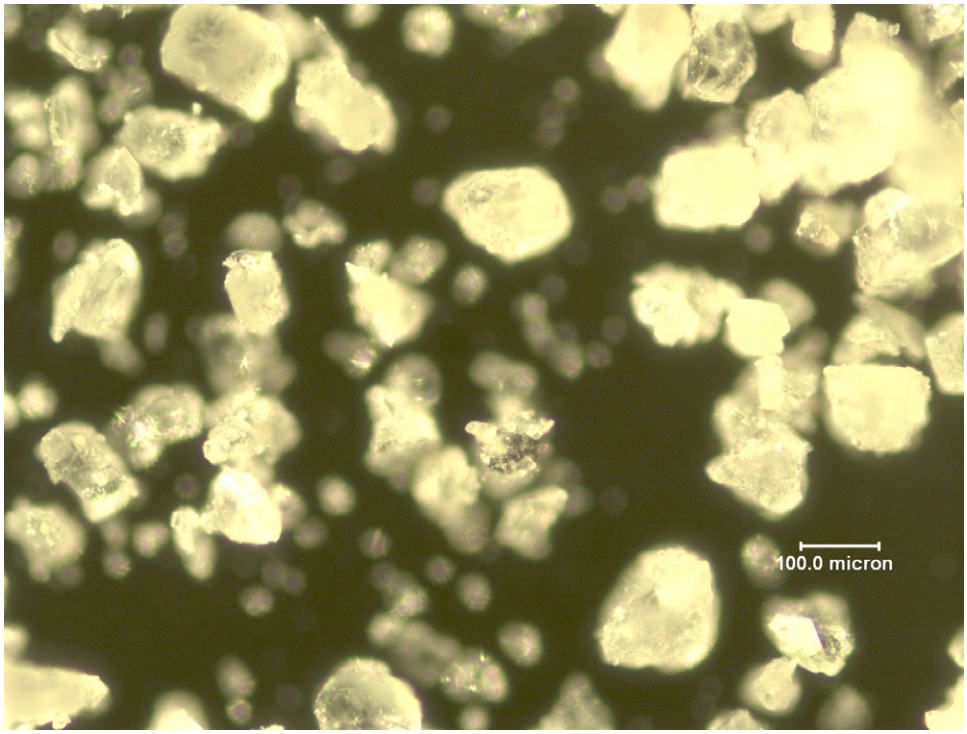
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/7/2005	0.839	0.550	120.9	1.4700	21589	3006	0.0376	0.1193	3486.24	1.75	3487.99	2.88E+08	35.79	0.00033







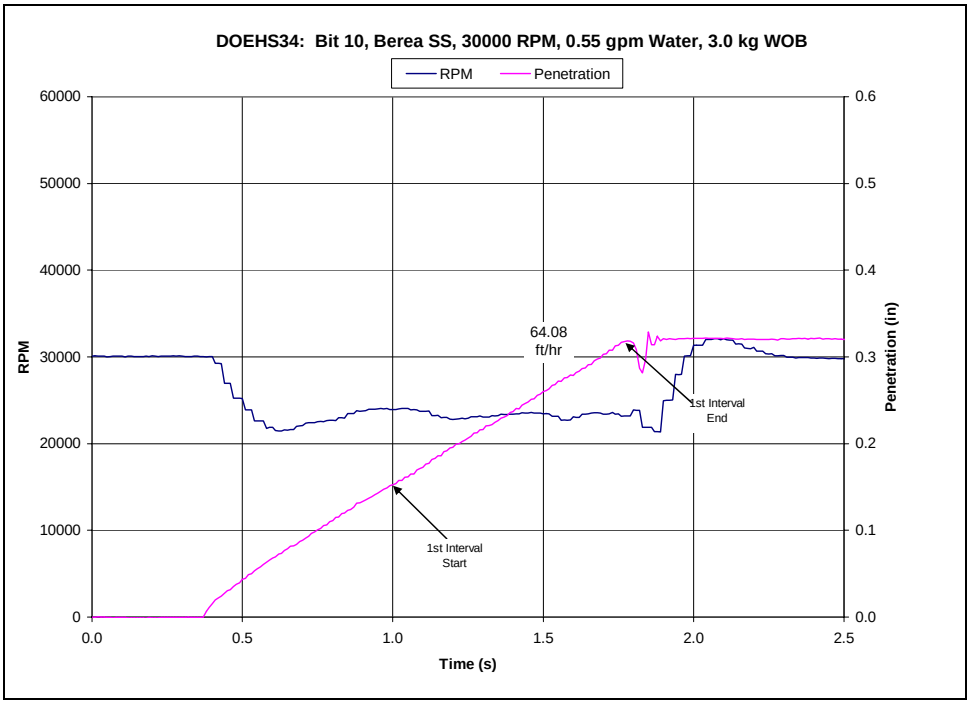
DOEH33 Berea cuttings 25,000 rpm.

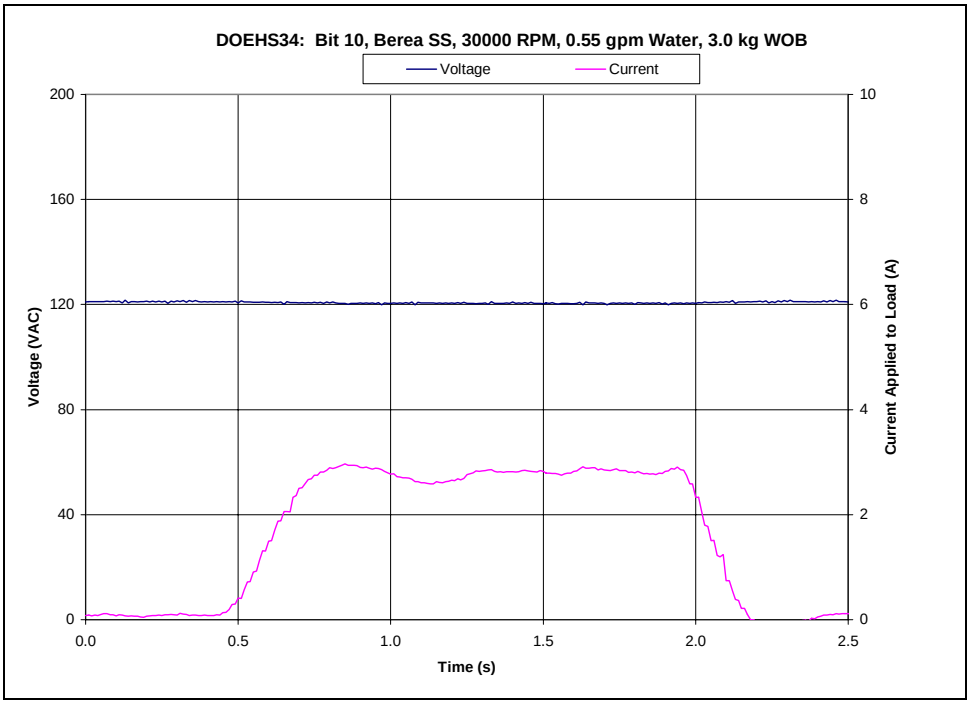


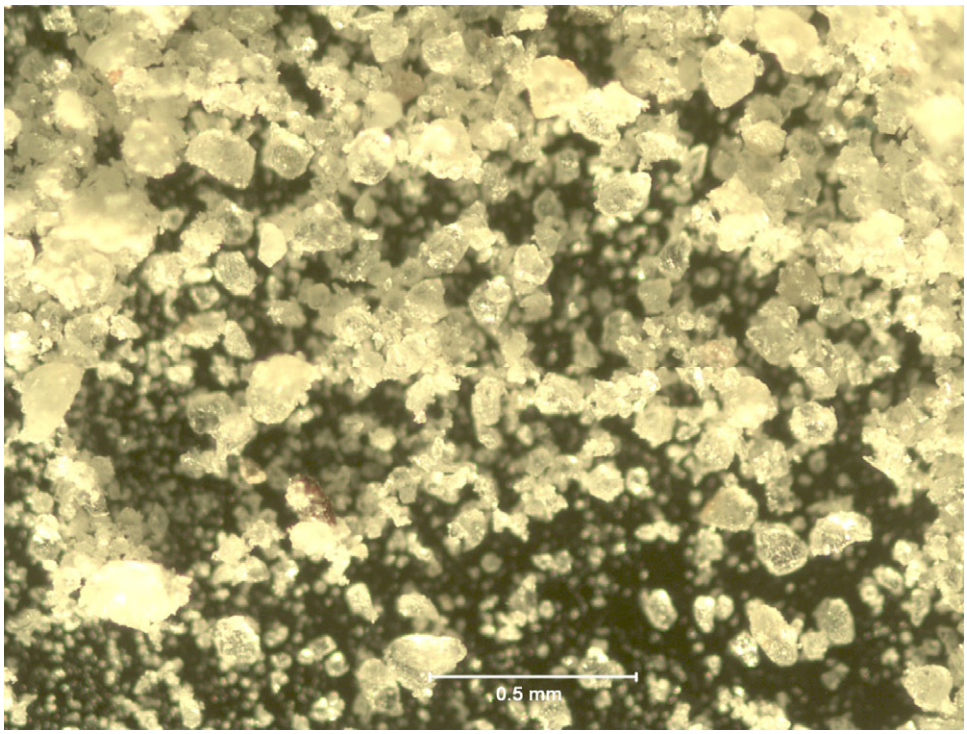
DOEH33 Berea cuttings 25,000 rpm.

DEAHS34: Summary data and plots and cuttings photographs.

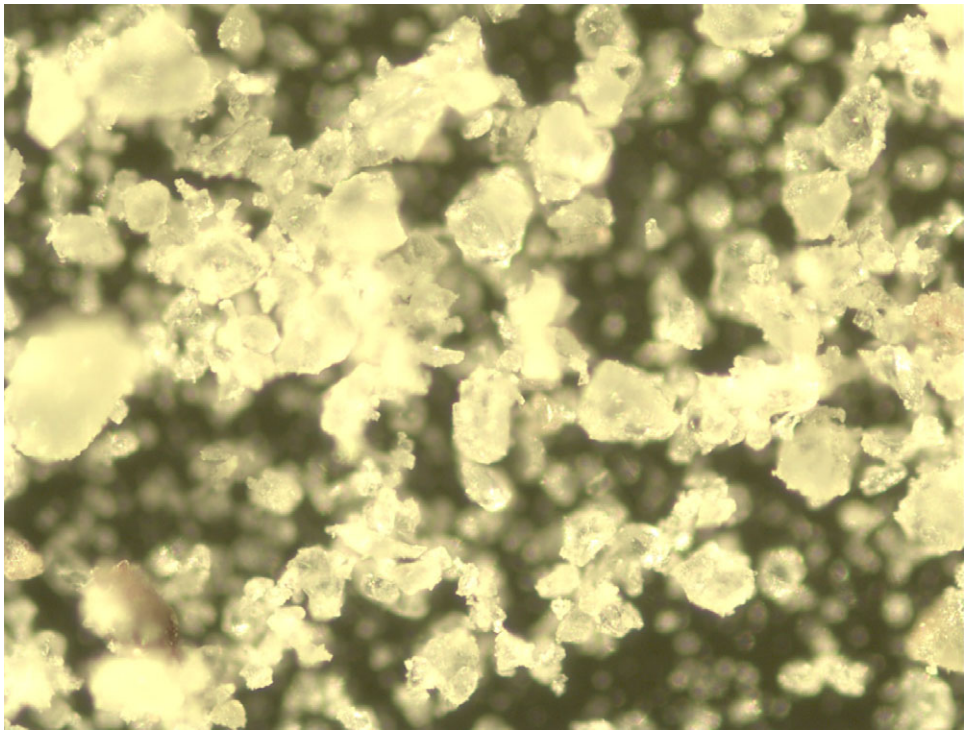
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/7/2005	0.840	0.550	120.5	2.7700	23340	3005	0.0676	0.2136	3640.82	1.74	3642.56	3.01E+08	64.08	0.00055







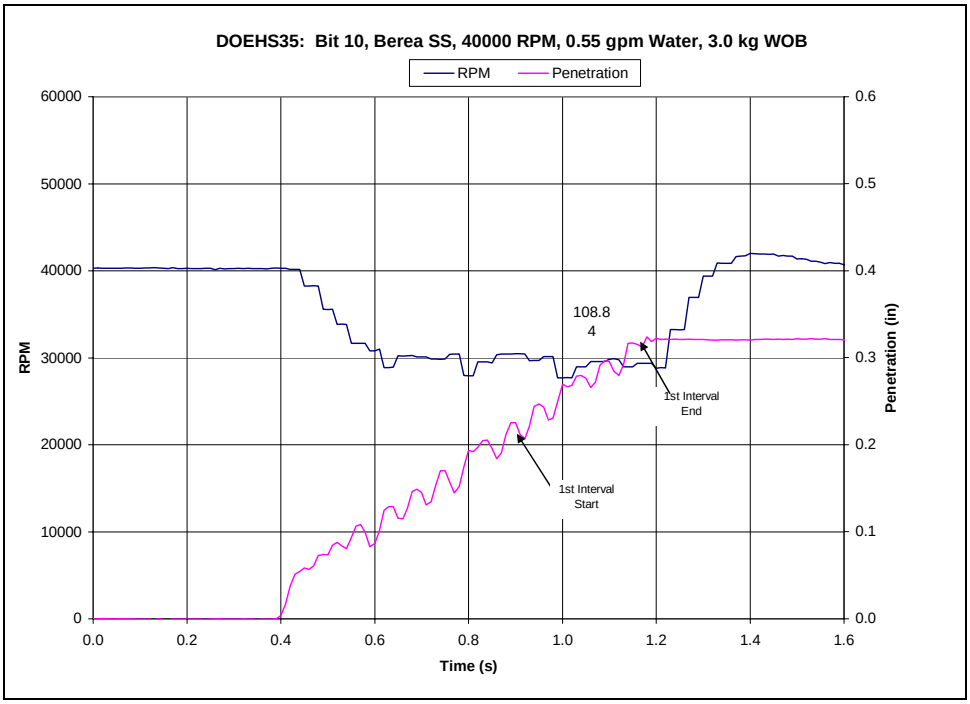
DOEH34 Berea cuttings 30,000 rpm.

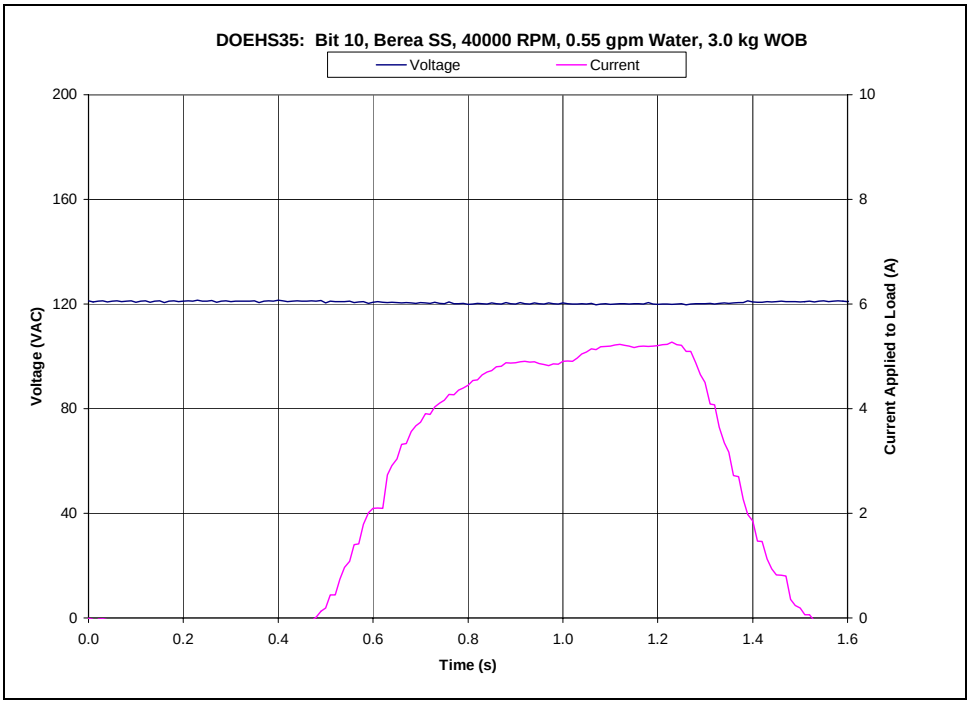


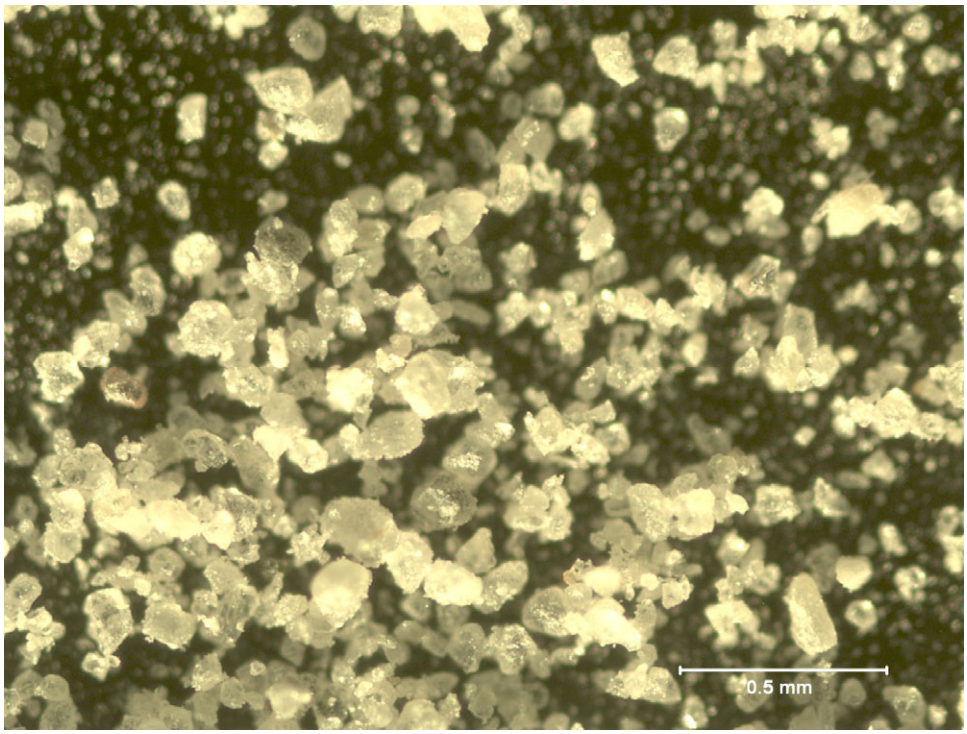
DOEH34 Berea cuttings 30,000 rpm.

DEAHS35: Summary data and plots and cuttings photographs.

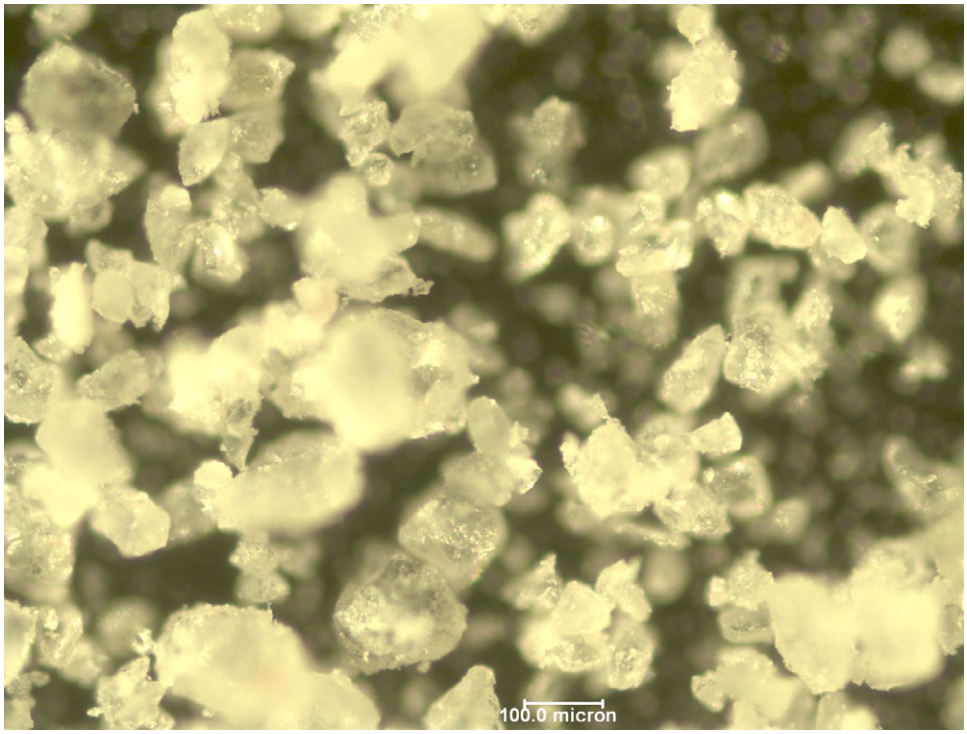
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/7/2005	0.851	0.533	120.1	5.0500	29296	3033	0.1254	0.3628	3567.39	1.61	3569.00	2.95E+08	108.84	0.00074







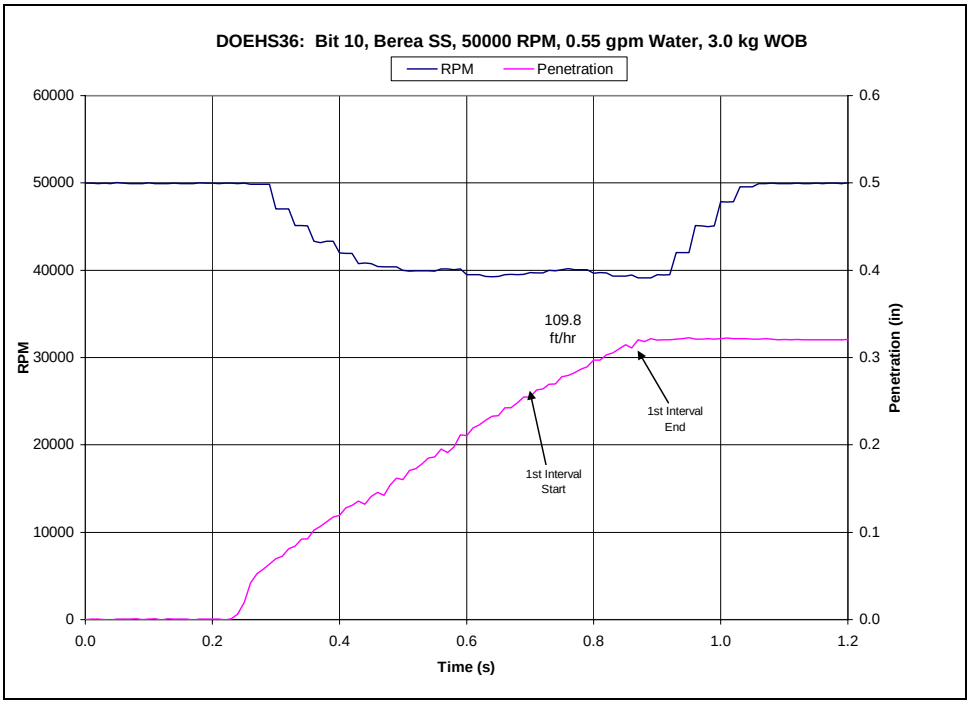
DOEH35 Berea cuttings 40,000 rpm.

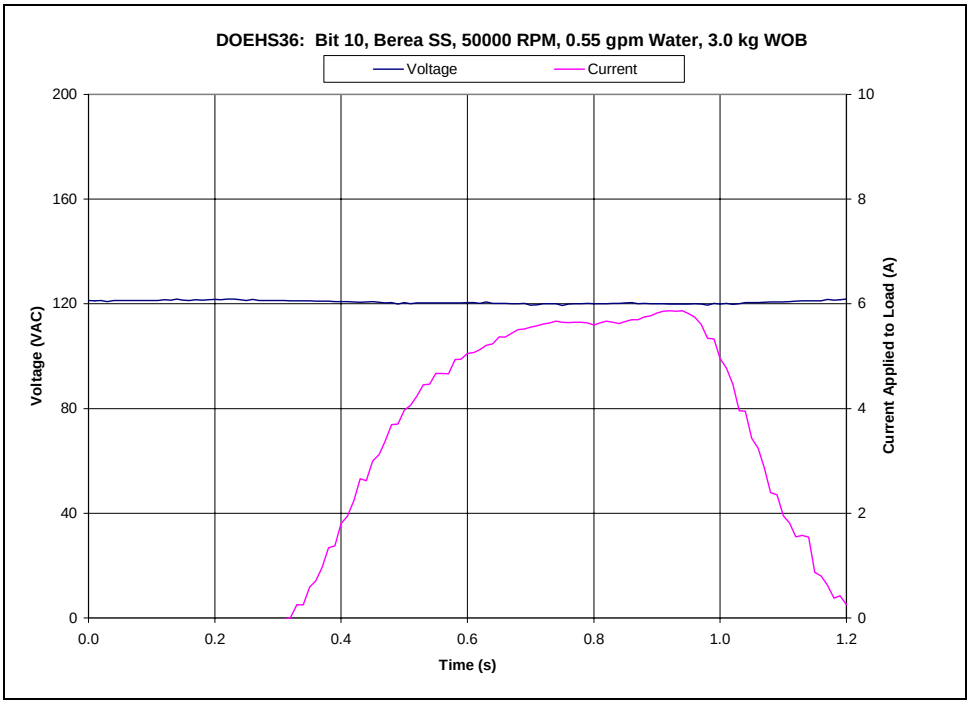


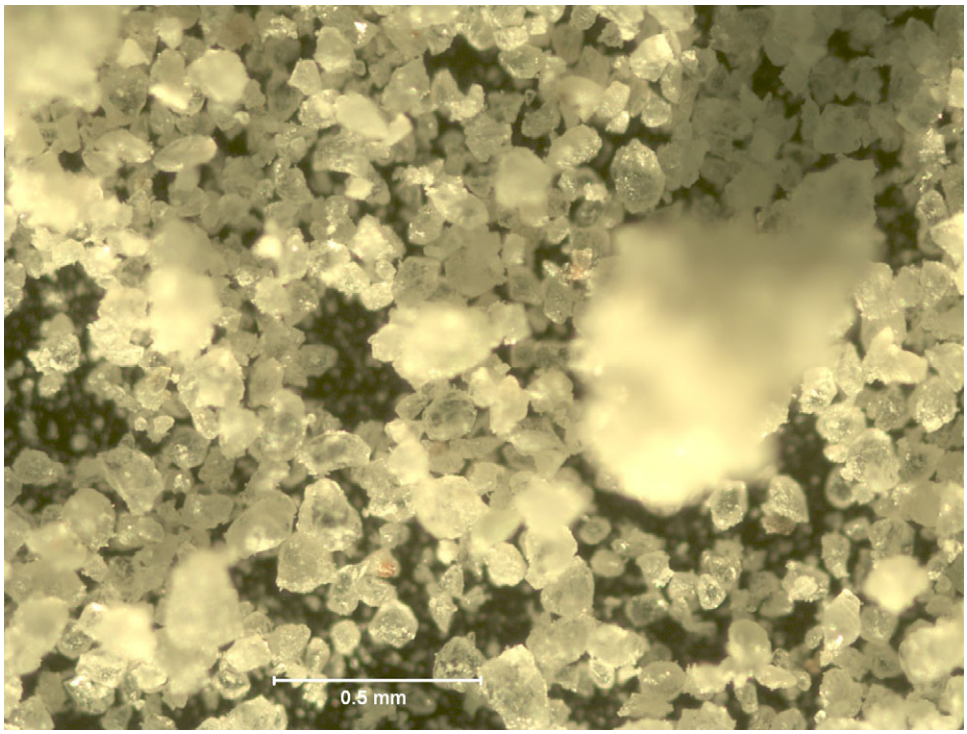
DOEH35 Berea cuttings 40,000 rpm.

DEAHS36: Summary data and plots and cuttings photographs.

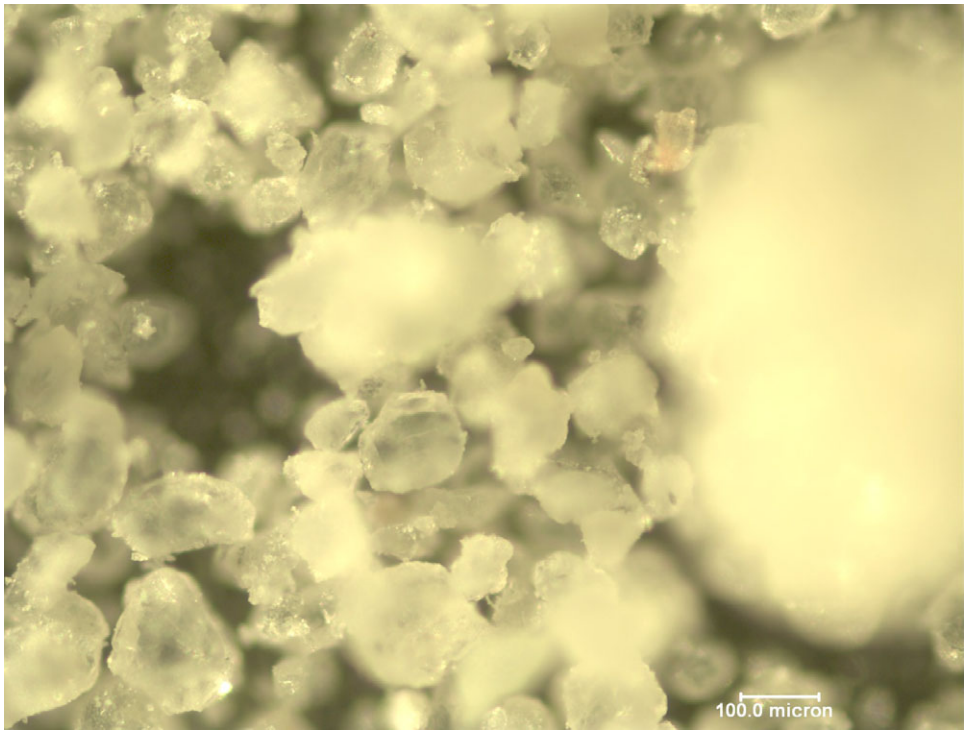
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/7/2005	0.852	0.540	120.1	5.6500	39705	3048	0.1248	0.3660	4009.25	1.64	4010.89	3.32E+08	109.80	0.00055







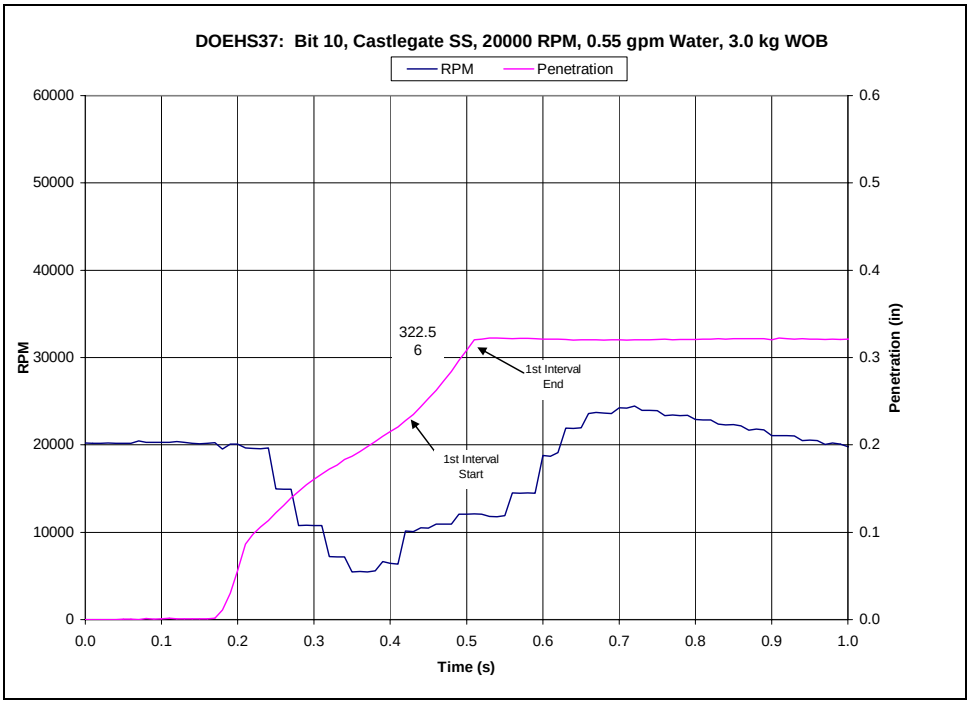
DOEH36 Berea cuttings 50,000 rpm

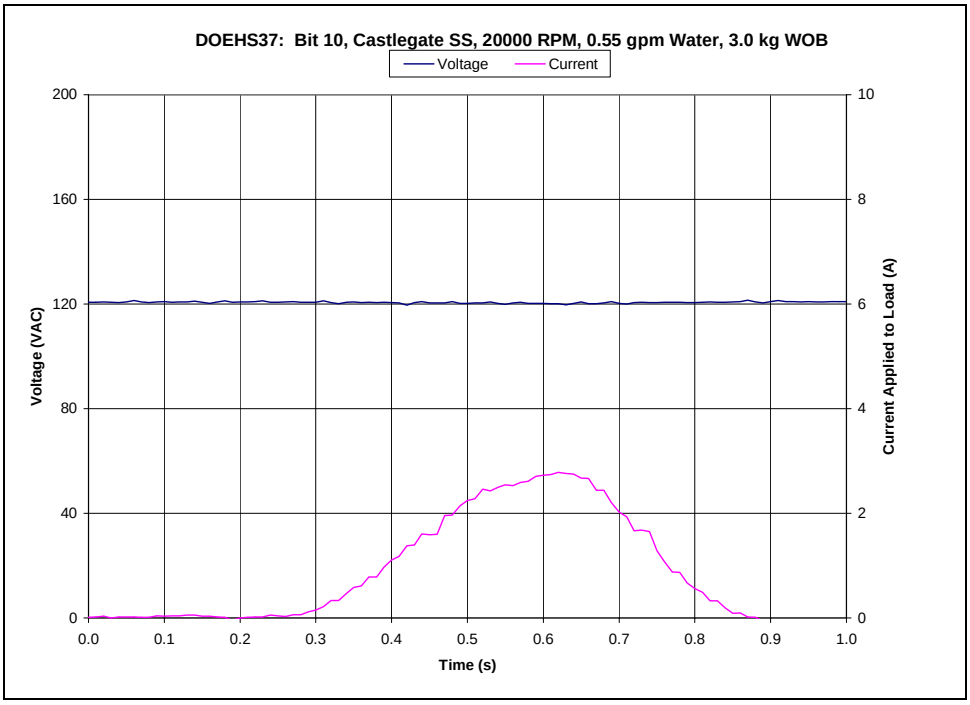


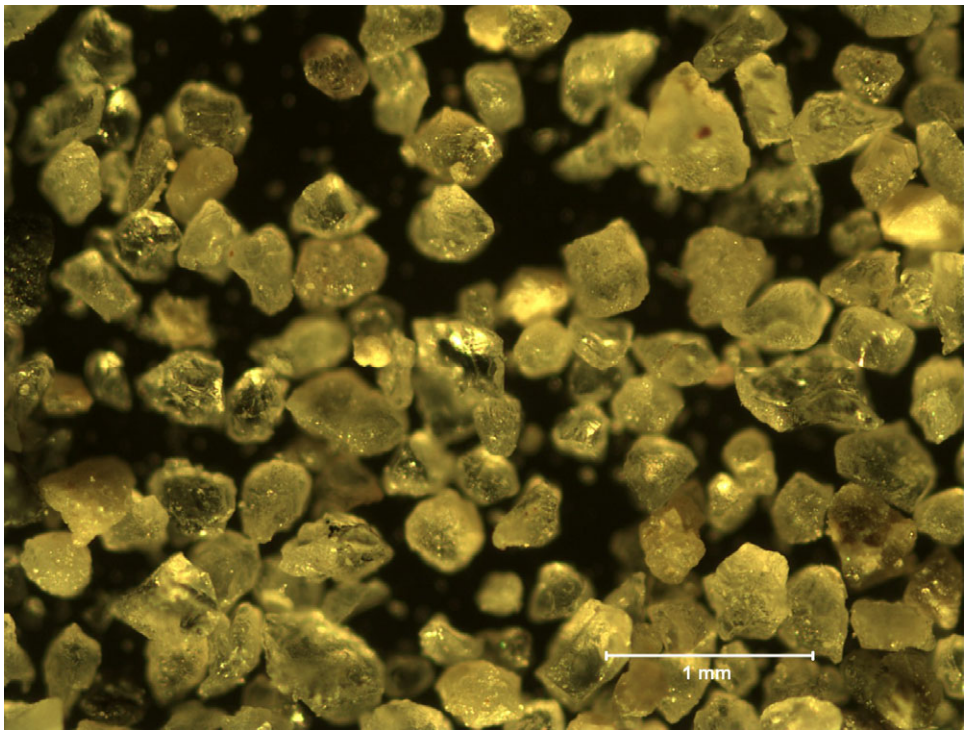
DOEH36 Berea cuttings 50,000 rpm.

DEAHS37: Summary data and plots and cuttings photographs.

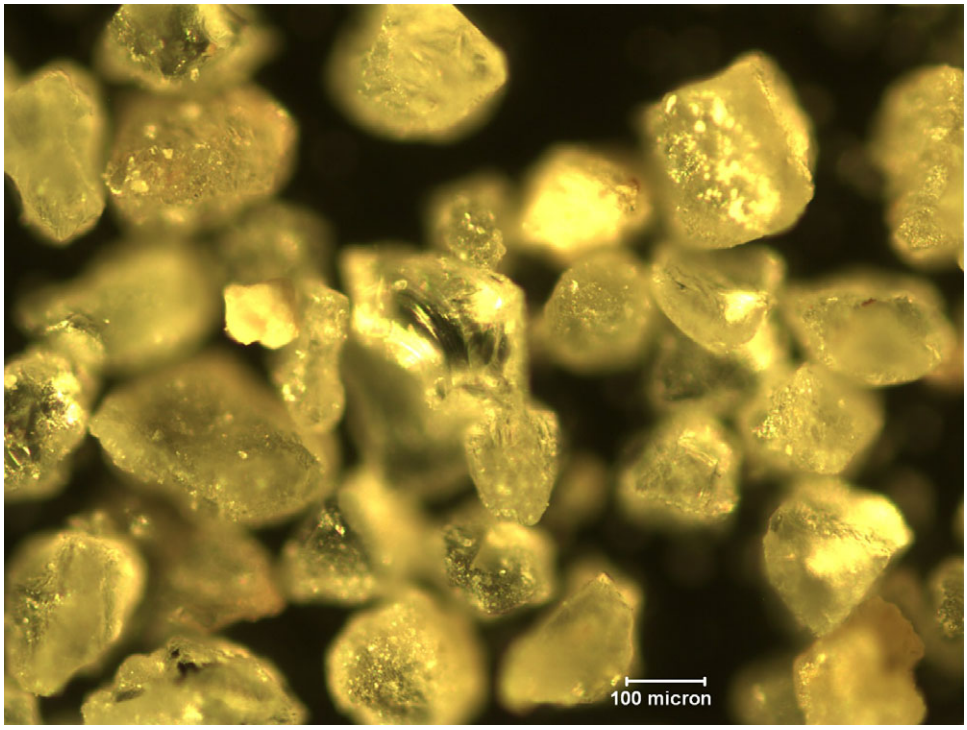
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/8/2005	0.849	0.546	120.5	2.7266	11118	3048	0.3569	1.0752	678.85	1.69	680.54	5.63E+07	322.56	0.00580







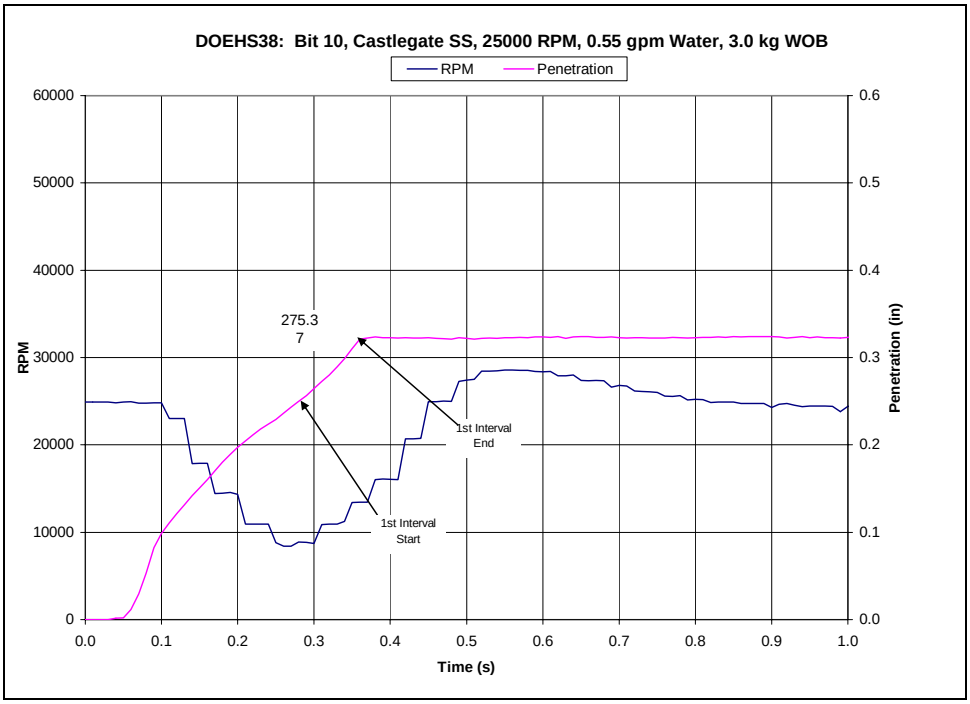
DOEH37 Casltegate cuttings 20,000 rpm.

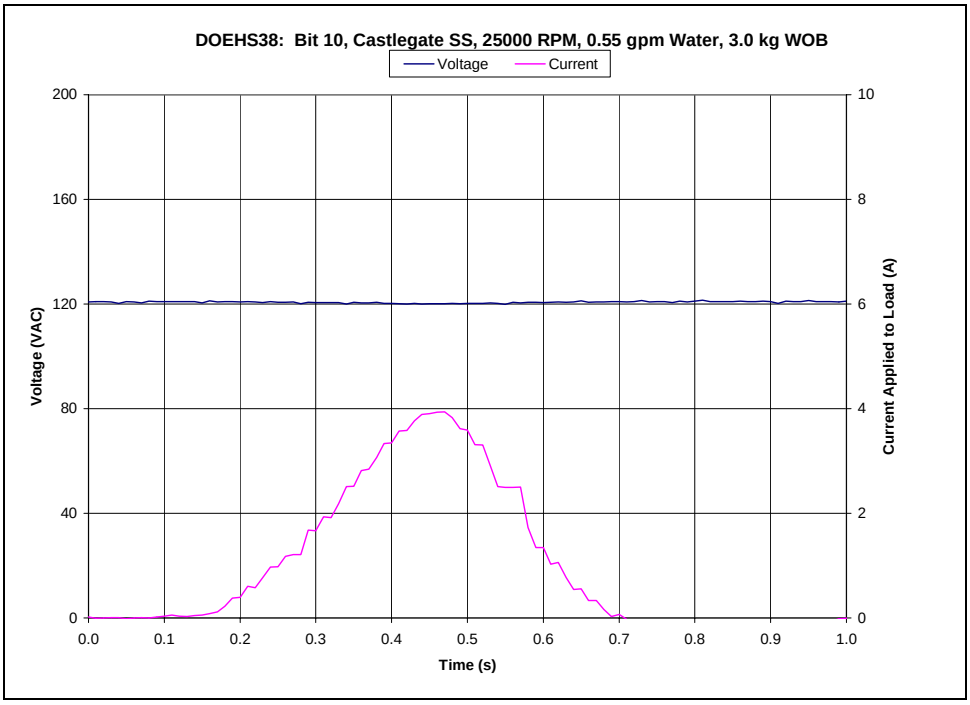


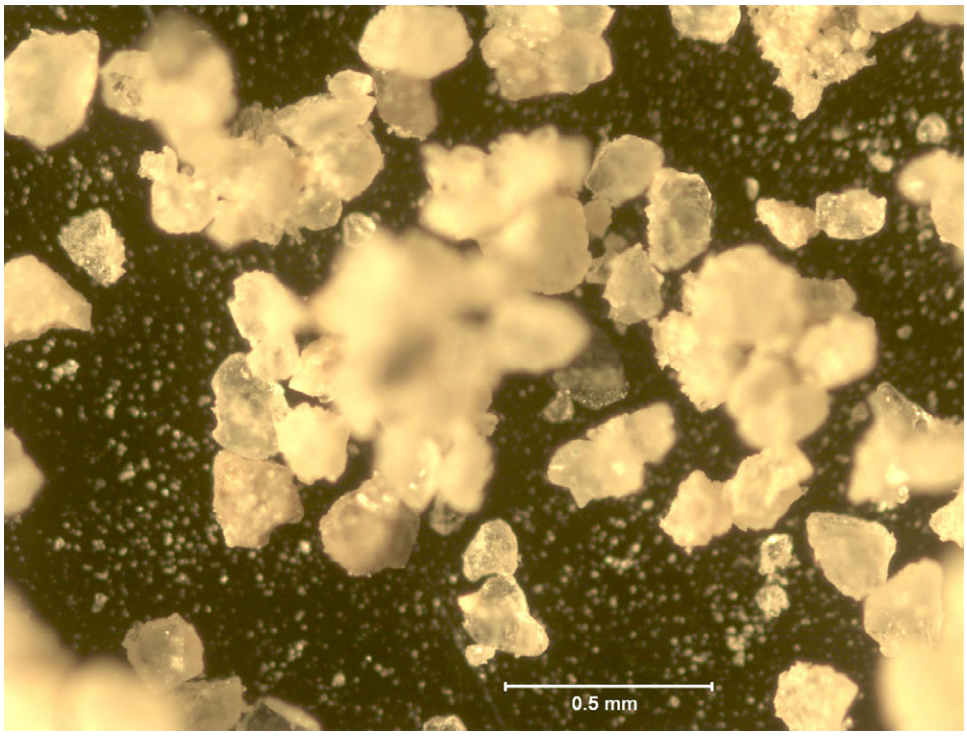
DOEH37 Casltegate cuttings 20,000 rpm.

DEAHS38: Summary data and plots and cuttings photographs.

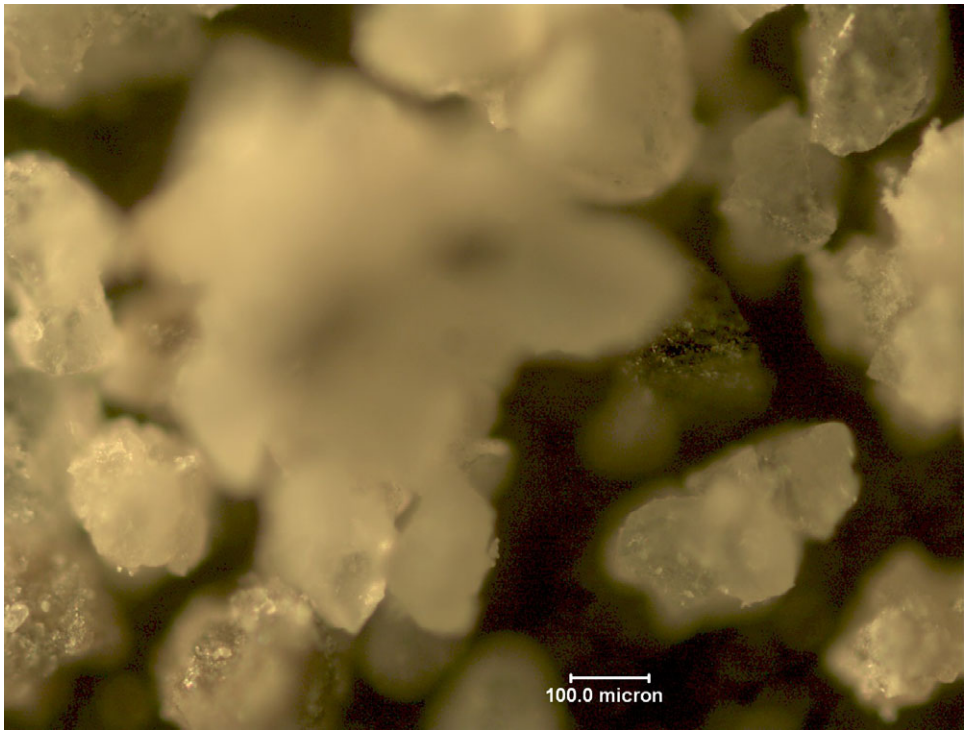
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/8/2005	0.856	0.537	120.5	3.9009	11054	3048	0.3204	0.9179	1082.15	1.60	1083.75	8.96E+07	275.37	0.00498







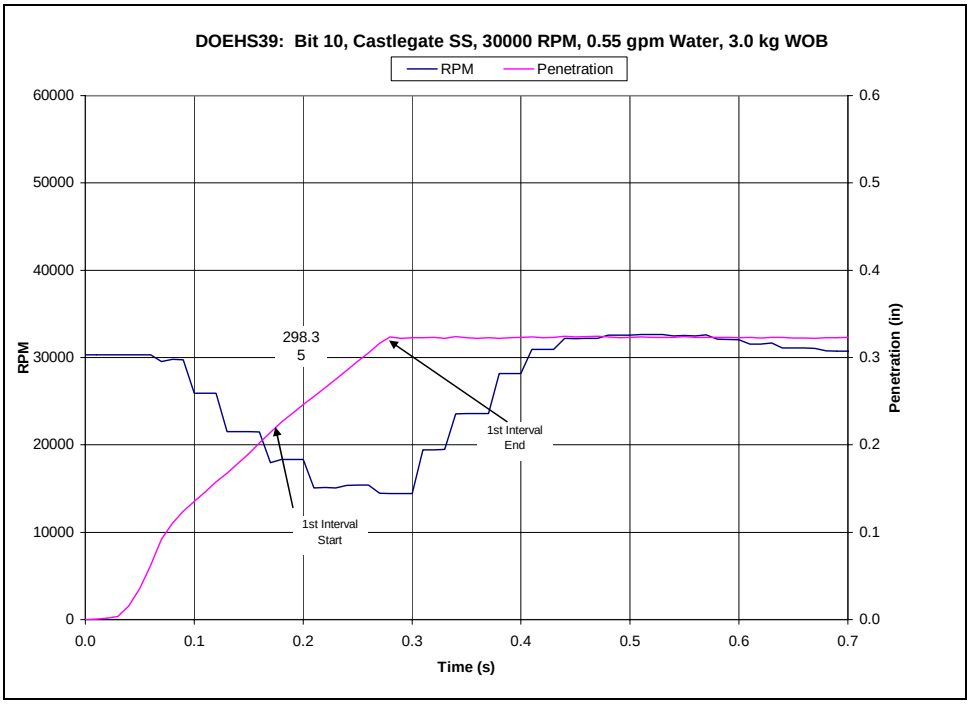
DOEH38 Casltegate cuttings 25,000 rpm.

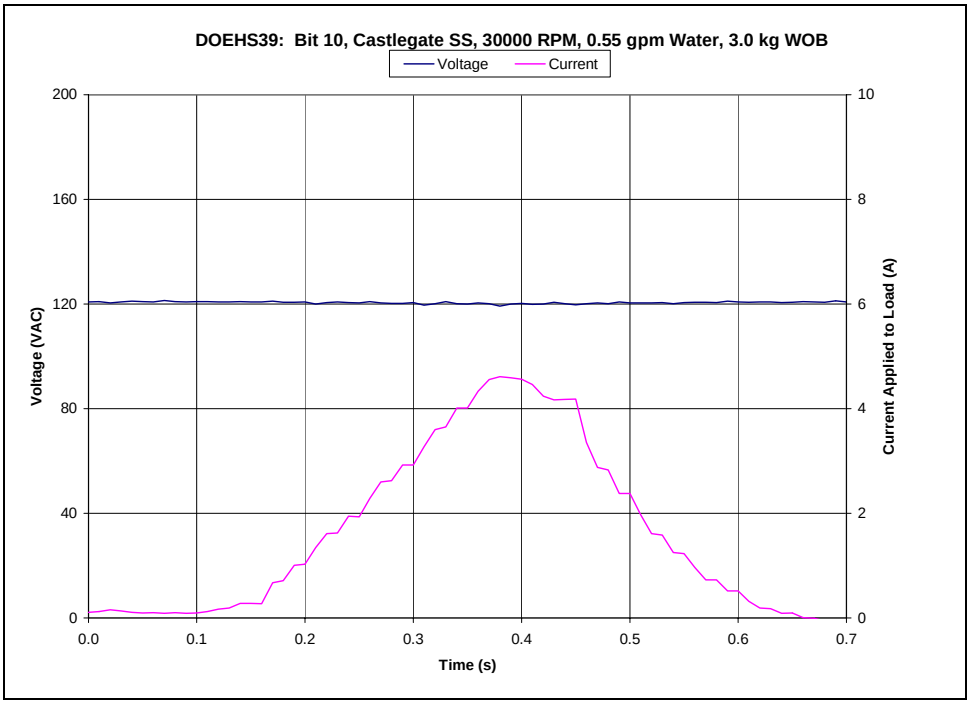


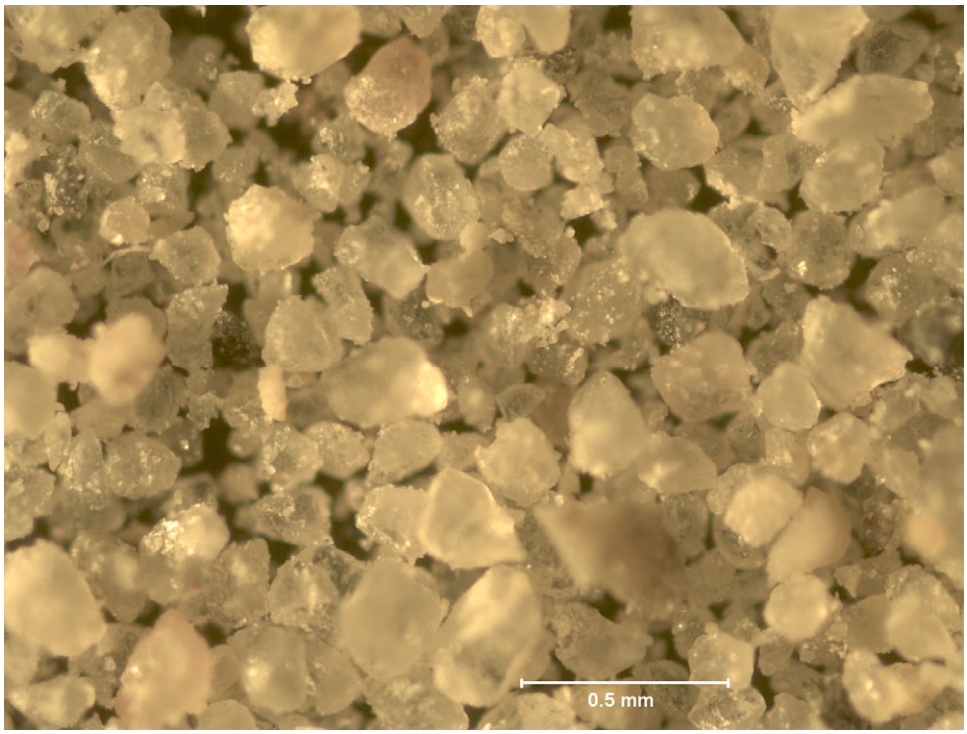
DOEH38 Casltegate cuttings 25,000 rpm.

DEAHS39: Summary data and plots and cuttings photographs.

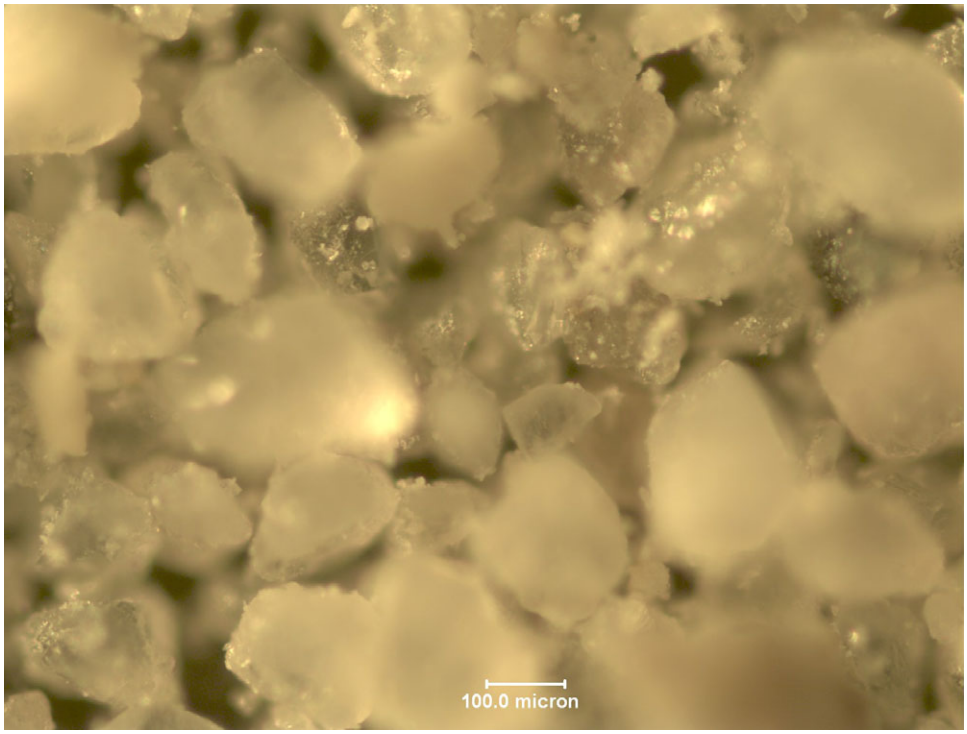
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/8/2005	0.859	0.537	120.6	4.3957	16110	3048	0.3511	0.9945	1113.88	1.59	1115.46	9.22E+07	298.35	0.00370







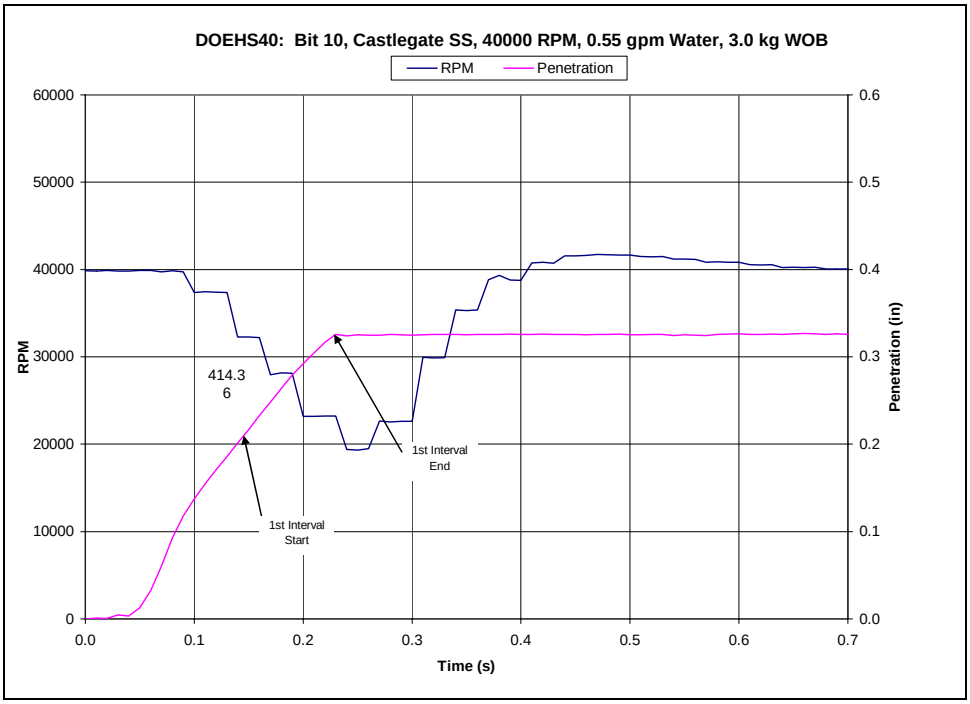
DOEH39 Casltegate cuttings 30,000 rpm.

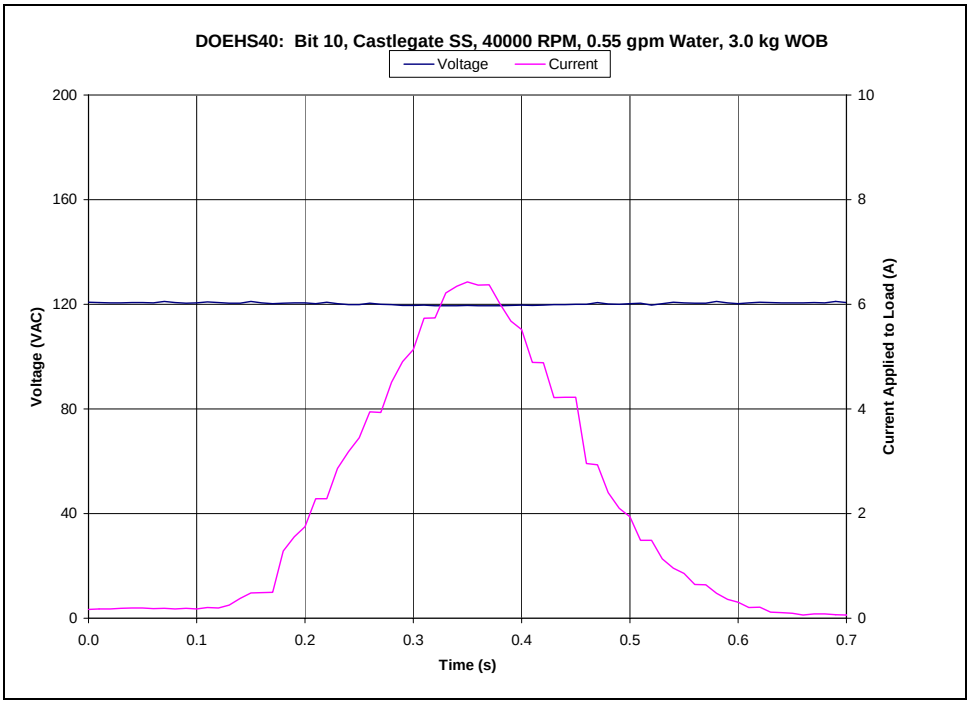


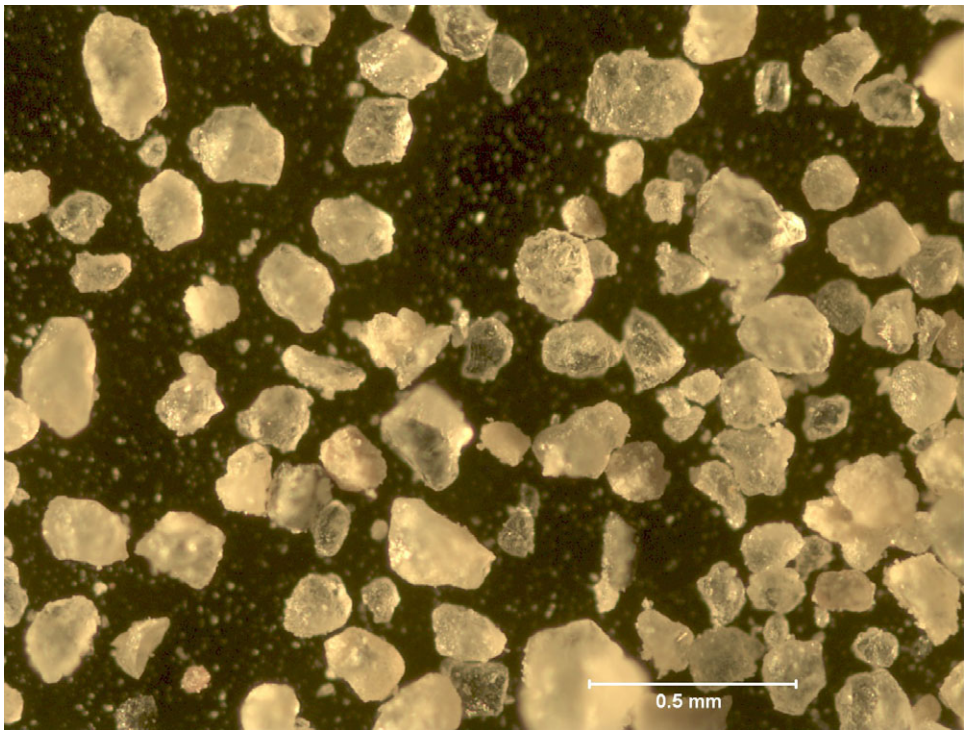
DOEH39 Casltegate cuttings 30,000 rpm.

DEAHS40: Summary data and plots and cuttings photographs.

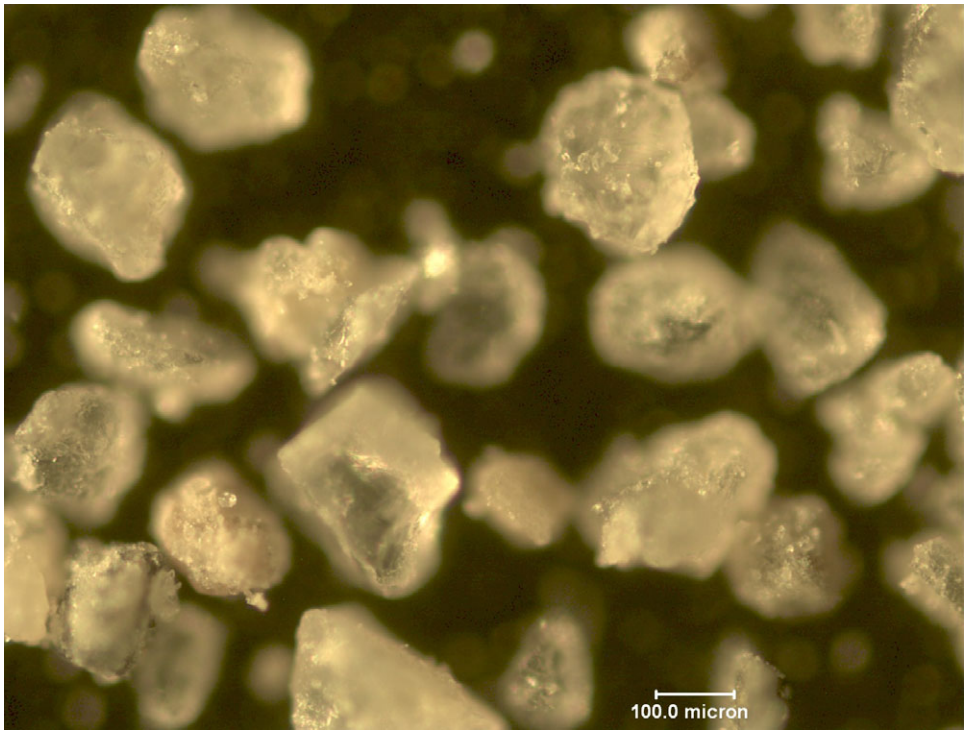
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/8/2005	0.859	0.542	120.5	6.3483	26848	3048	0.4818	1.3812	1171.46	1.61	1173.07	9.70E+07	414.36	0.00309







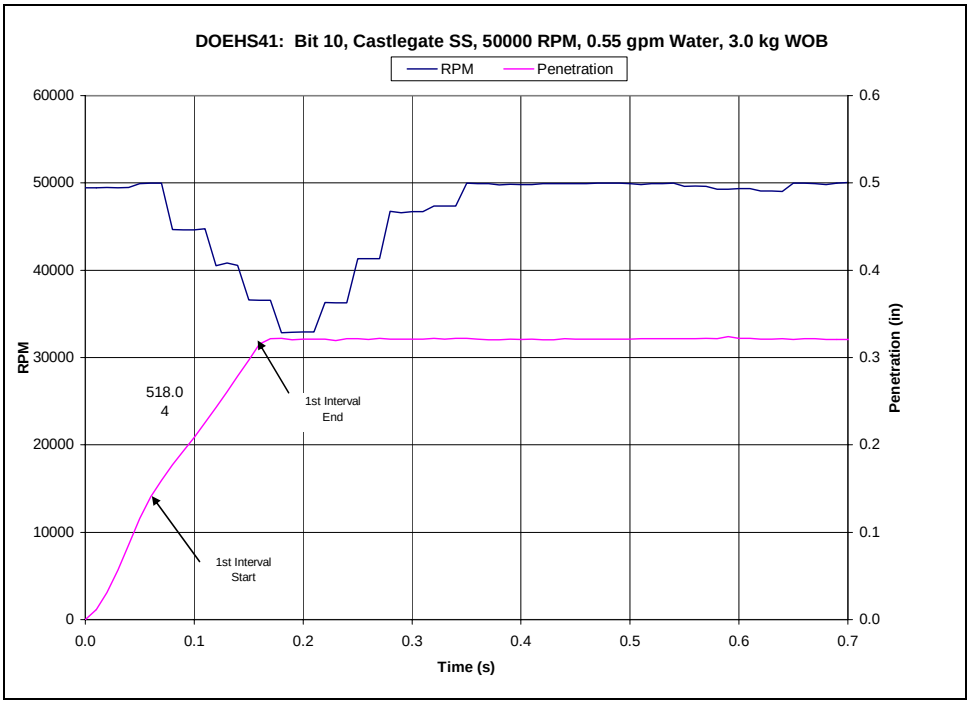
DOEH40 Casltegate cuttings 40,000 rpm.

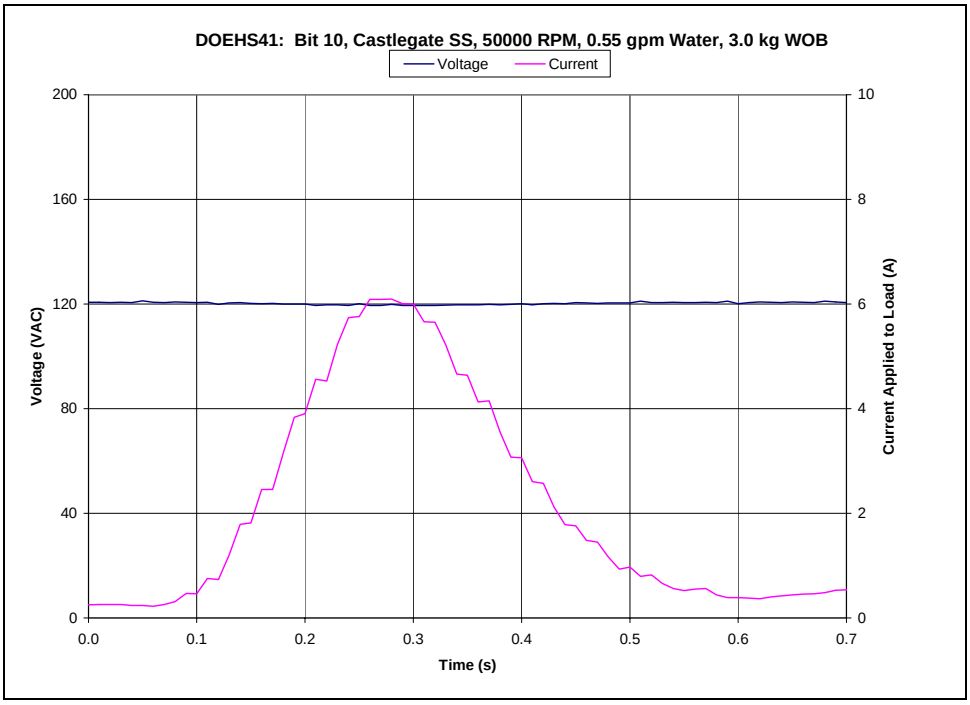


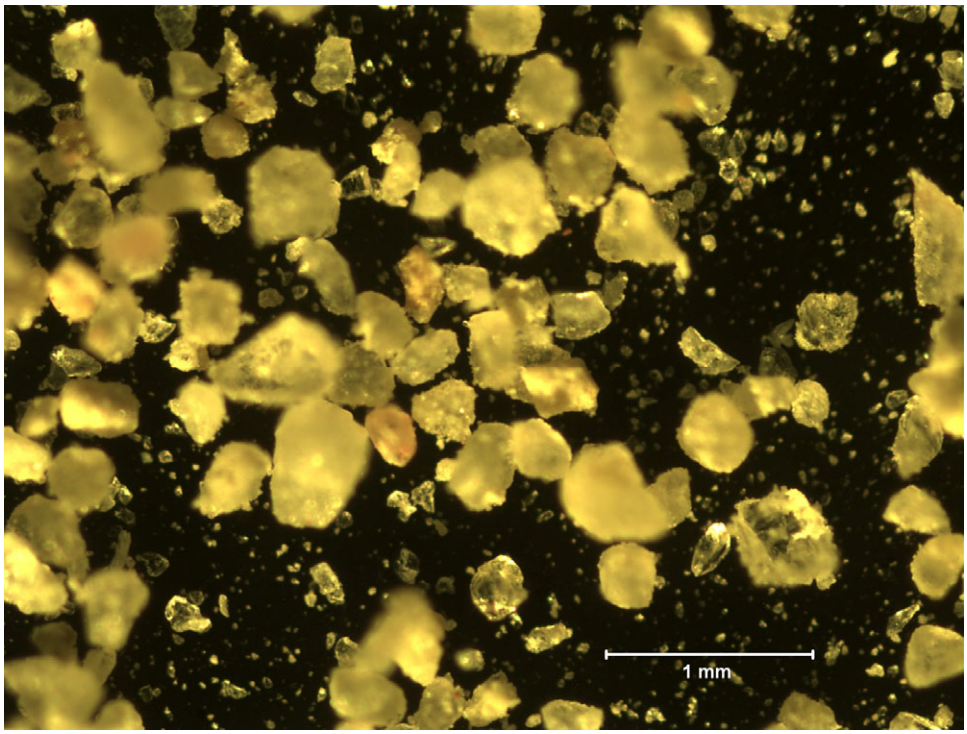
DOEH40 Casltegate cuttings 40,000 rpm.

DEAHS41: Summary data and plots and cuttings photographs.

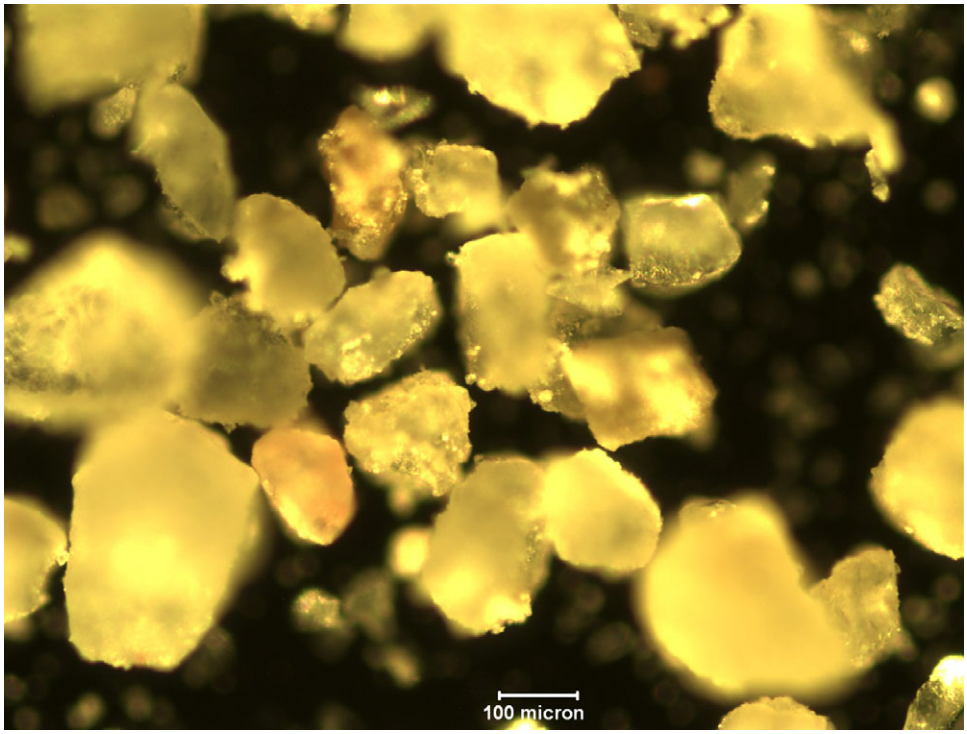
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/8/2005	0.858	0.546	120.5	6.0549	43063	3048	0.5941	1.7268	905.76	1.63	907.39	7.50E+07	518.04	0.00241







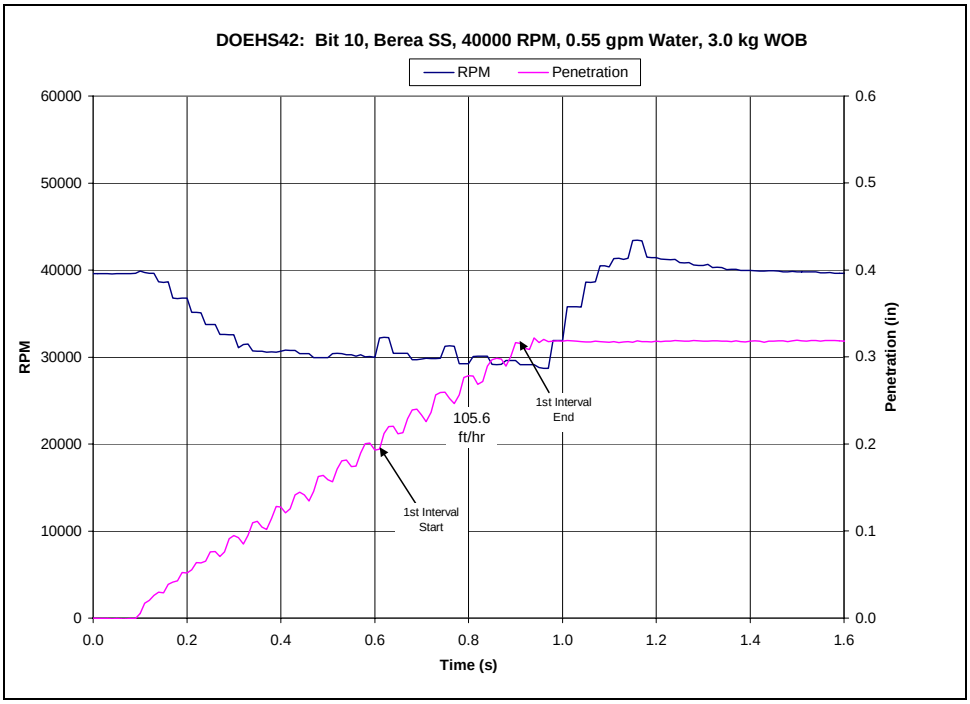
DOEH41 Casltegate cuttings 50,000 rpm.

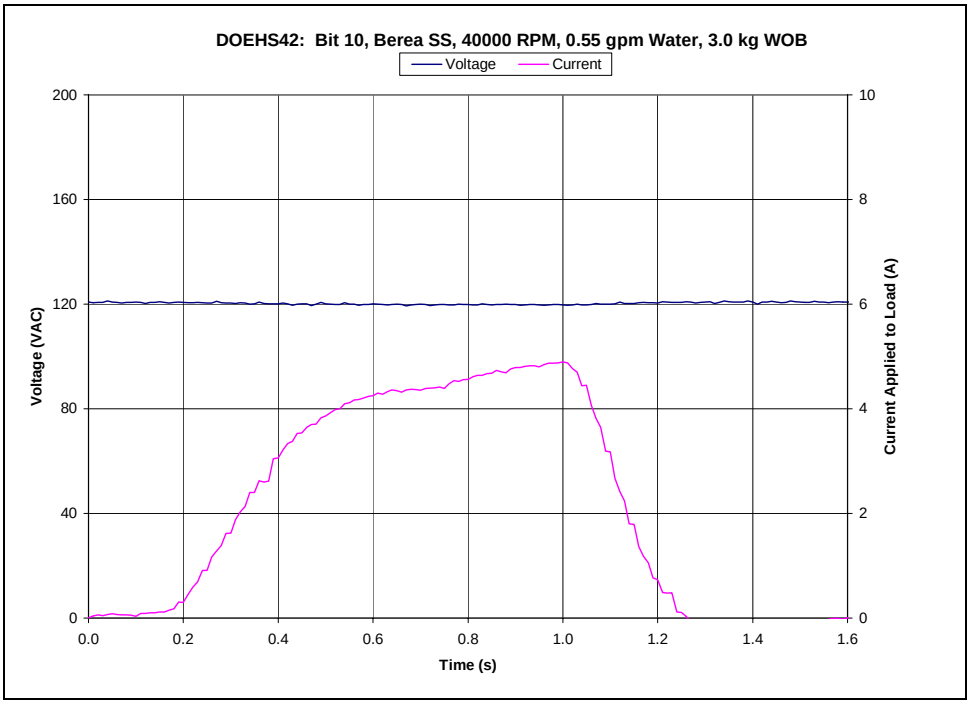


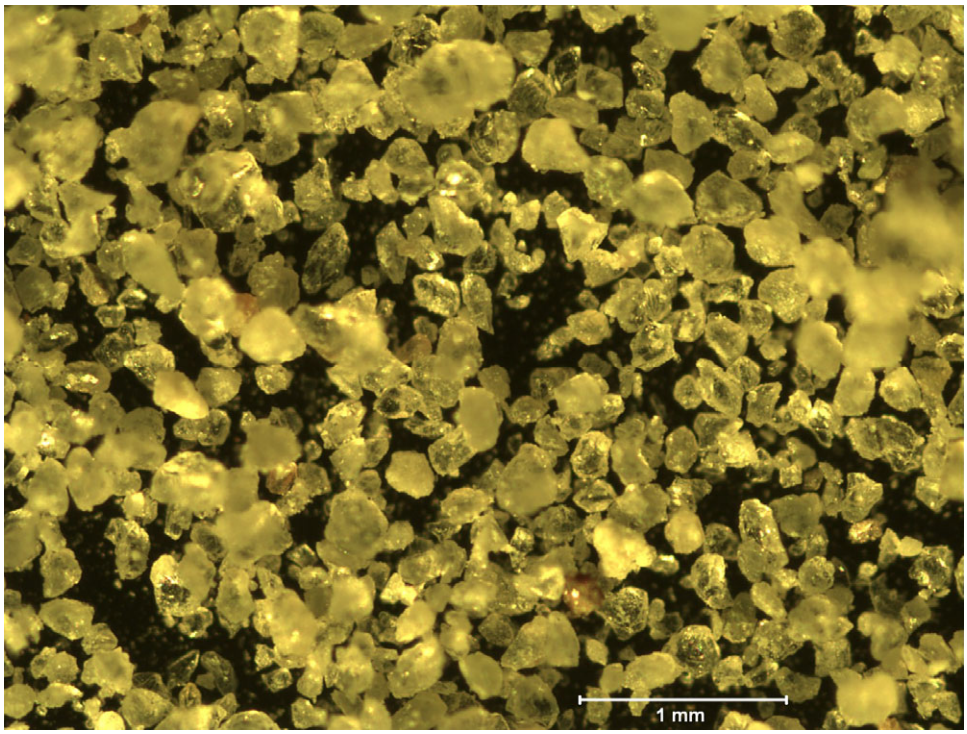
DOEH41 Casltegate cuttings 50,000 rpm.

DEAHS42: Summary data and plots and cuttings photographs.

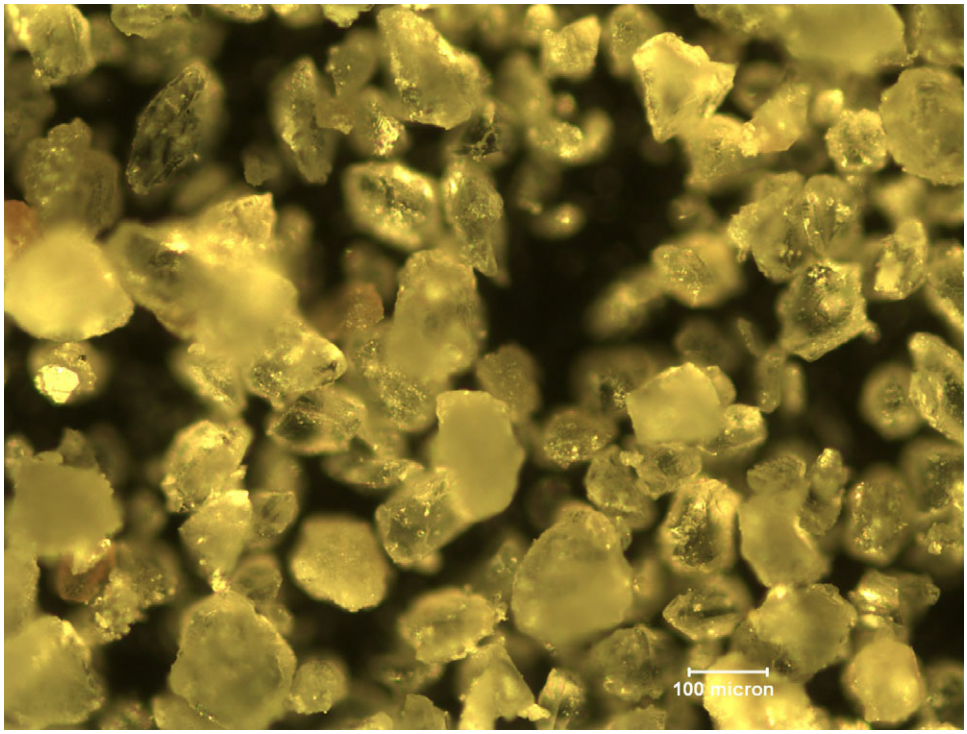
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/8/2005	0.836	0.519	119.8	4.5600	29832	3015	0.1187	0.3520	3393.34	1.64	3394.98	2.81E+08	105.60	0.00071







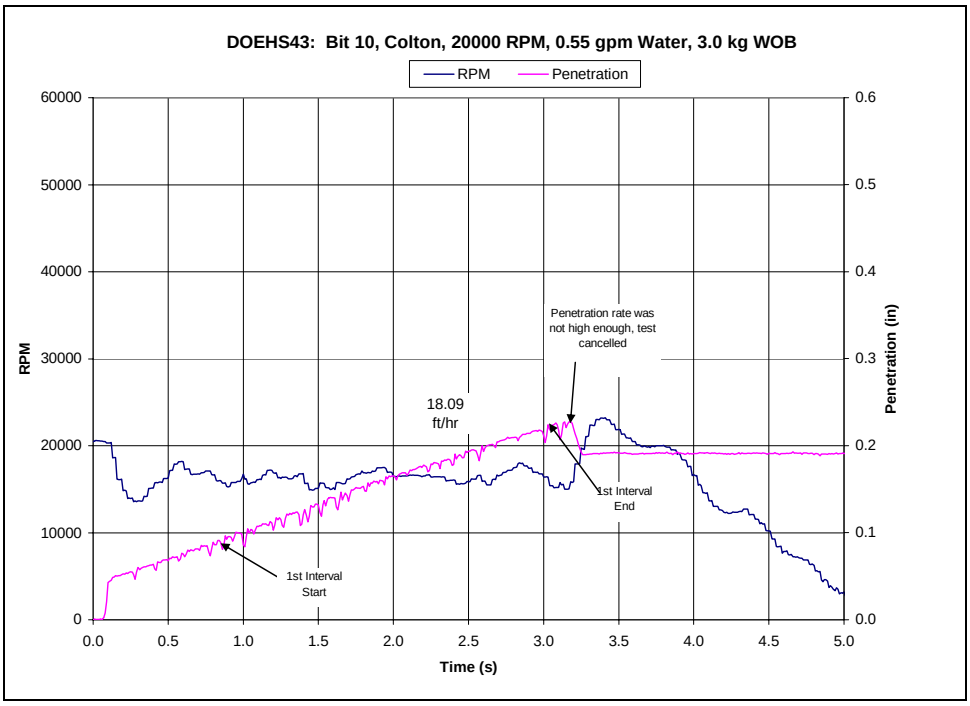
DOEH42 Berea cuttings 40,000 rpm.

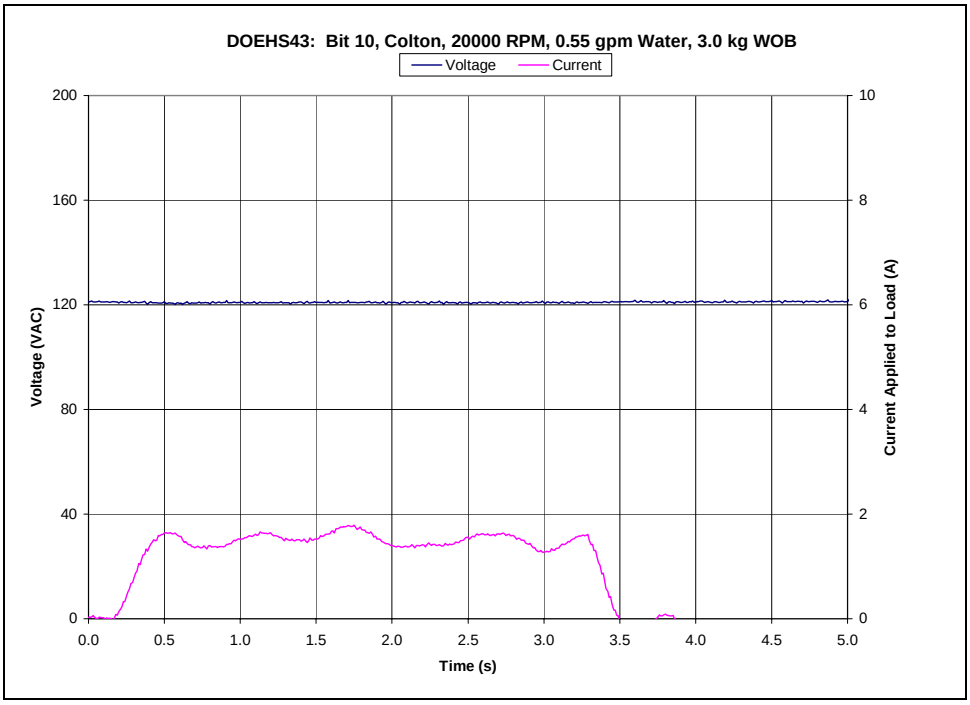


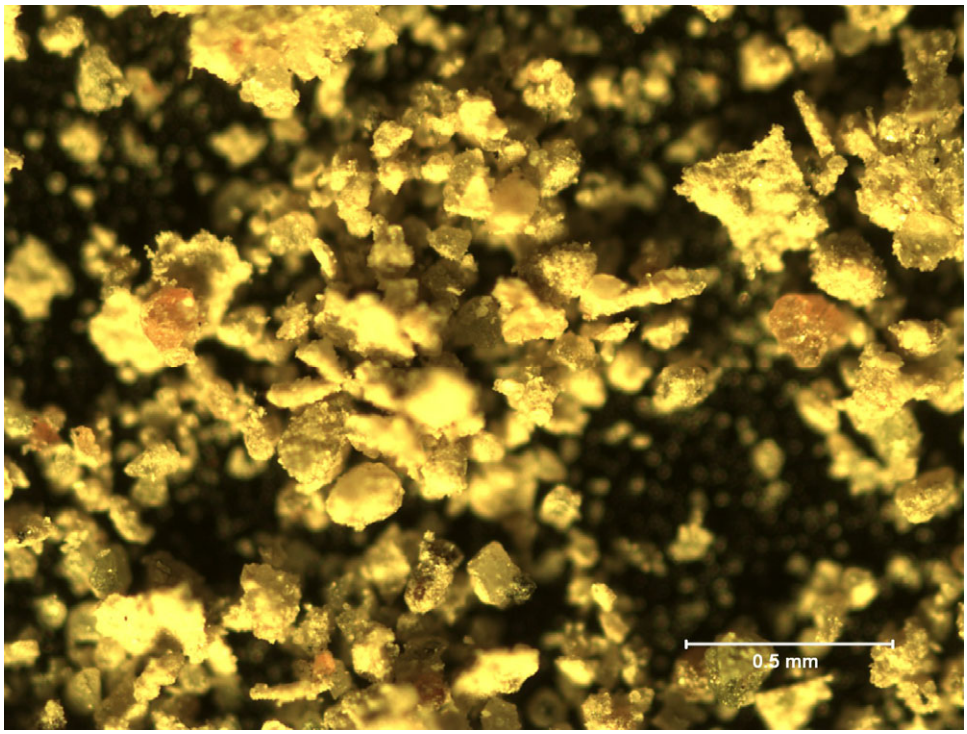
DOEH42 Berea cuttings 40,000 rpm.

DEAHS43: Summary data and plots and cuttings photographs.

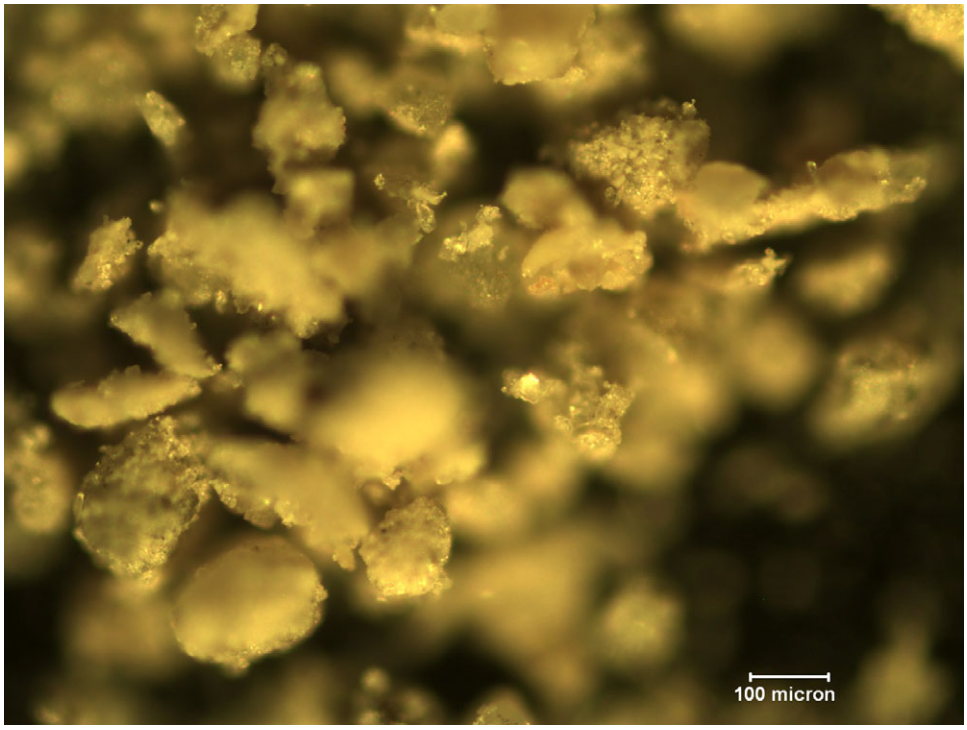
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/8/2005	0.826	0.516	120.9	1.5100	16318	2973	0.0197	0.0603	6834.68	1.67	6836.35	5.65E+08	18.09	0.00022







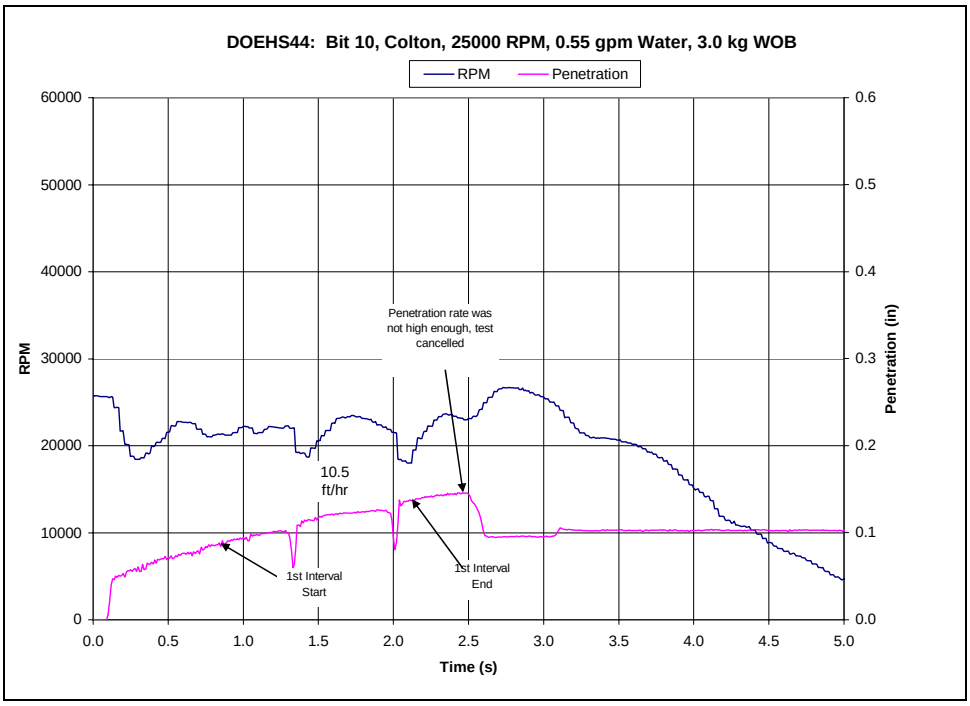
Test DOEH43 Colton cuttings at 20,000 RPM

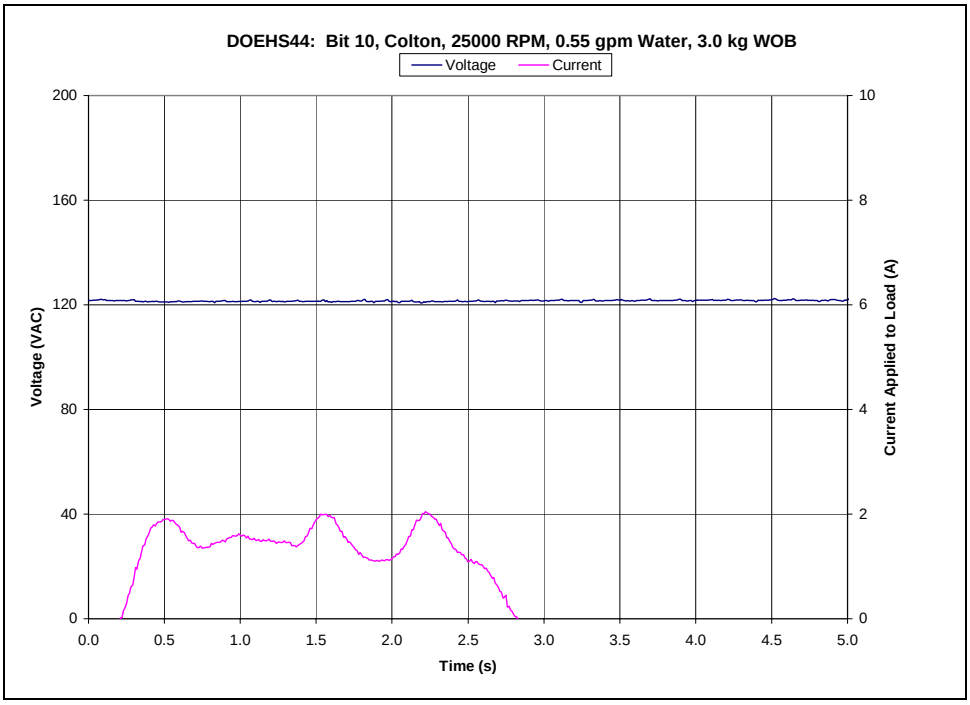


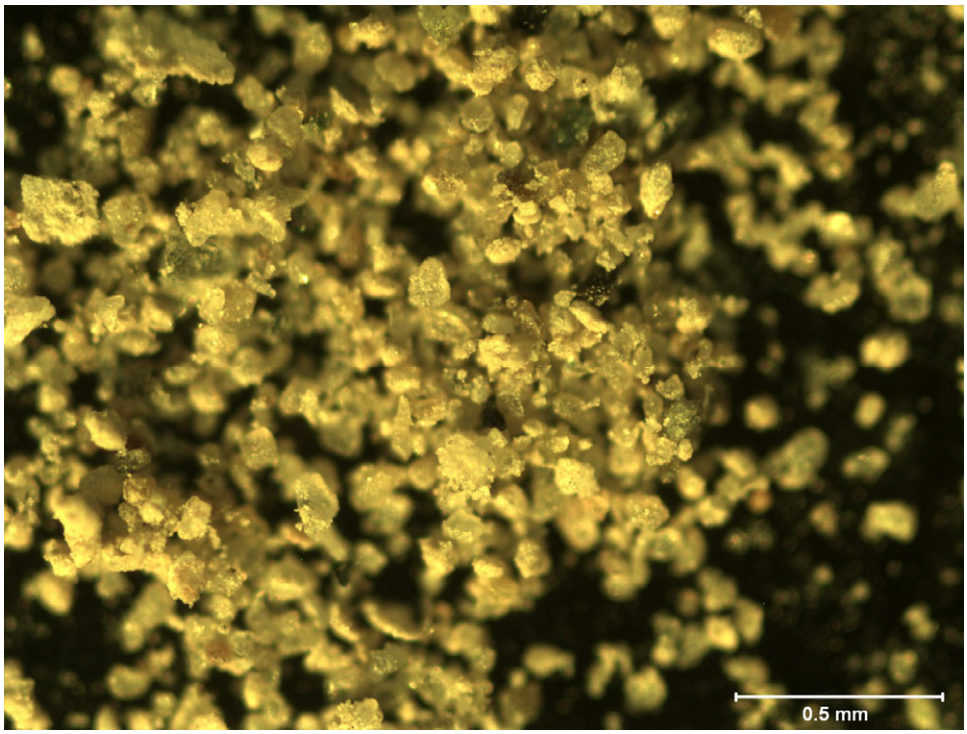
Test DOEH43 Colton cuttings 20,000 RPM

DEAHS44: Summary data and plots and cuttings photographs.

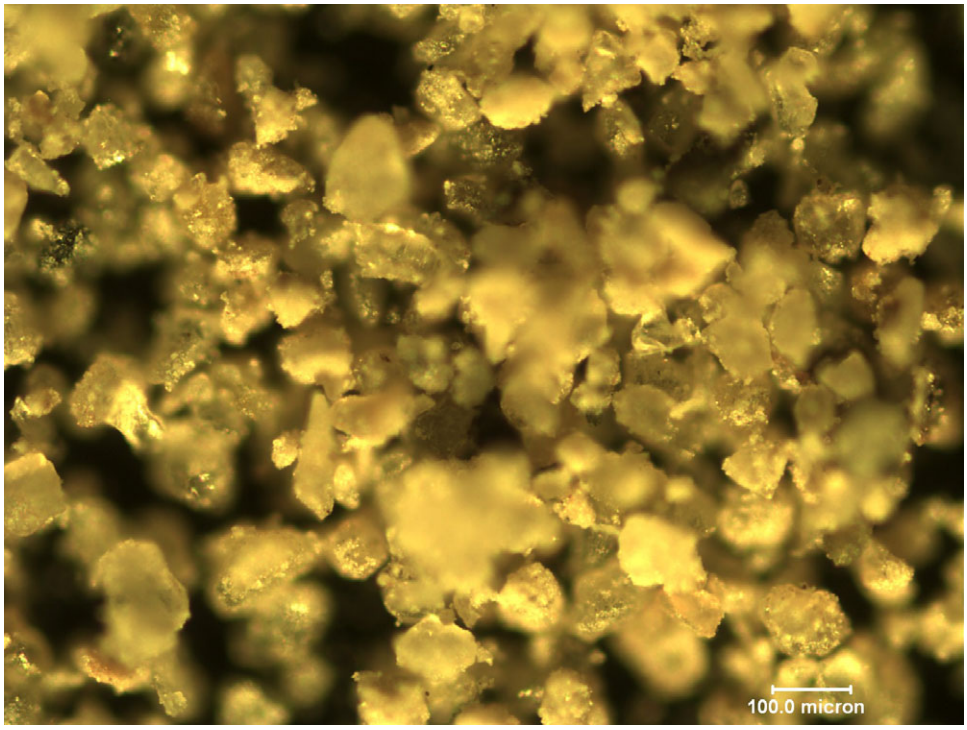
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/8/2005	0.826	0.525	121.4	1.4800	21485	3004	0.0112	0.0350	11855.97	1.73	11857.70	9.80E+08	10.50	0.00010







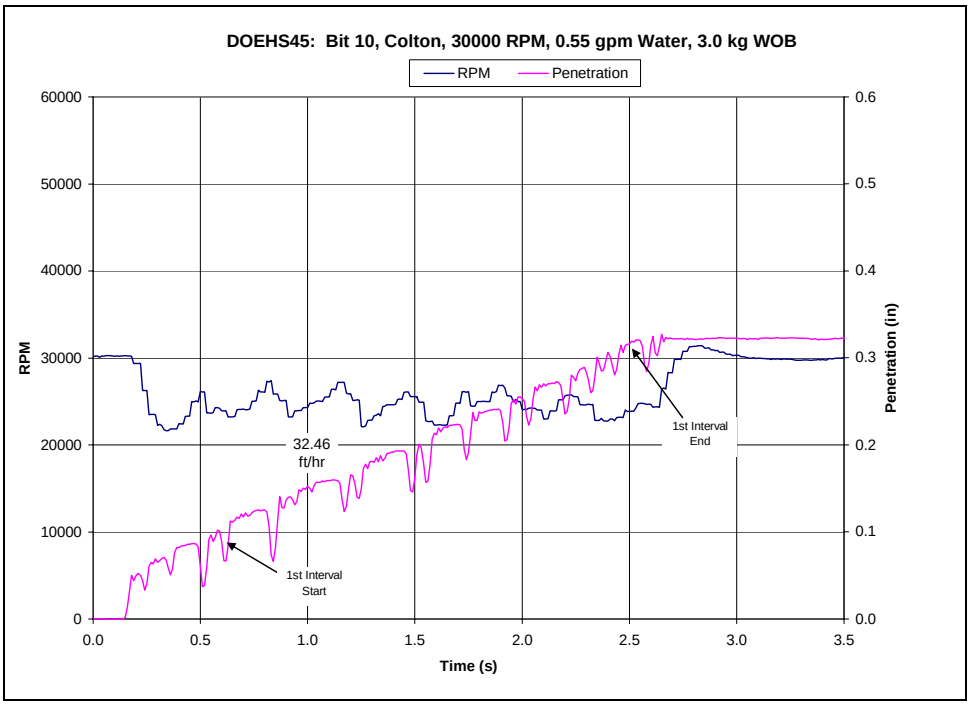
Test DOEH44 Colton cuttings 25,000 RPM

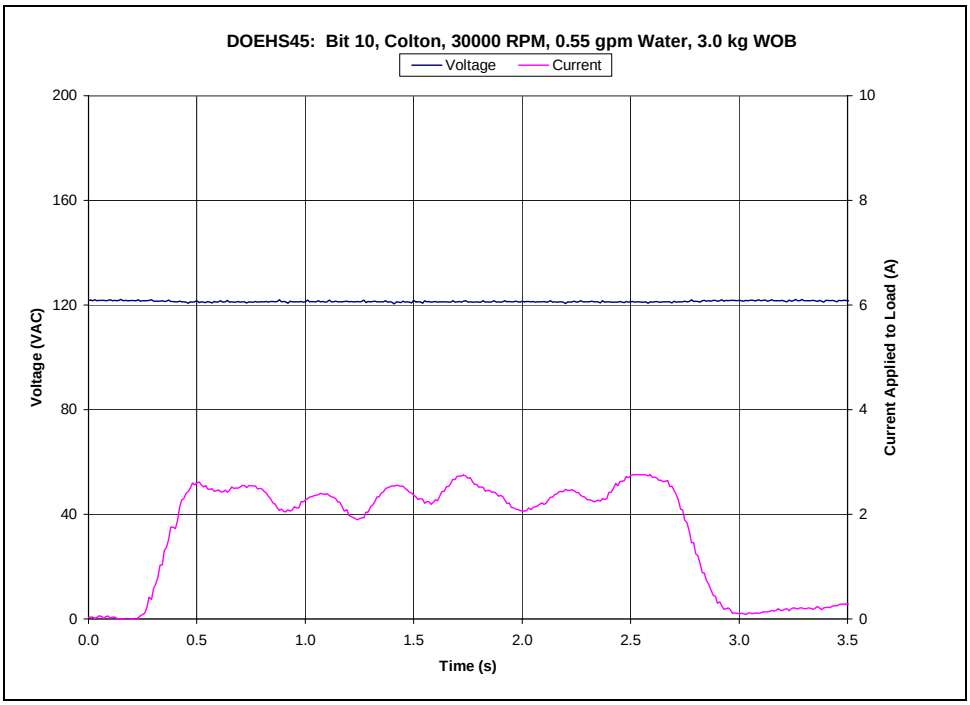


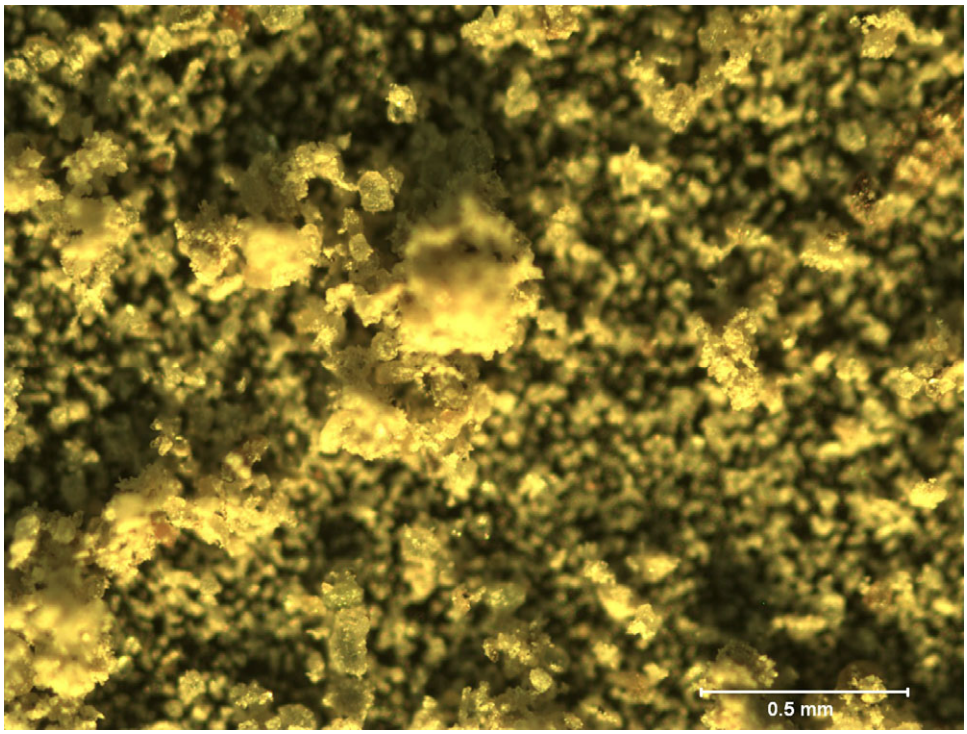
Test DOEH44 Colton cuttings 25,000 RPM

DEAHS45: Summary data and plots and cuttings photographs.

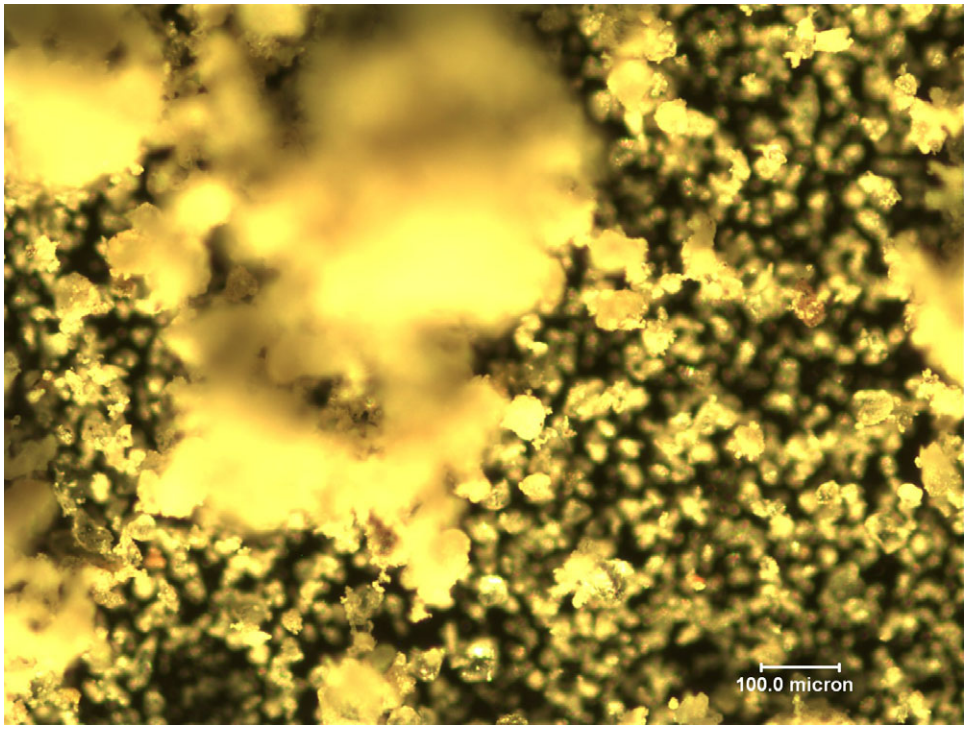
Test	Hole OD	Hole ID	Volts	Amps	RPM	WOB	Volume Removal	ROP	S. E. Rotation	S. E. WOB	Total S. E.	Total S. E.	ROP	
Date	(in)	(In)	(v)	(a)	(rpm)	(gms)	(in3/sec)	(in/sec)	(ft-lbs/in3)	(ft-lbs/in3)	(ft-lbs/in3)	(Joules/m3)	(ft/hr)	(in/rev)
11/8/2005	0.826	0.515	121.2	2.3500	24572	3012	0.0354	0.1082	5927.90	1.69	5929.59	4.90E+08	32.46	0.00026







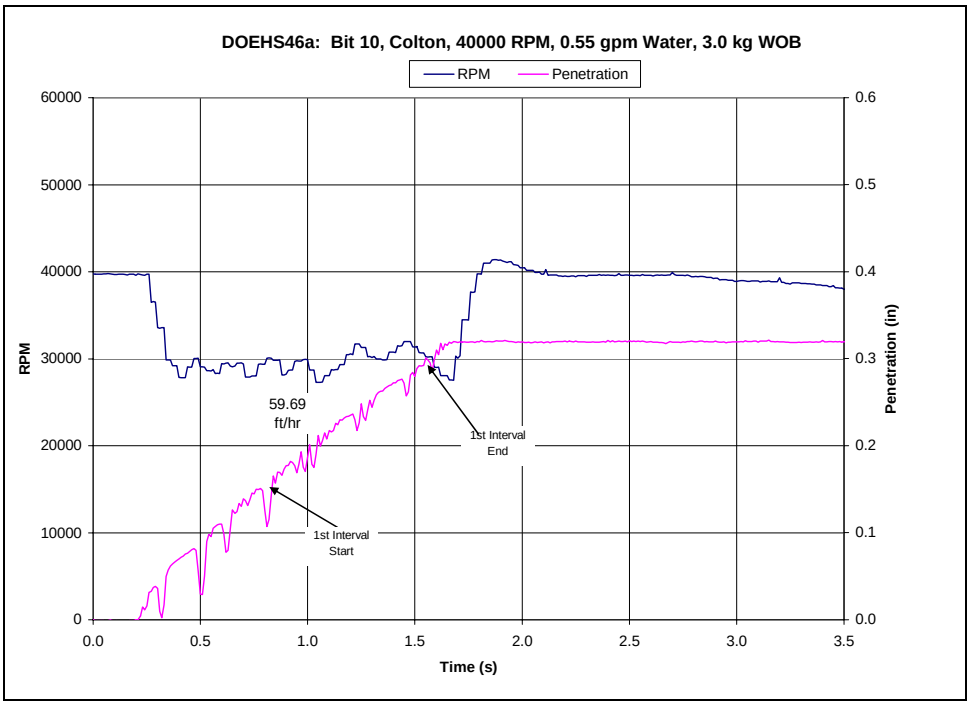
Test DOEH45 Colton cuttings 30,000 RPM

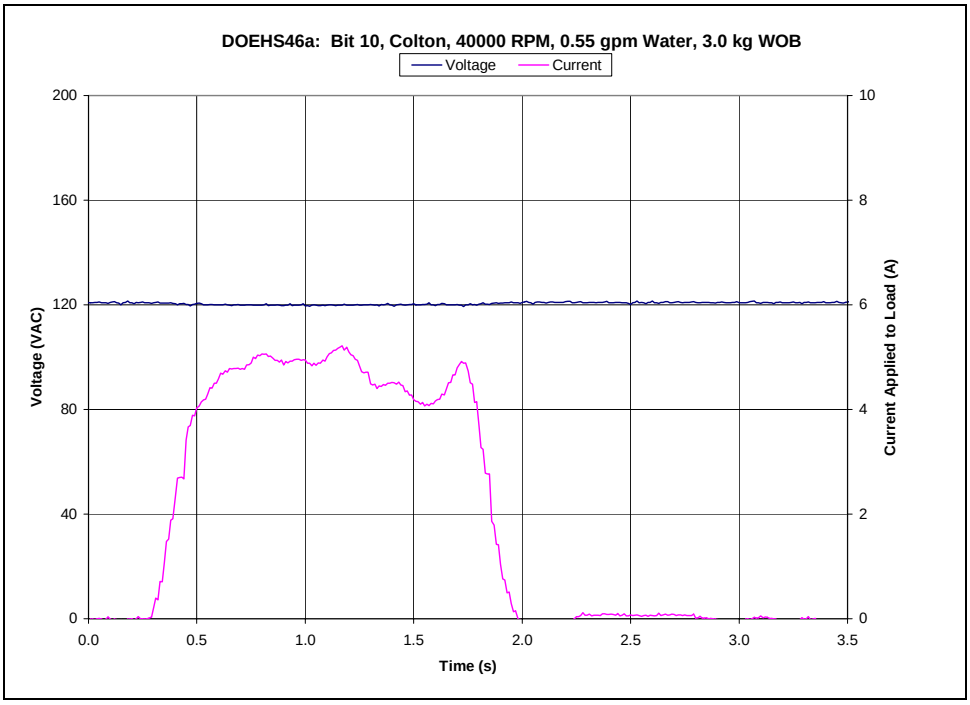


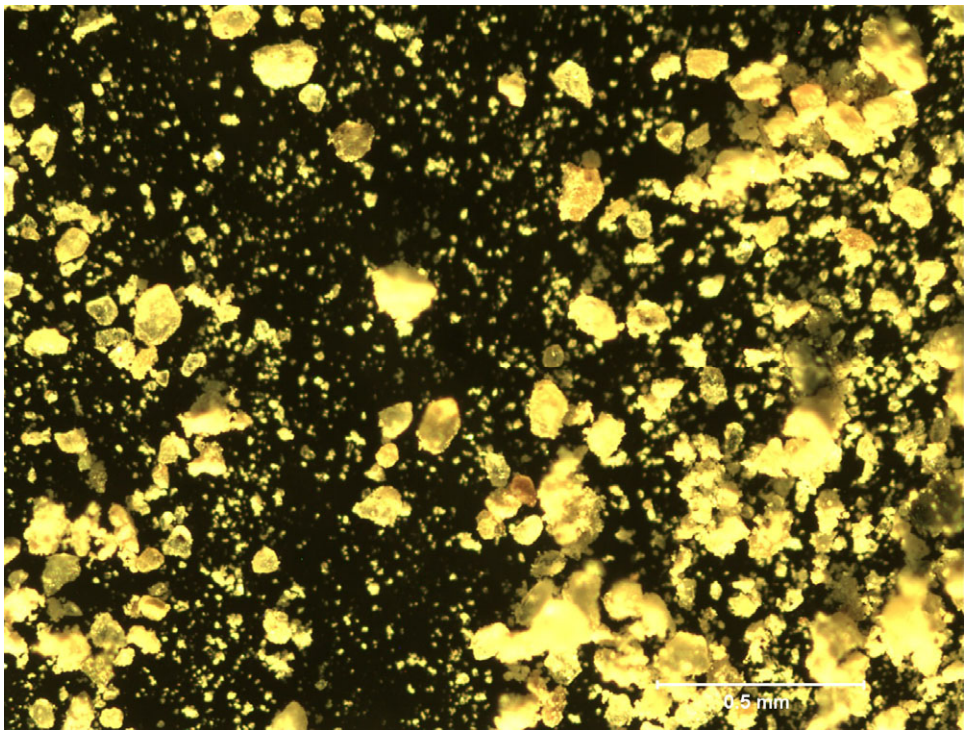
Test DOEH45 Colton cuttings 30,000 RPM

DEAHS46a: Summary data and plots and cuttings photographs.

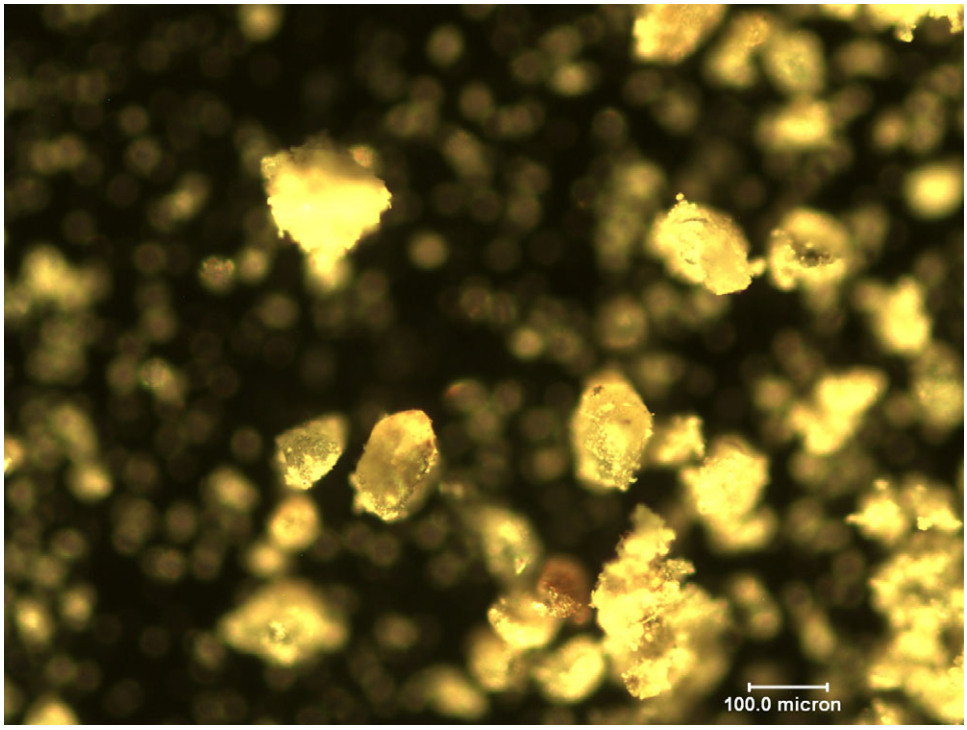
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/8/2005	0.828	0.522	120.0	4.7000	29735	3013	0.0645	0.1989	6446.67	1.71	6448.38	5.33E+08	59.67	0.00040







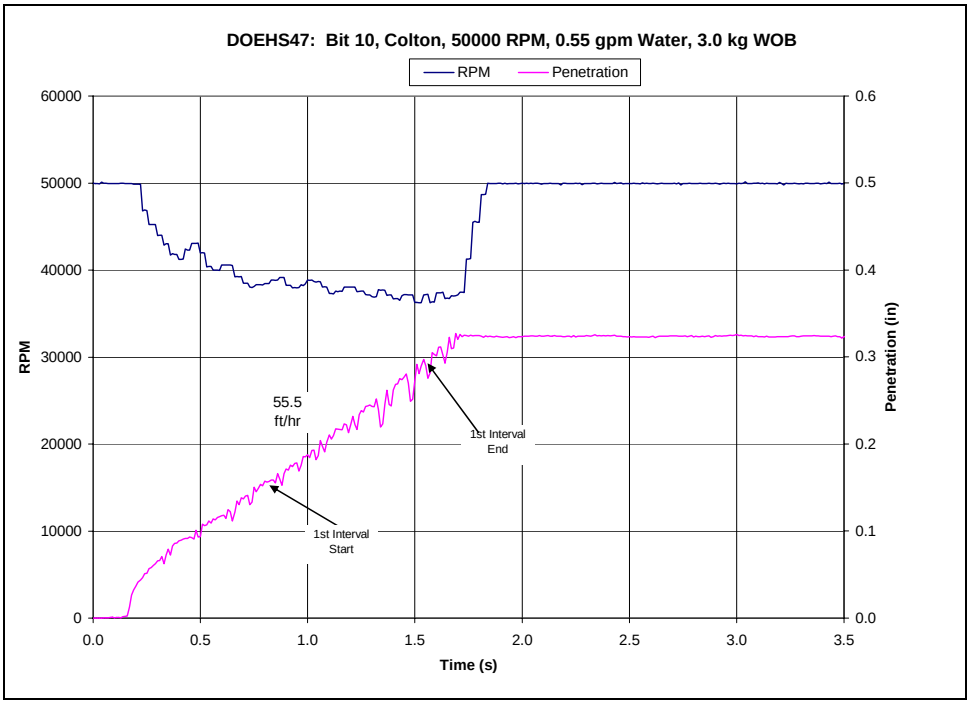
Test DOEH46 Colton cuttings 40,000 RPM

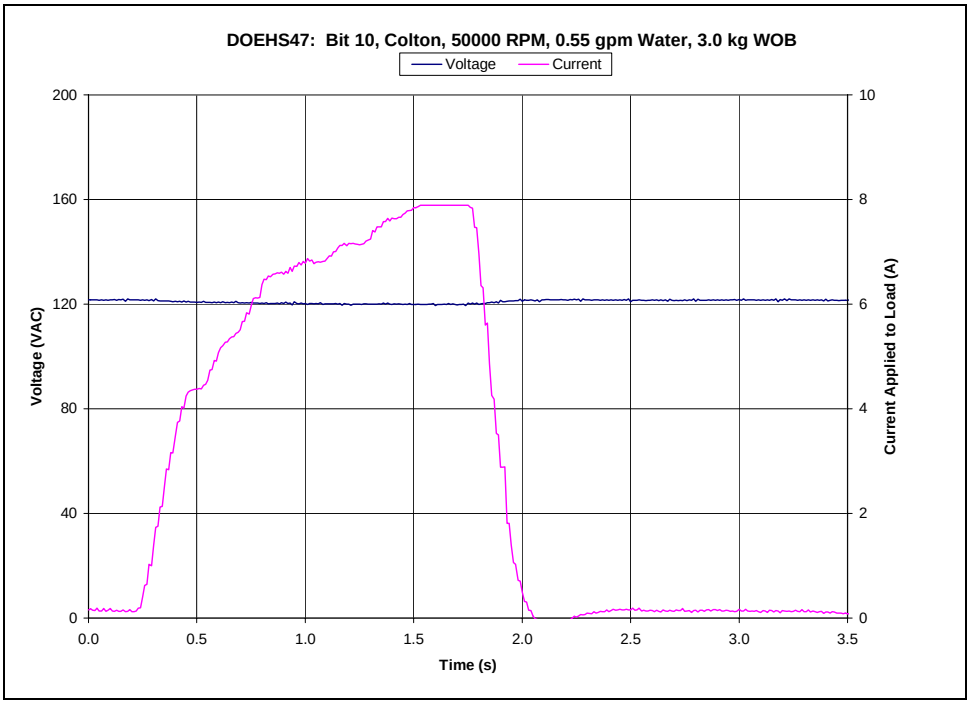


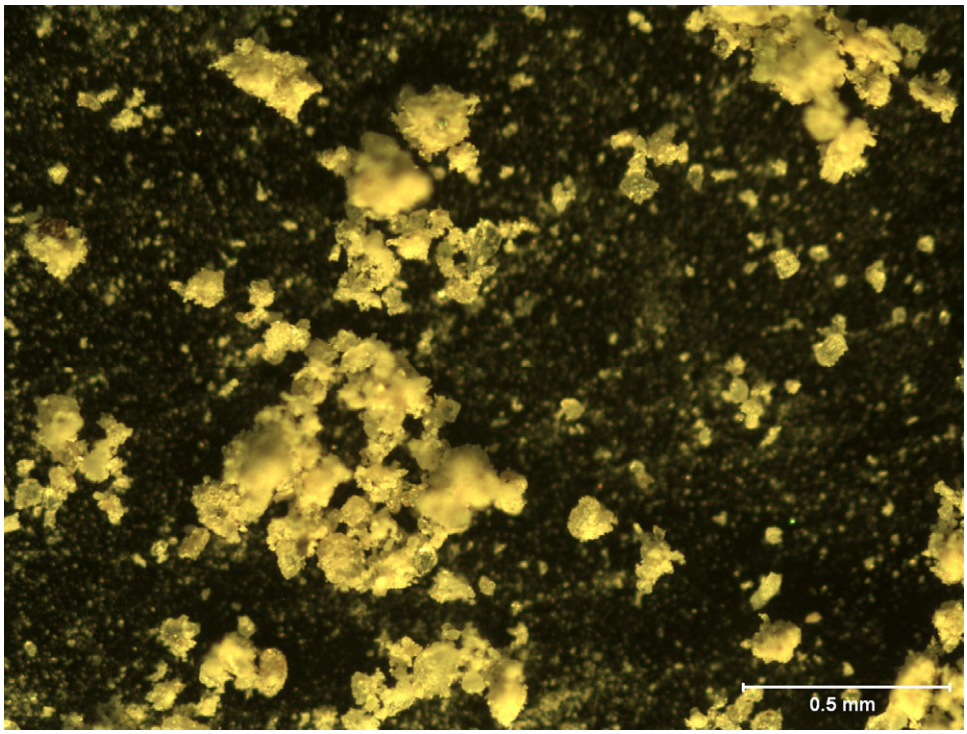
Test DOEH46 Colton cuttings 40,000 RPM

DEAHS47: Summary data and plots and cuttings photographs.

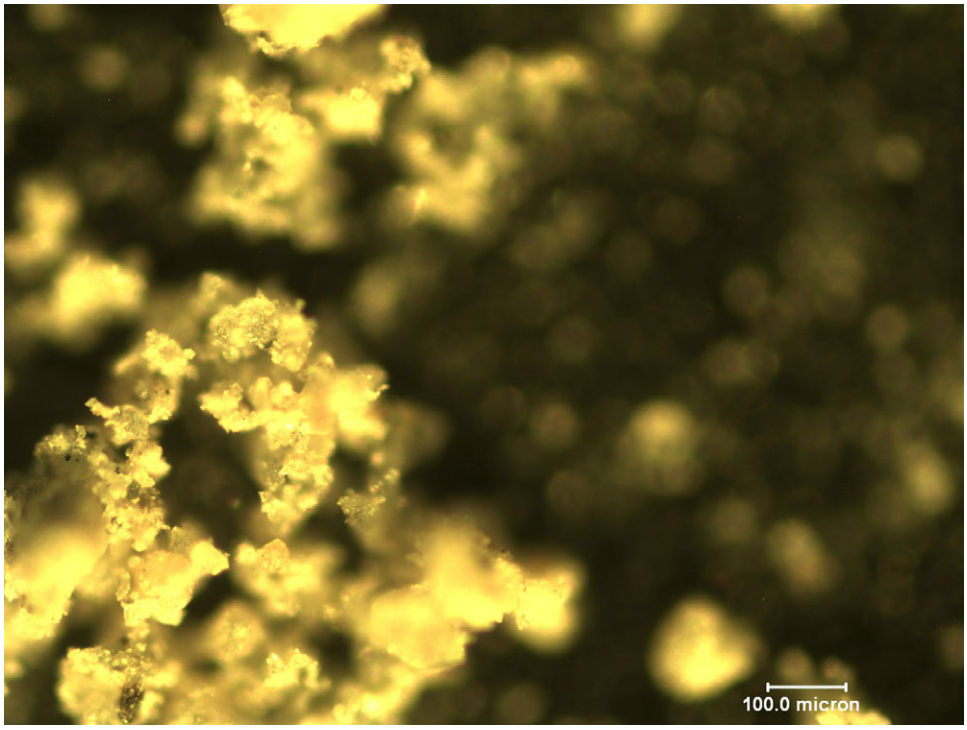
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/8/2005	0.829	0.518	120.1	7.2300	37628	3017	0.0609	0.1850	10522.72	1.68	10524.41	8.70E+08	55.50	0.00029







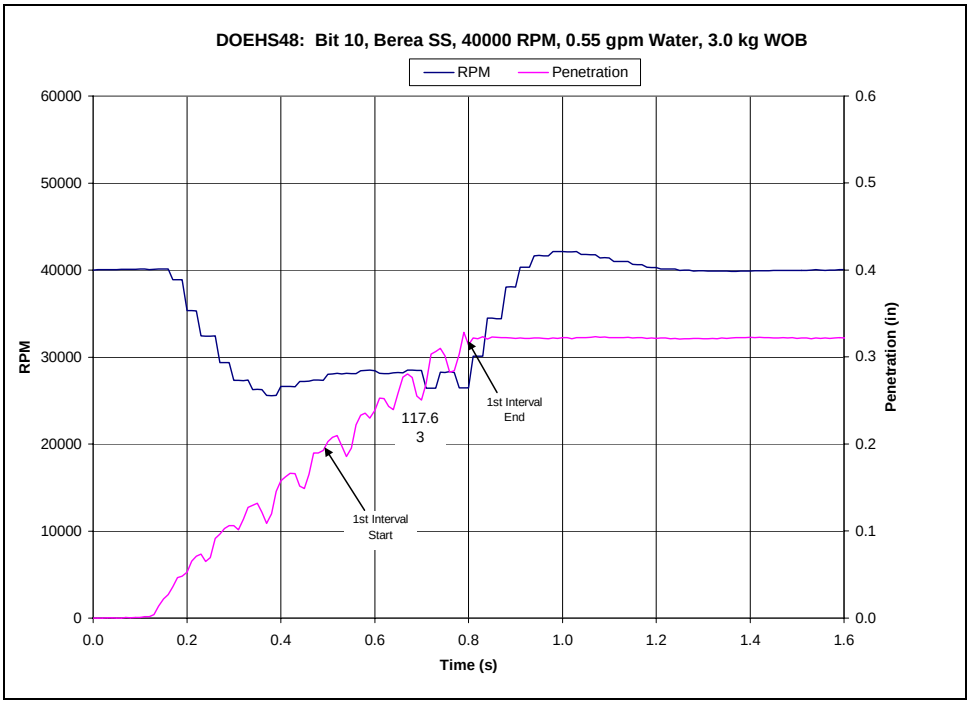
Test DOEH47 Colton cuttings 50,000 RPM

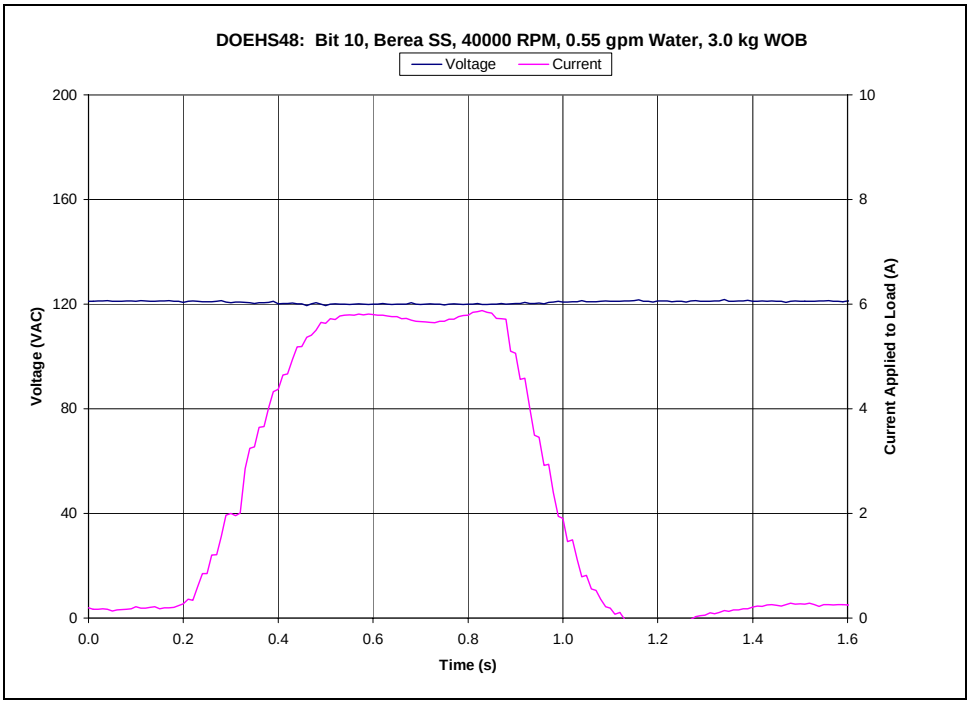


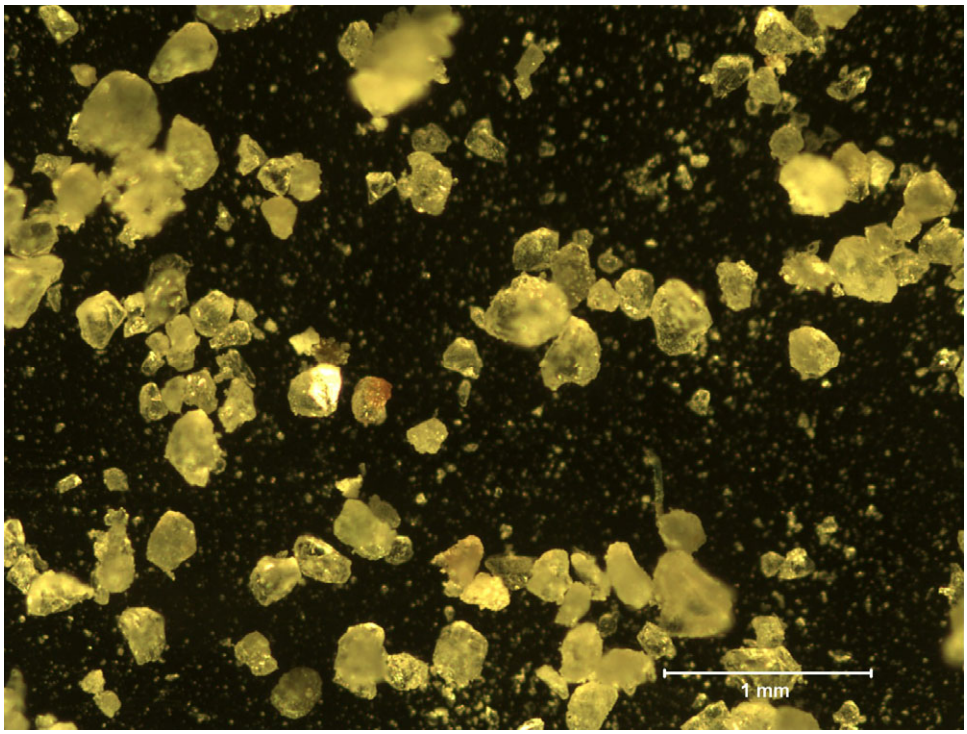
Test DOEH47 Colton cuttings 50,000 RPM

DEAHS48: Summary data and plots and cuttings photographs.

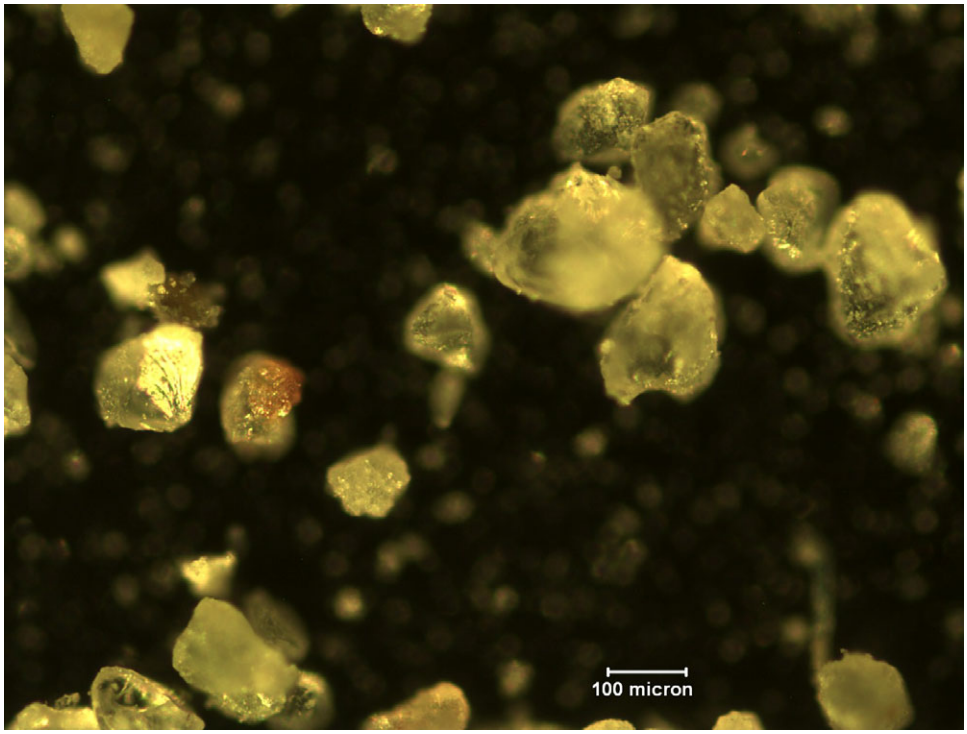
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/8/2005	0.826	0.515	120.0	5.7500	28102	2984	0.1284	0.3921	3962.87	1.67	3964.54	3.28E+08	117.63	0.00084







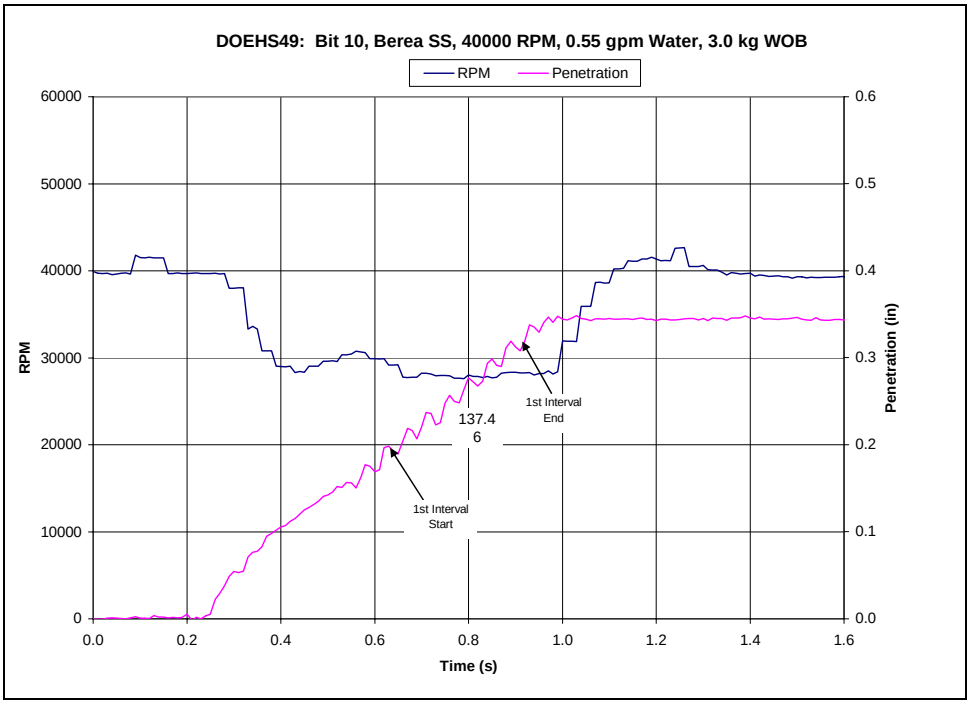
Test DOEH48 Berea cuttings 40,000 RPM

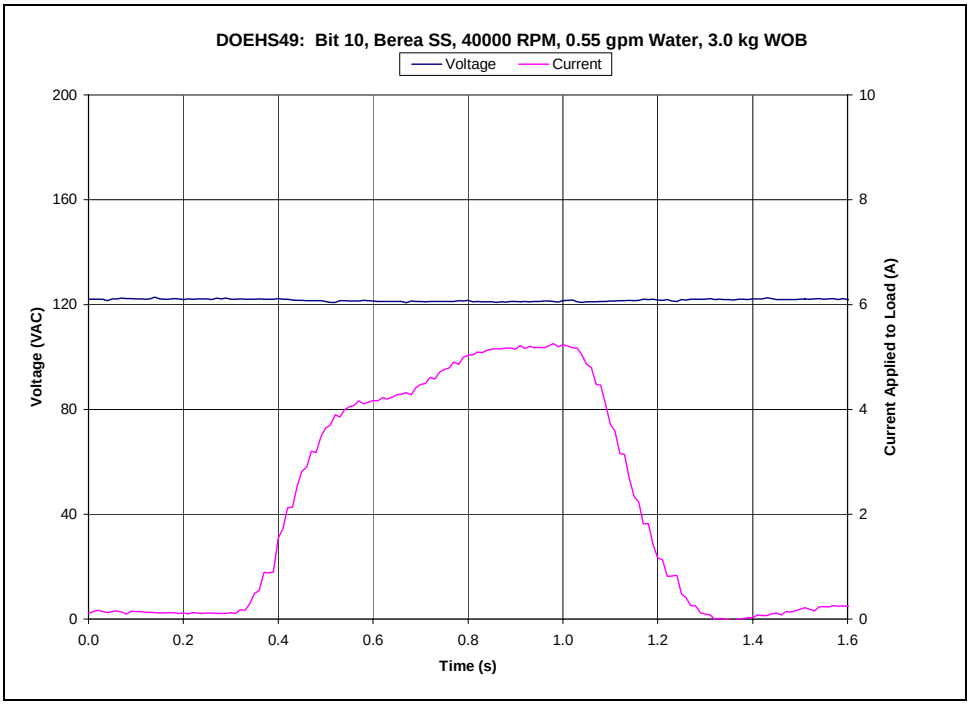


Test DOEH48 Berea cuttings 40,000 RPM

DEAHS49: Summary data and plots and cuttings photographs.

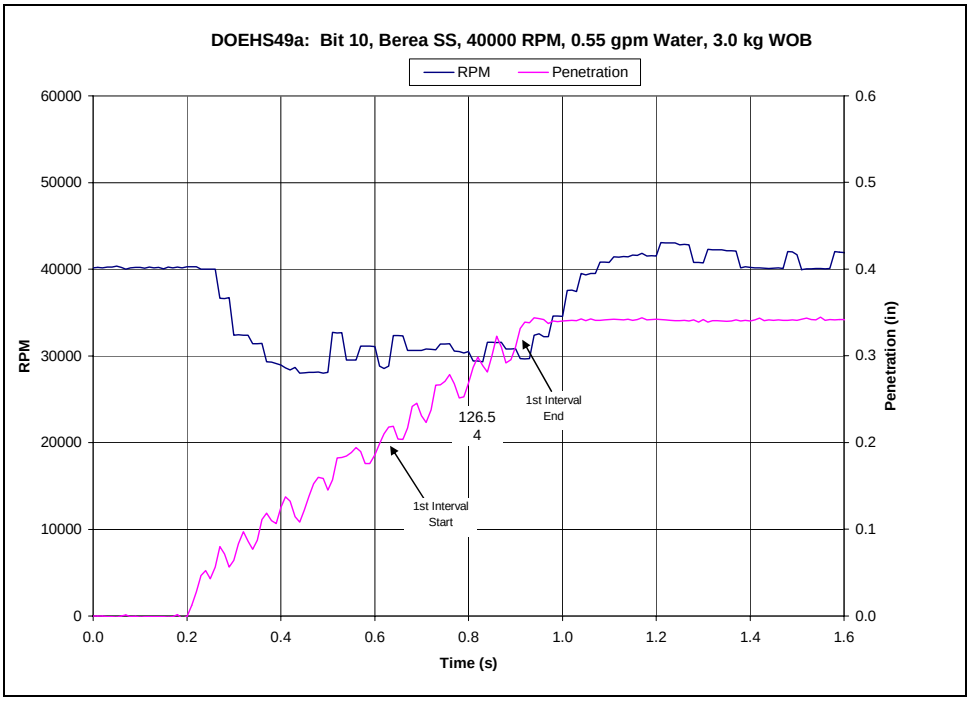
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/14/2005	0.845	0.551	122.0	4.8800	28068	3032	0.1477	0.4582	2973.30	1.73	2975.03	2.46E+08	137.46	0.00098

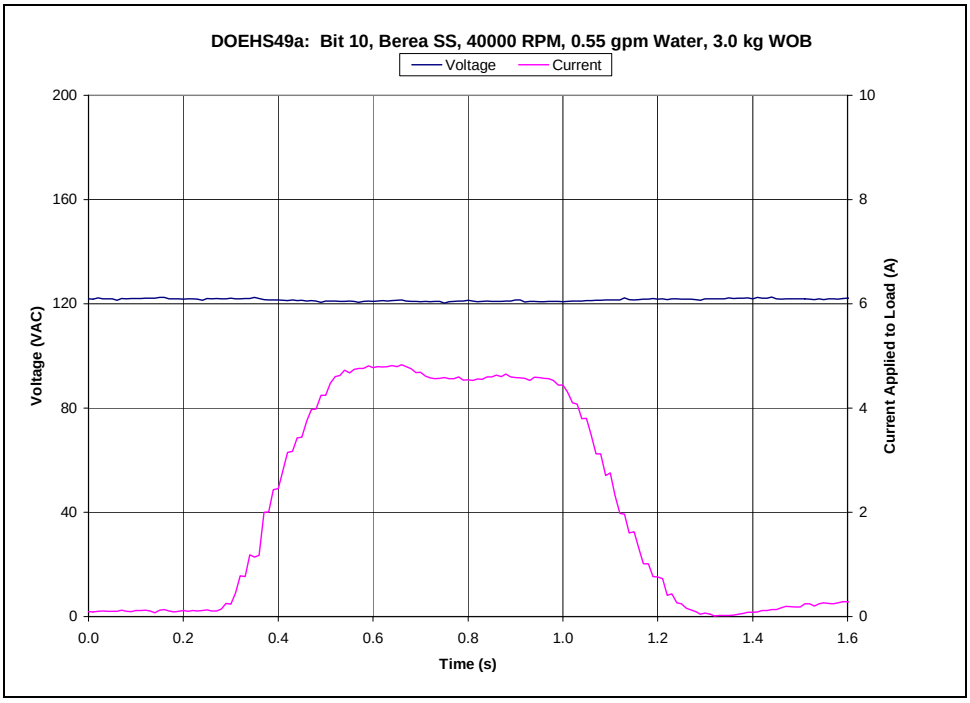




DEAHS50: Summary data and plots and cuttings photographs.

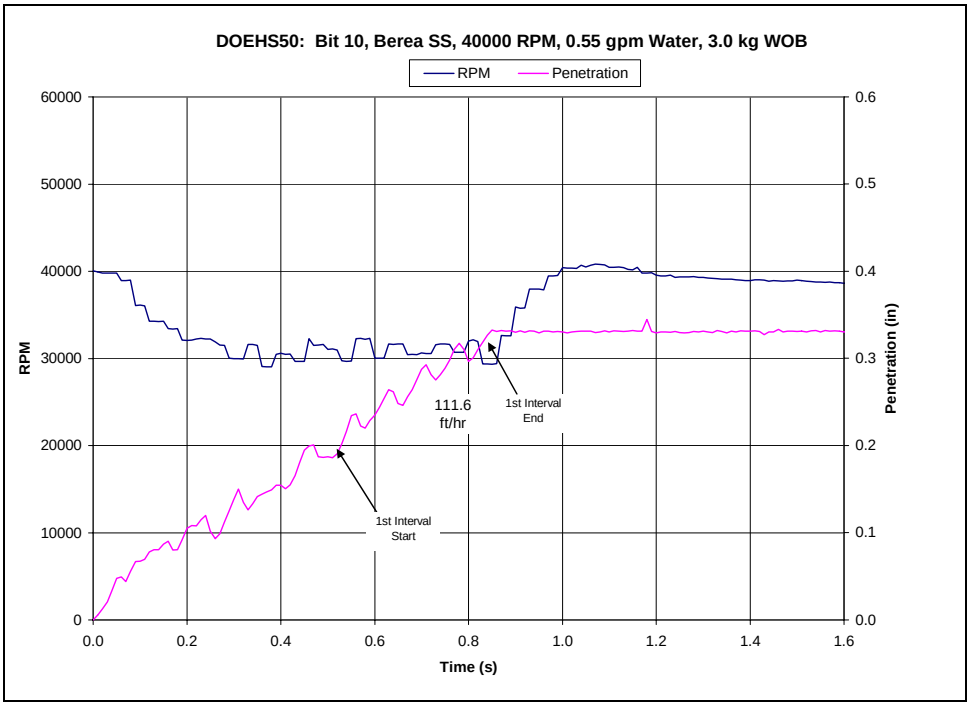
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/14/2005	0.849	0.540	121.0	4.6500	30676	2757	0.1422	0.4218	2918.89	1.50	2920.39	2.41E+08	126.54	0.00083

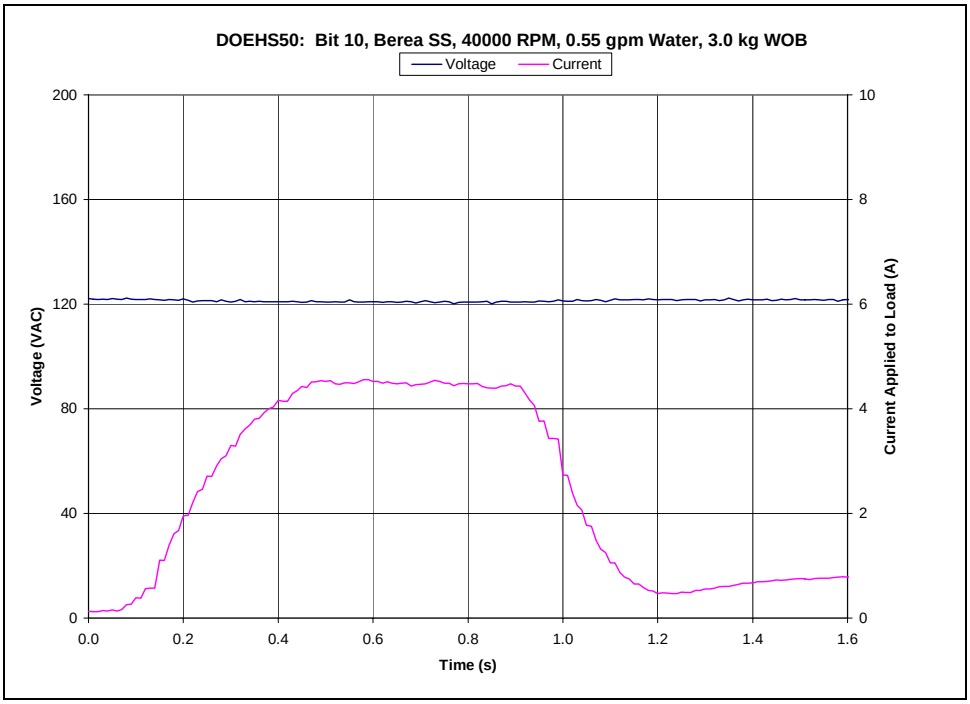




DEAHS50: Summary data and plots and cuttings photographs.

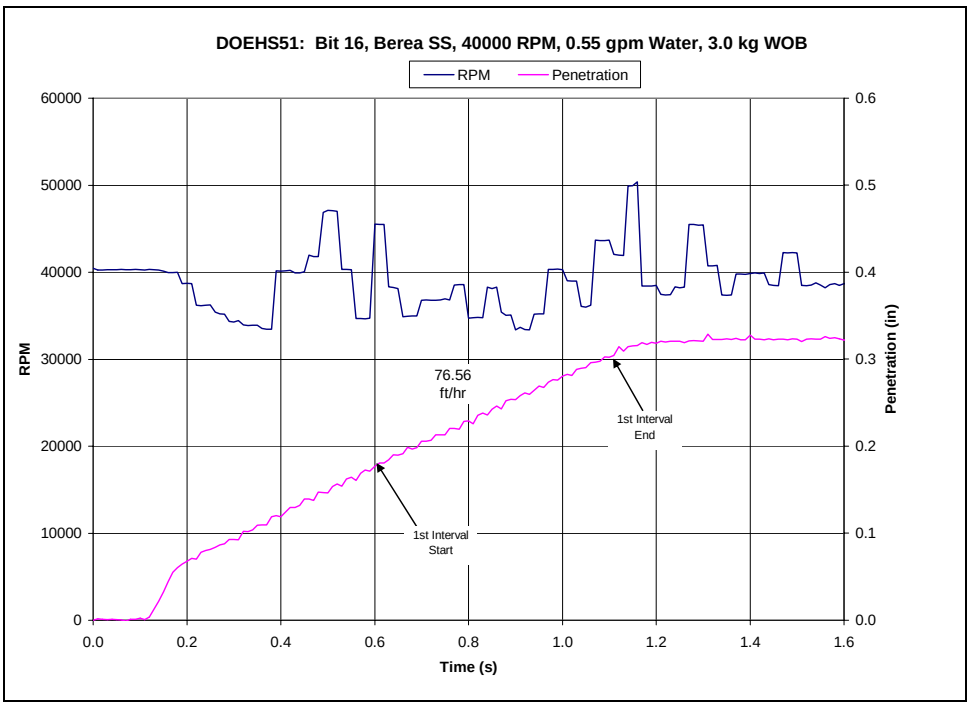
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/15/2005	0.853	0.544	120.9	4.4900	30983	2783	0.1262	0.3721	3173.98	1.51	3175.49	2.63E+08	111.63	0.00072

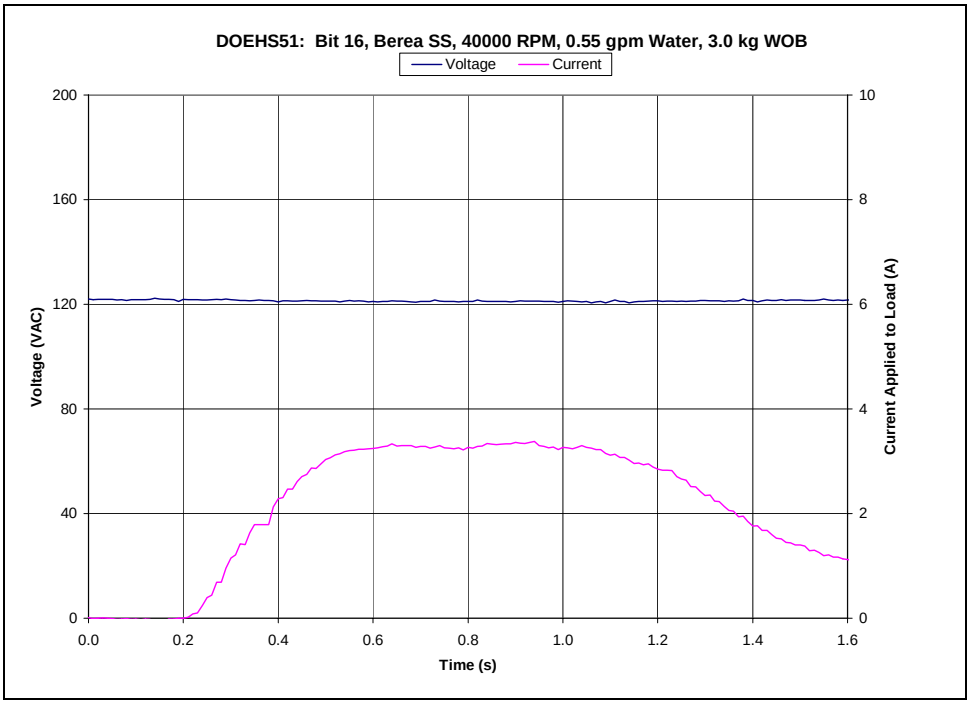




DEAHS51: Summary data and plots and cuttings photographs.

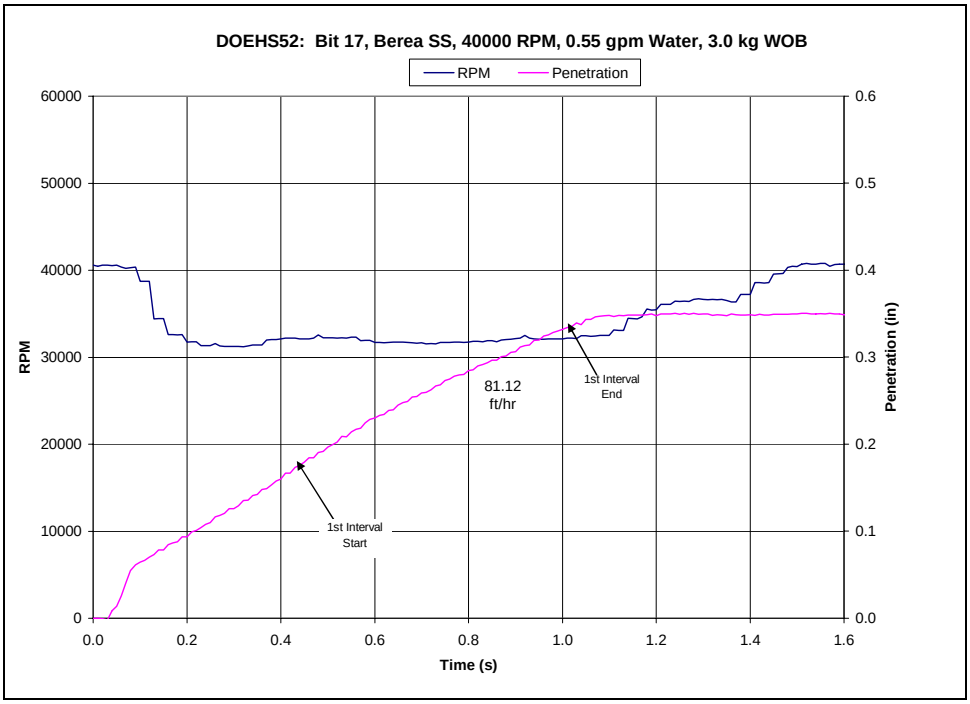
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/15/2005	0.838	0.562	121.1	3.2700	37831	2478	0.0774	0.2552	3771.56	1.50	3773.06	3.12E+08	76.56	0.00040

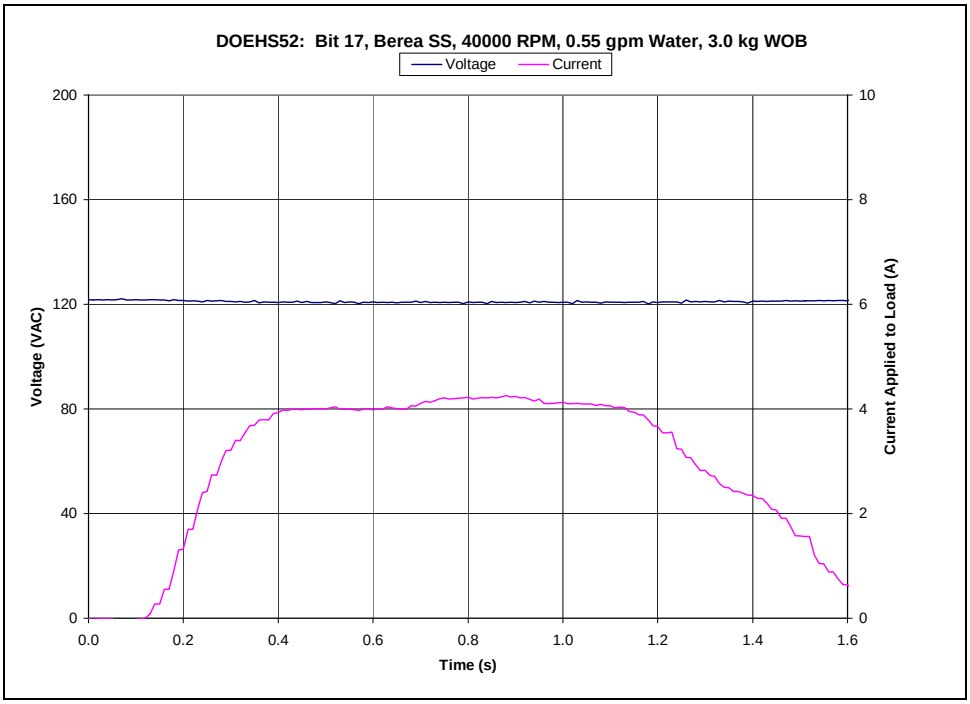




DEAHS52: Summary data and plots and cuttings photographs.

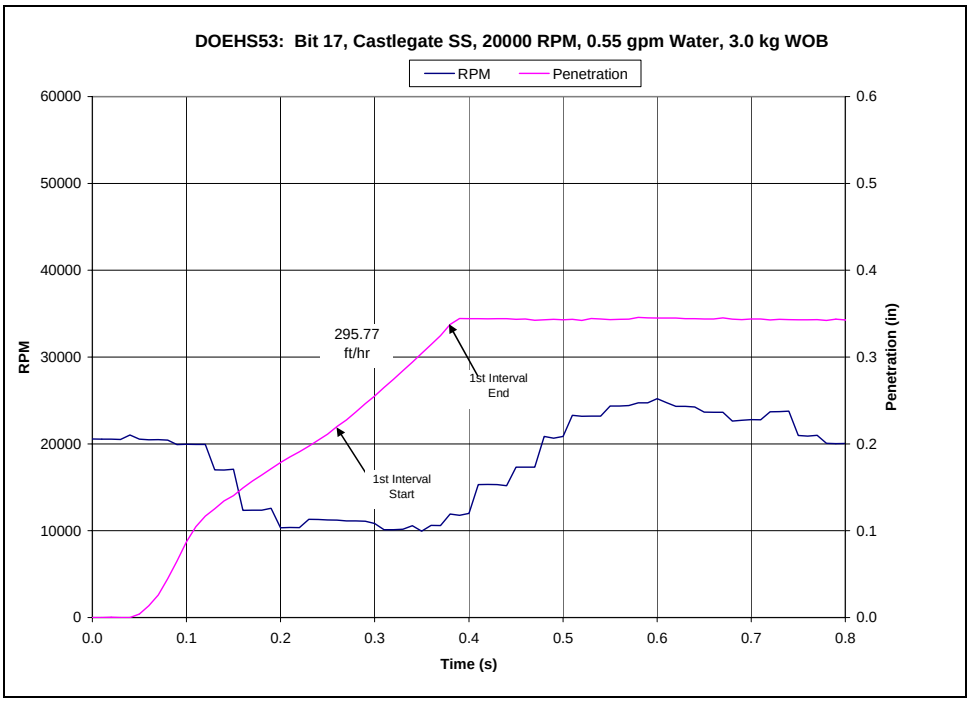
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/15/2005	0.849	0.551	120.9	4.4900	30983	3000	0.1219	0.3721	3284.09	1.68	3285.77	2.72E+08	111.63	0.00072

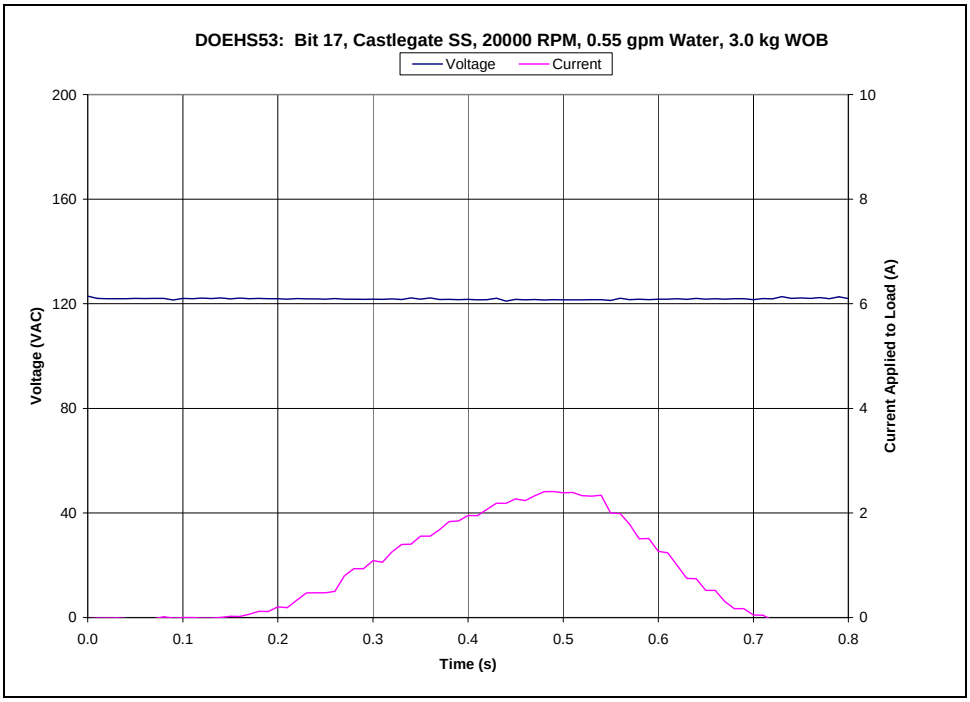


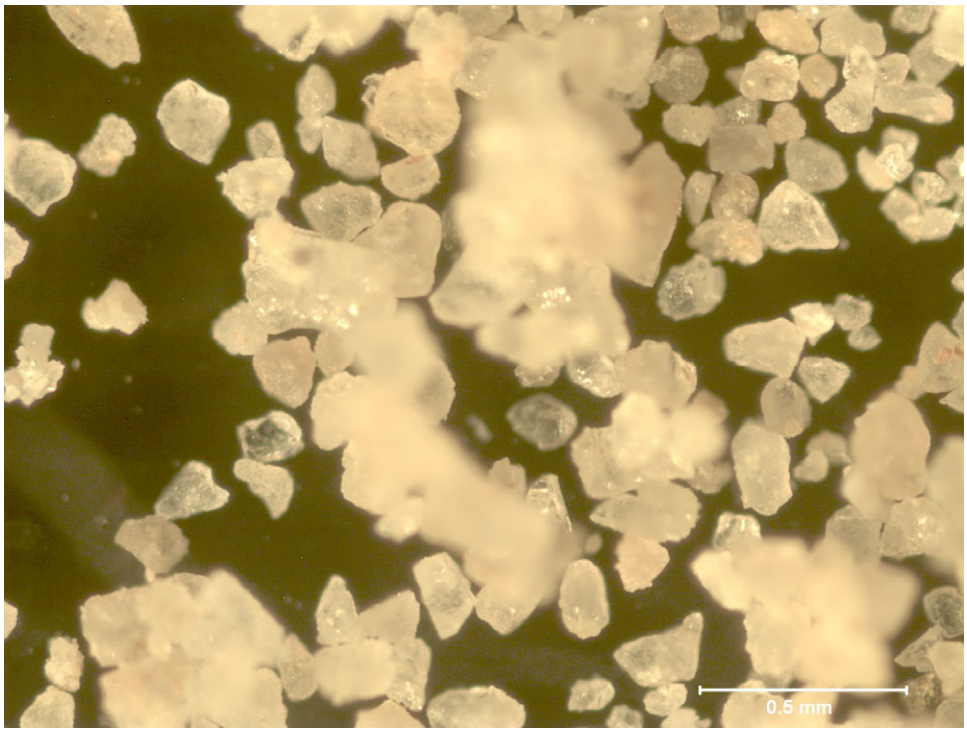


DEAHS53: Summary data and plots and cuttings photographs.

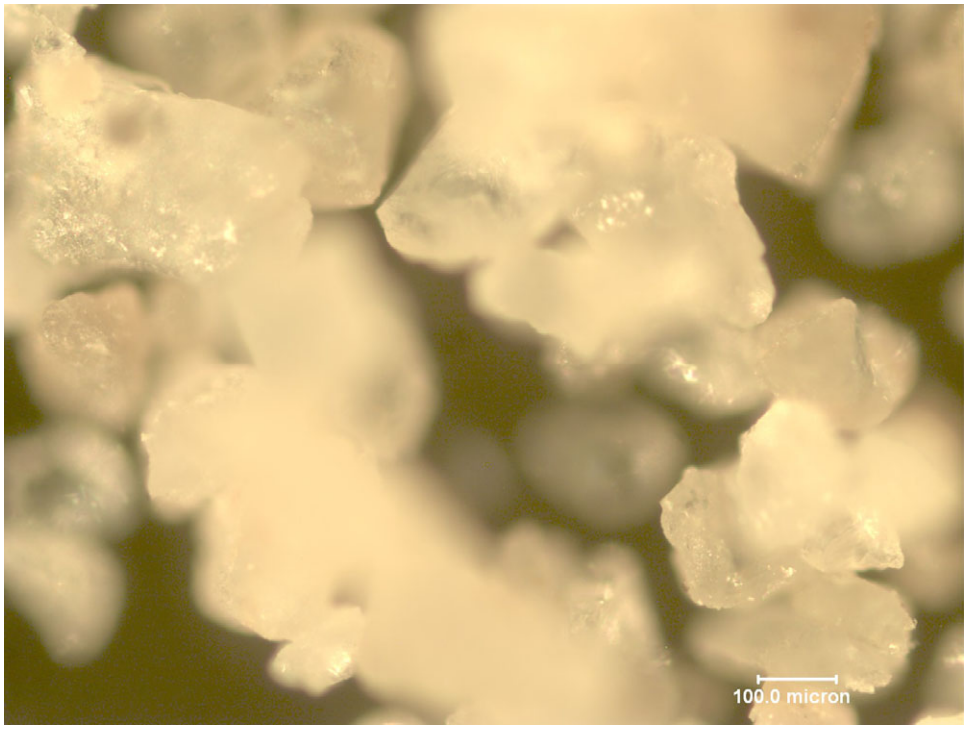
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/15/2005	0.839	0.547	121.8	2.3750	10683	3000	0.3134	0.9859	680.89	1.73	682.63	5.64E+07	295.77	0.00554







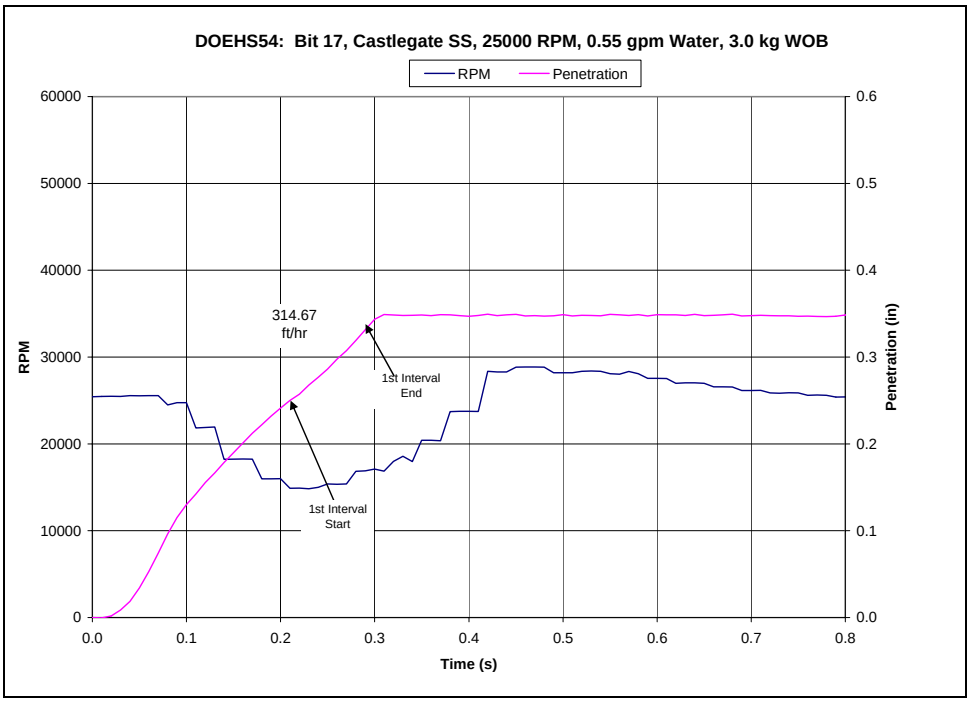
Test DOEH53 Castlegate cuttings 20,000 RPM

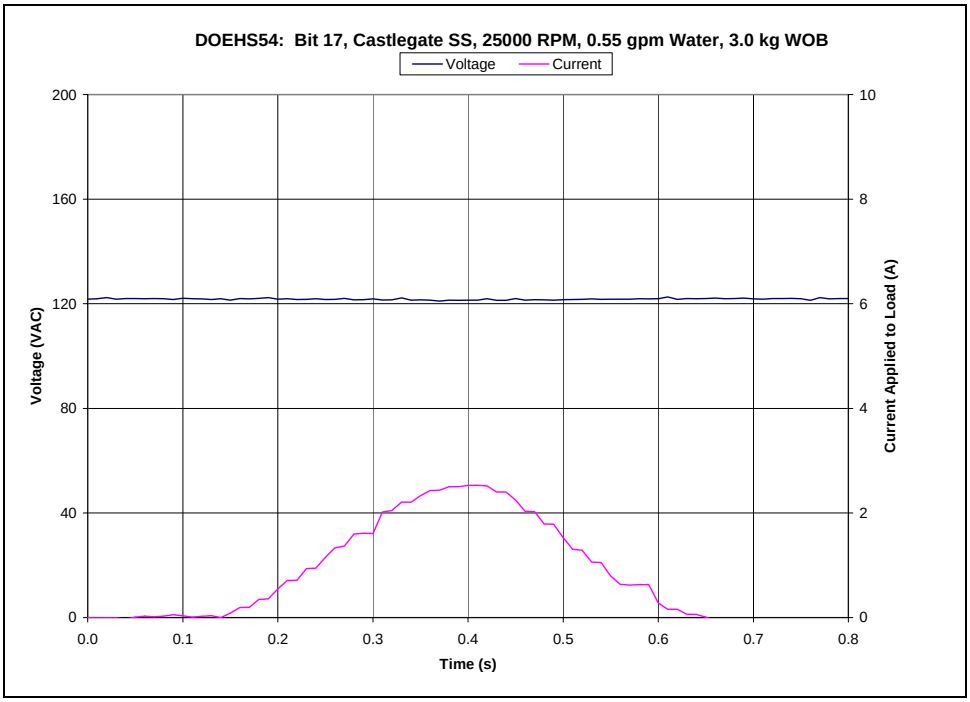


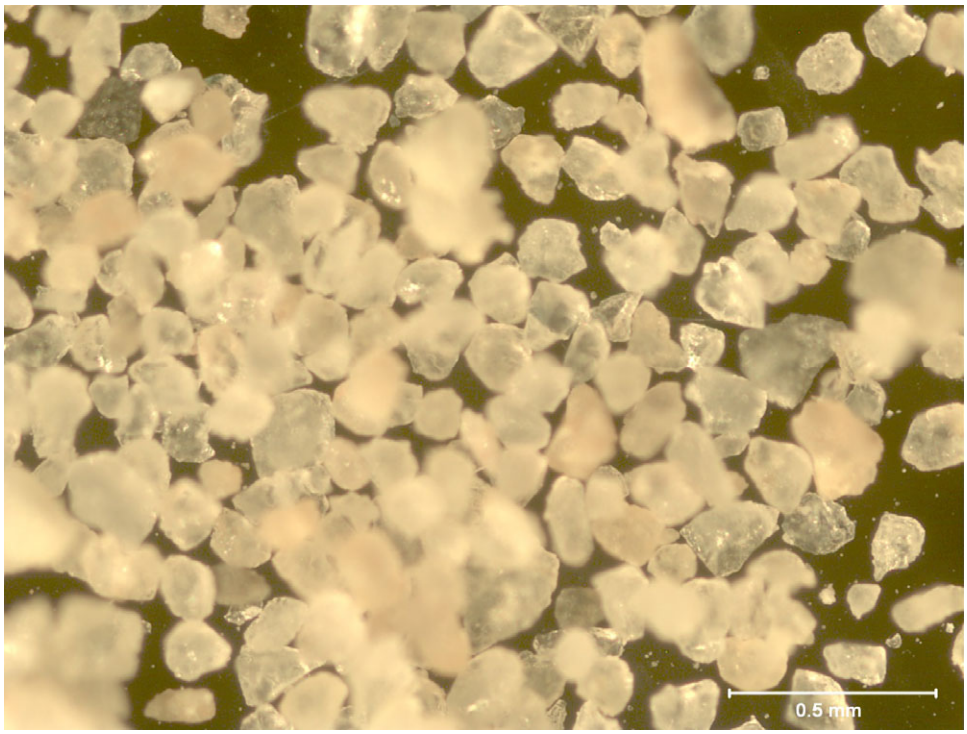
Test DOEH53 Castlegate cuttings 20,000 RPM

DEAHS54: Summary data and plots and cuttings photographs.

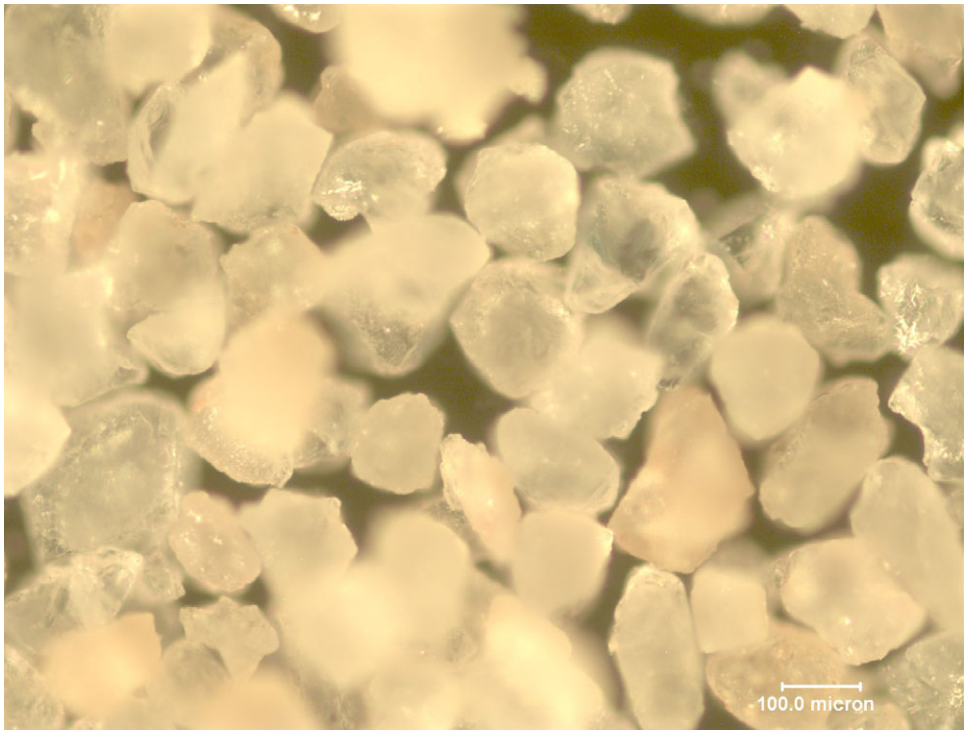
Test	Hole OD	Hole ID	Volts	Amps	RPM	WOB	Volume Removal	ROP	S. E. Rotation	S. E. WOB	Total S. E.	Total S. E.	ROP	
Date	(in)	(In)	(v)	(a)	(rpm)	(gms)	(in3/sec)	(in/sec)	(ft-lbs/in3)	(ft-lbs/in3)	(ft-lbs/in3)	(Joules/m3)	(ft/hr)	(in/rev)
11/15/2005	0.850	0.548	121.7	2.4961	15572	3000	0.3478	1.0489	644.24	1.66	645.91	5.34E+07	314.67	0.00404







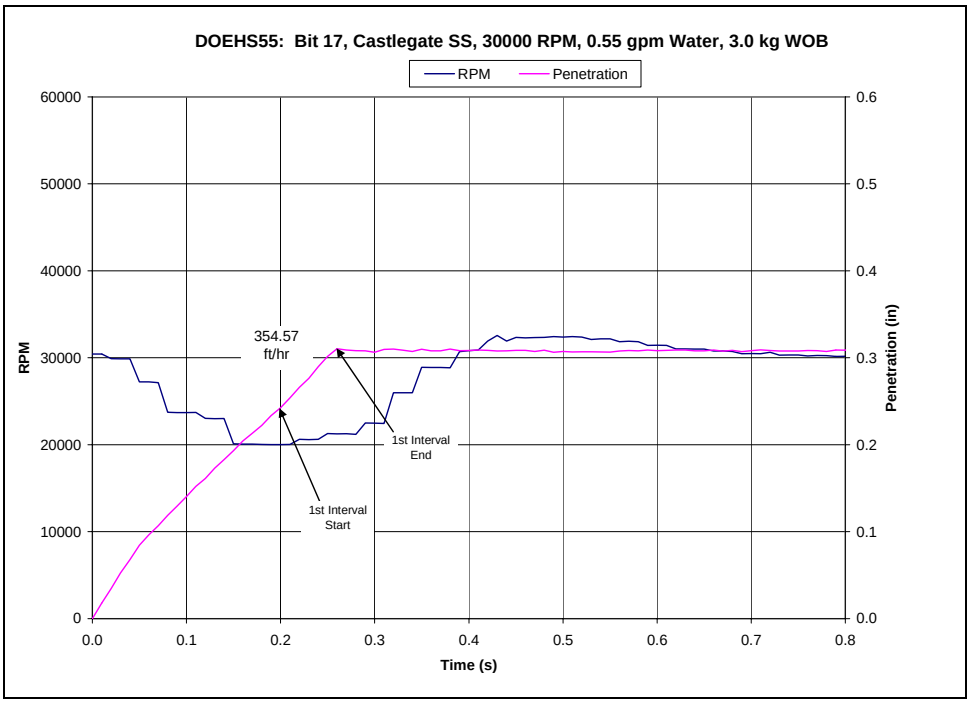
Test DOEH54 Castlegate cuttings 25,000 RPM

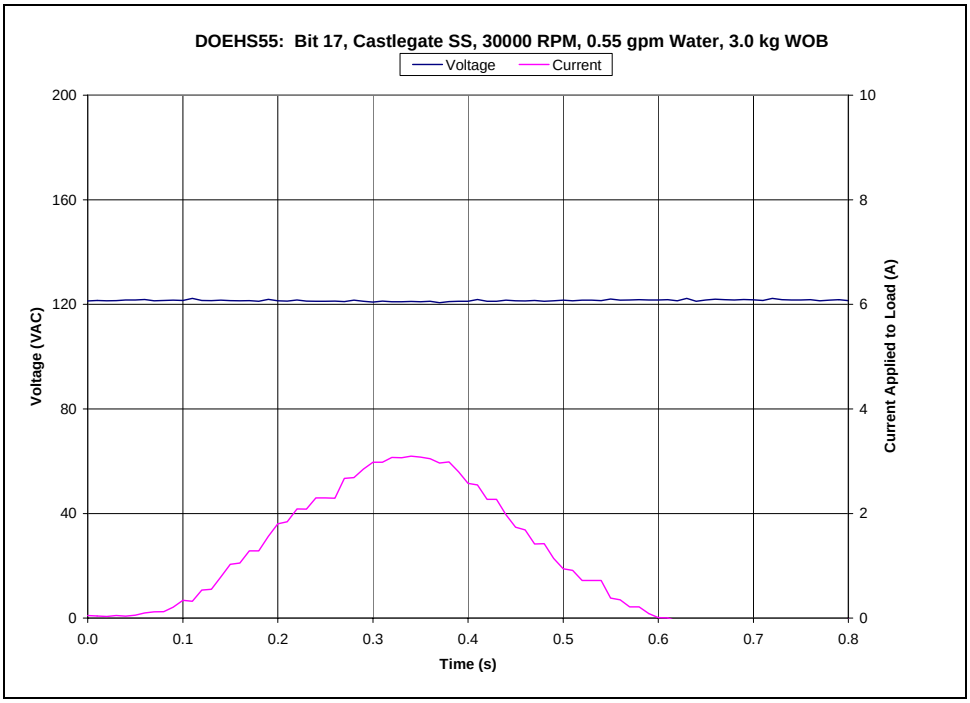


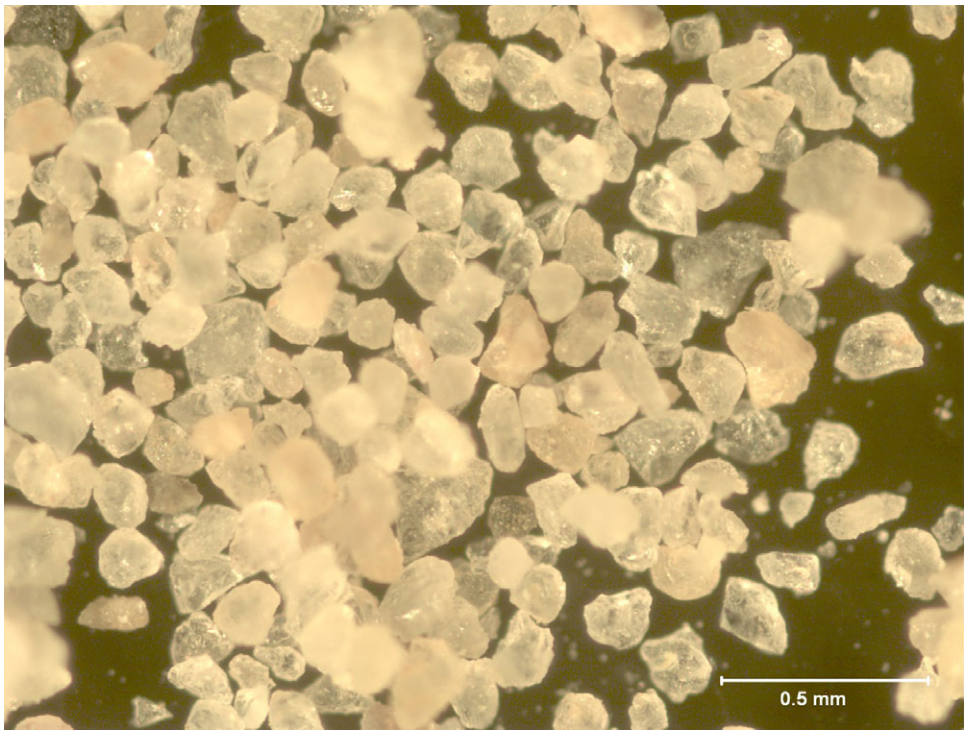
Test DOEH54 Castlegate cuttings 25,000 RPM

DEAHS55: Summary data and plots and cuttings photographs.

Test	Hole OD	Hole ID	Volts	Amps	RPM	WOB	Volume Removal	ROP	S. E. Rotation	S. E. WOB	Total S. E.	Total S. E.	ROP	
Date	(in)	(In)	(v)	(a)	(rpm)	(gms)	(in3/sec)	(in/sec)	(ft-lbs/in3)	(ft-lbs/in3)	(ft-lbs/in3)	(Joules/m3)	(ft/hr)	(in/rev)
11/15/2005	0.865	0.544	121.3	3.0440	20535	3000	0.4198	1.1819	648.72	1.55	650.27	5.38E+07	354.57	0.00345





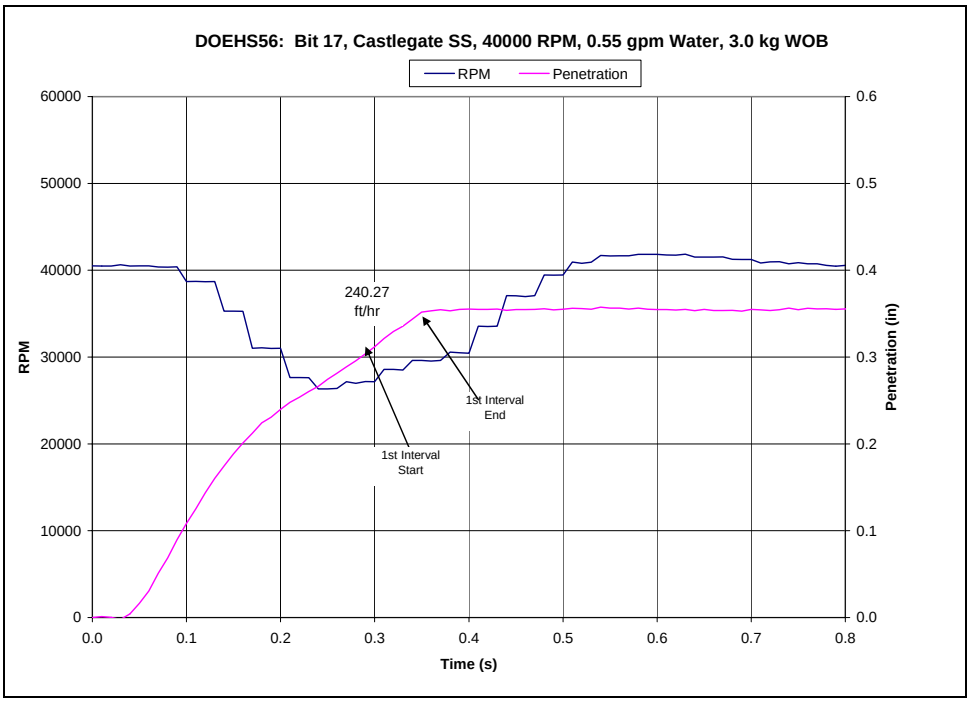


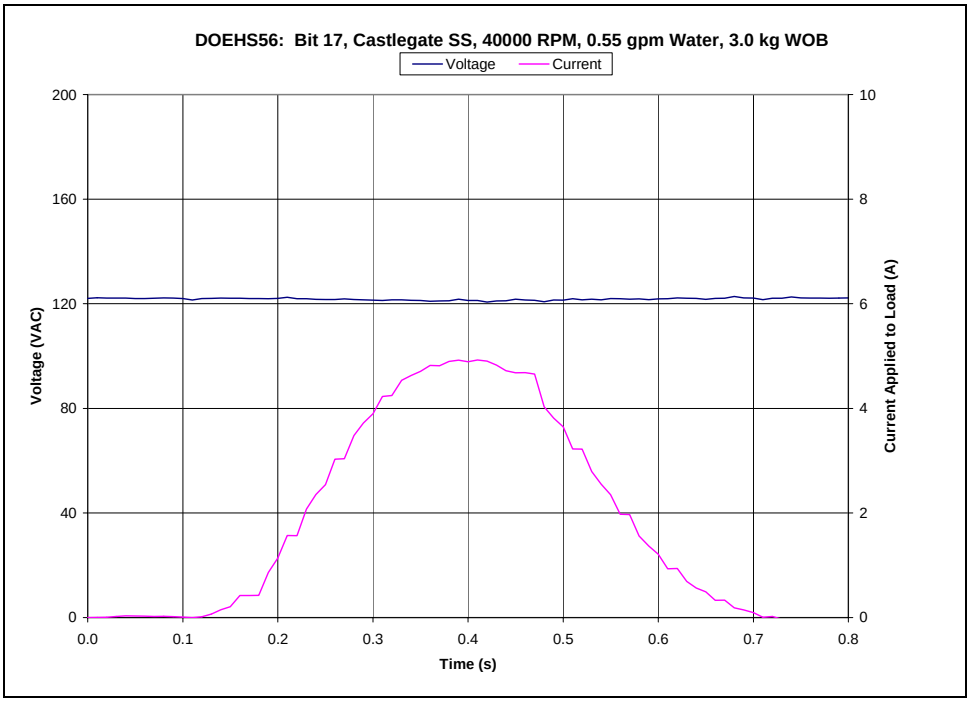
Test DOEH55 Castlegate cuttings 30,000 RPM

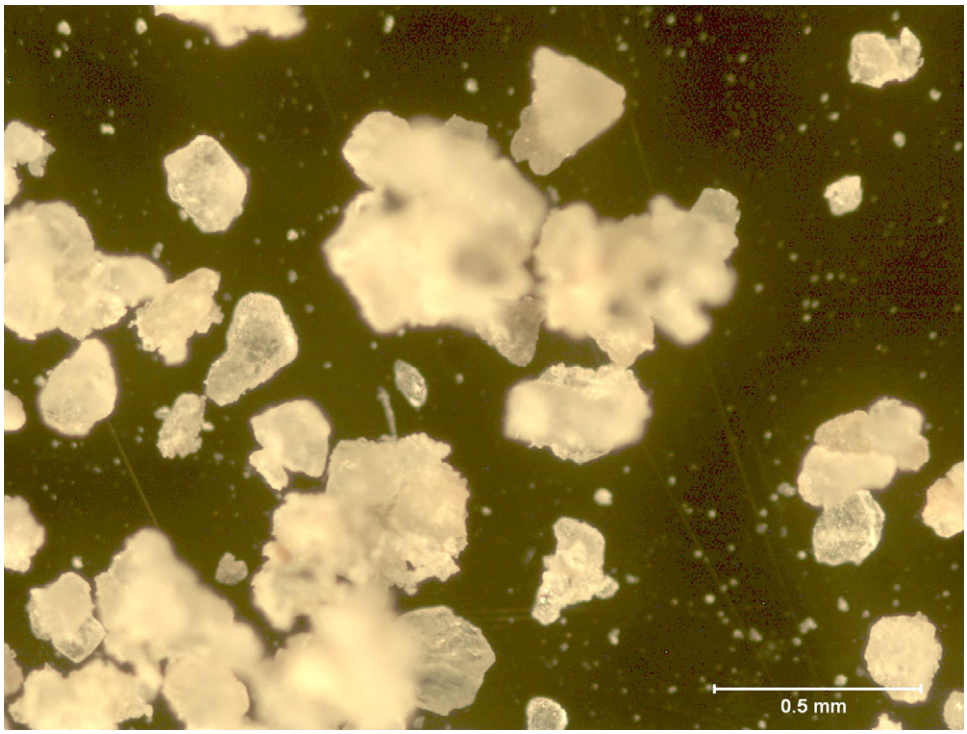
Test DOEH55 Castlegate cuttings 30,000 RPM

DEAHS56: Summary data and plots and cuttings photographs.

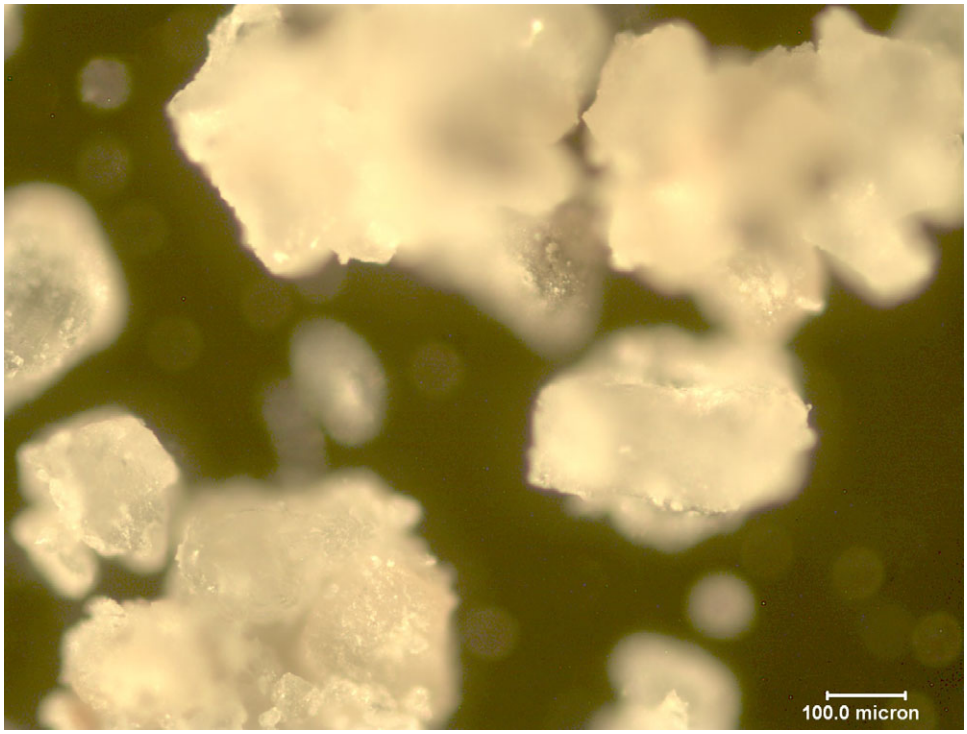
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/15/2005	0.854	0.540	121.4	4.8585	28275	3000	0.2753	0.8009	1580.14	1.60	1581.75	1.31E+08	240.27	0.00170







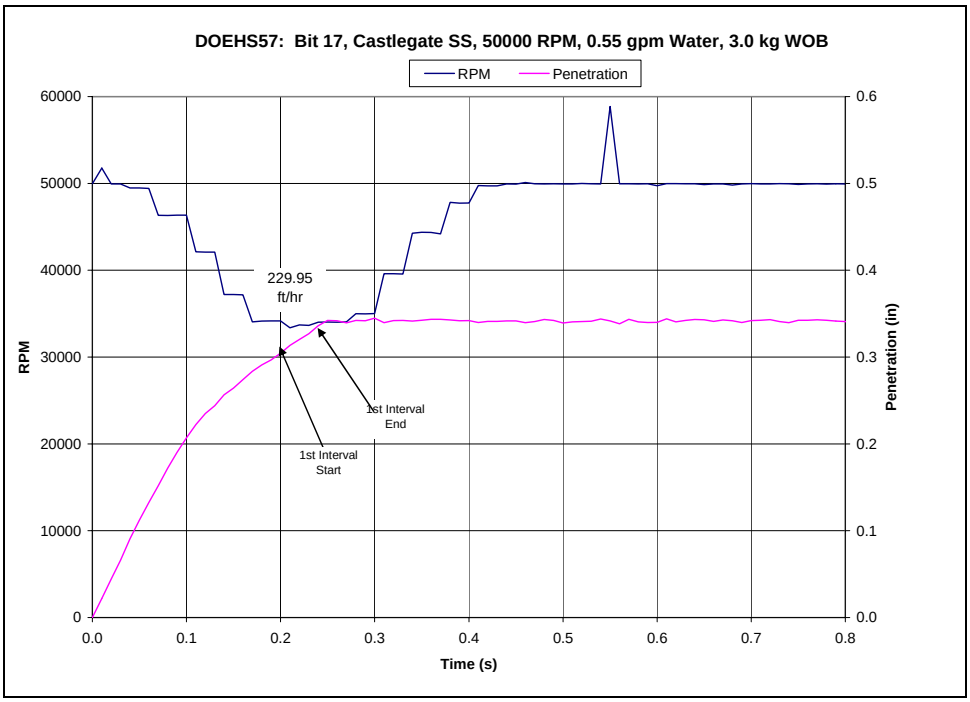
Test DOEH56 Castlegate cuttings 40,000 RPM

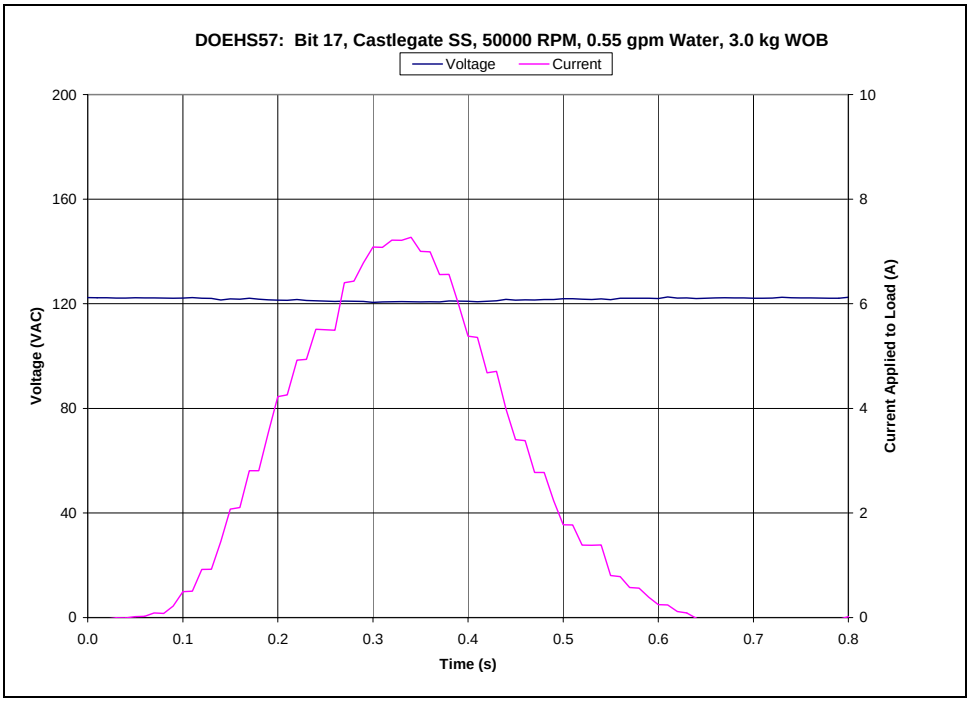


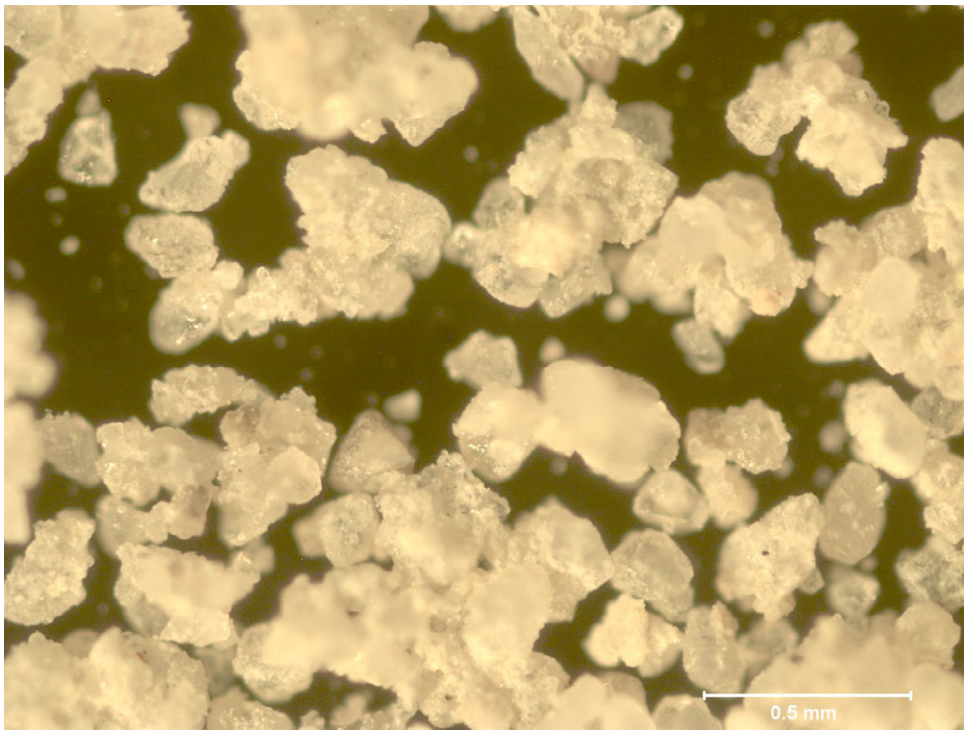
Test DOEH56 Castlegate cuttings 40,000 RPM

DEAHS57: Summary data and plots and cuttings photographs.

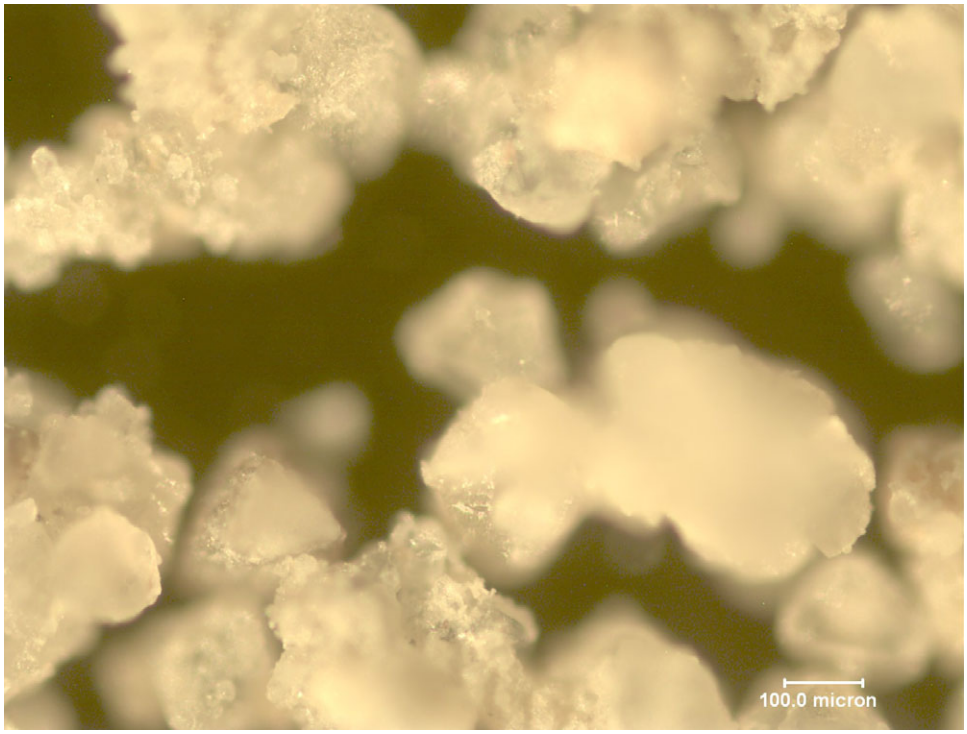
Test	Hole OD	Hole ID	Volts	Amps	RPM	WOB	Volume Removal	ROP	S. E. Rotation	S. E. WOB	Total S. E.	Total S. E.	ROP	
Date	(in)	(In)	(v)	(a)	(rpm)	(gms)	(in3/sec)	(in/sec)	(ft-lbs/in3)	(ft-lbs/in3)	(ft-lbs/in3)	(Joules/m3)	(ft/hr)	(in/rev)
11/15/2005	0.859	0.545	121.4	7.2327	33782	3000	0.2654	0.7665	2440.38	1.59	2441.97	2.02E+08	229.95	0.00136







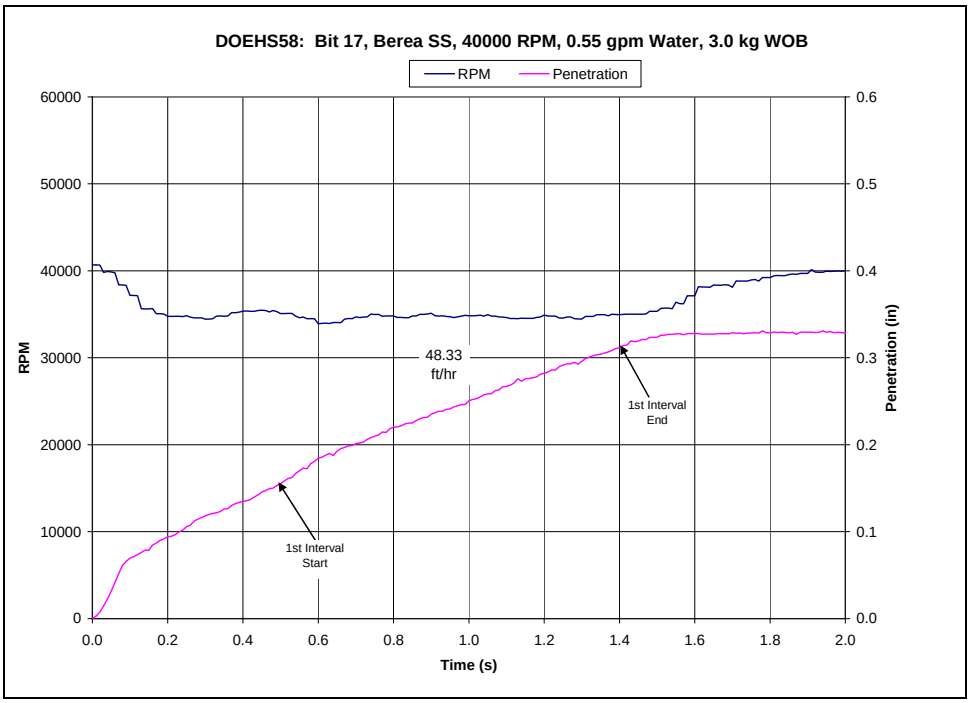
Test DOEH57 Castlegate cuttings 50,000 RPM

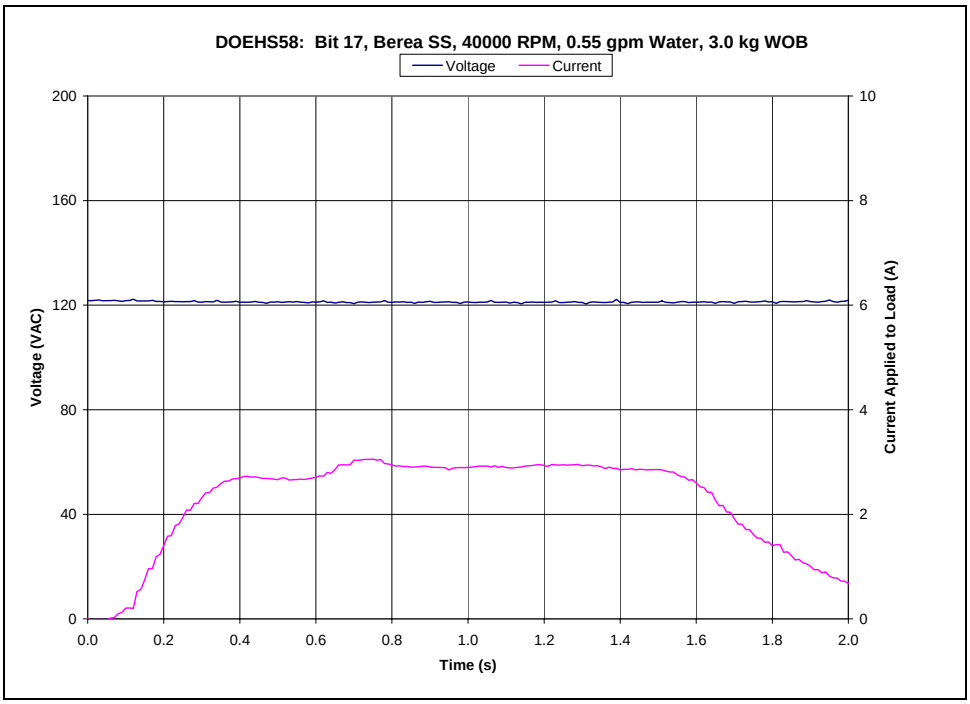


Test DOEH57 Castlegate cuttings 50,000 RPM

DEAHS58: Summary data and plots and cuttings photographs.

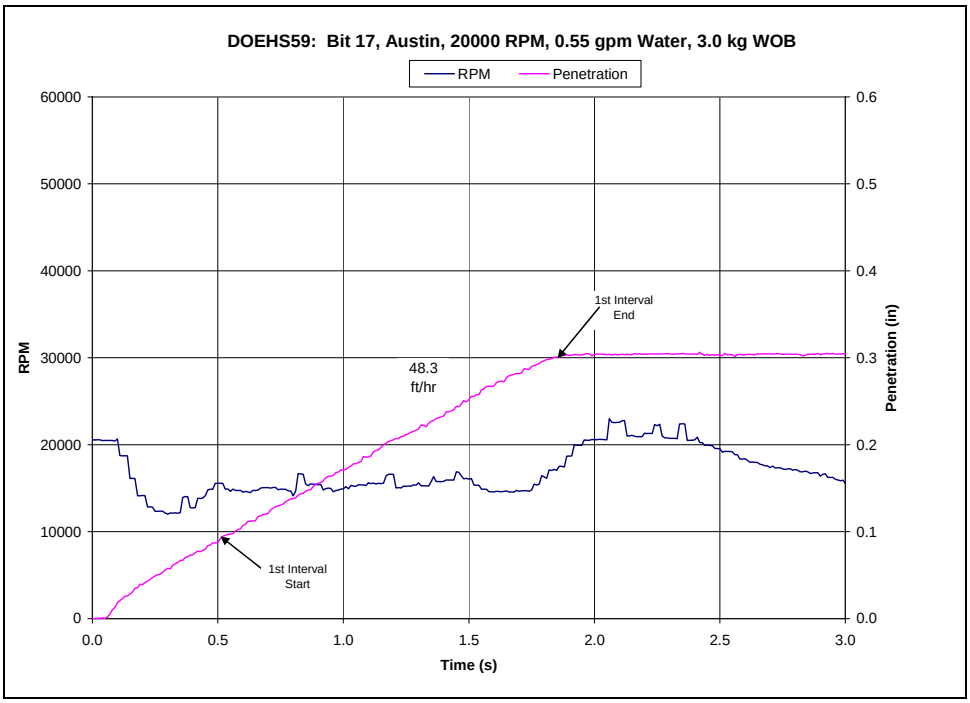
Test	Hole OD	Hole ID	Volts	Amps	RPM	WOB	Volume Removal	ROP	S. E. Rotation	S. E. WOB	Total S. E.	Total S. E.	ROP	
Date	(in)	(In)	(v)	(a)	(rpm)	(gms)	(in3/sec)	(in/sec)	(ft-lbs/in3)	(ft-lbs/in3)	(ft-lbs/in3)	(Joules/m3)	(ft/hr)	(in/rev)
11/15/2005	0.842	0.555	121.1	2.8975	34718	3000	0.0507	0.1611	5102.00	1.75	5103.75	4.22E+08	48.33	0.00028

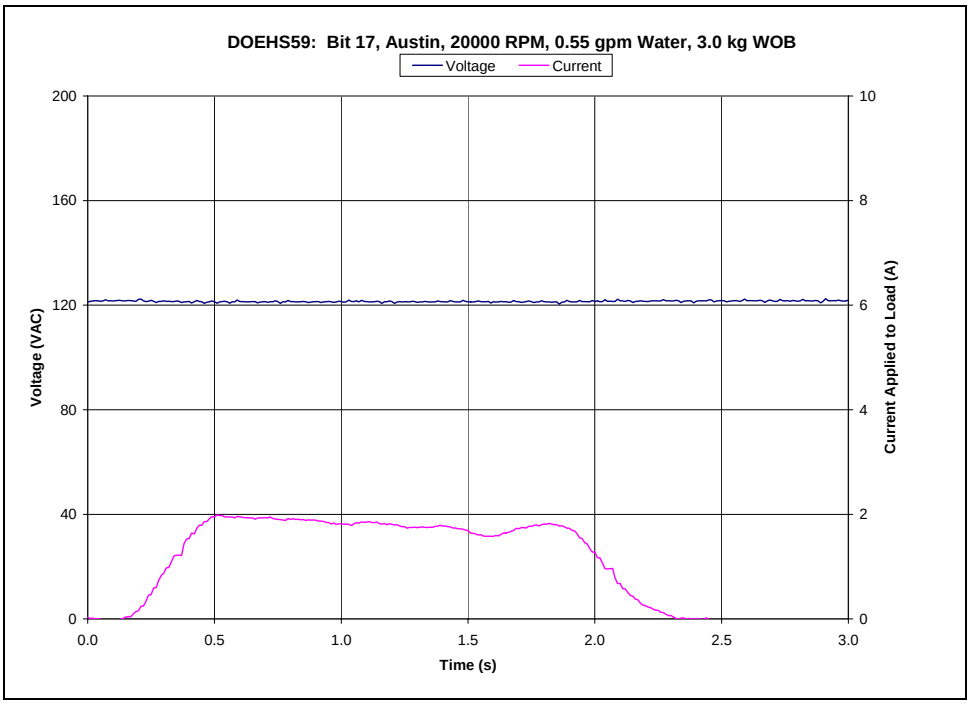


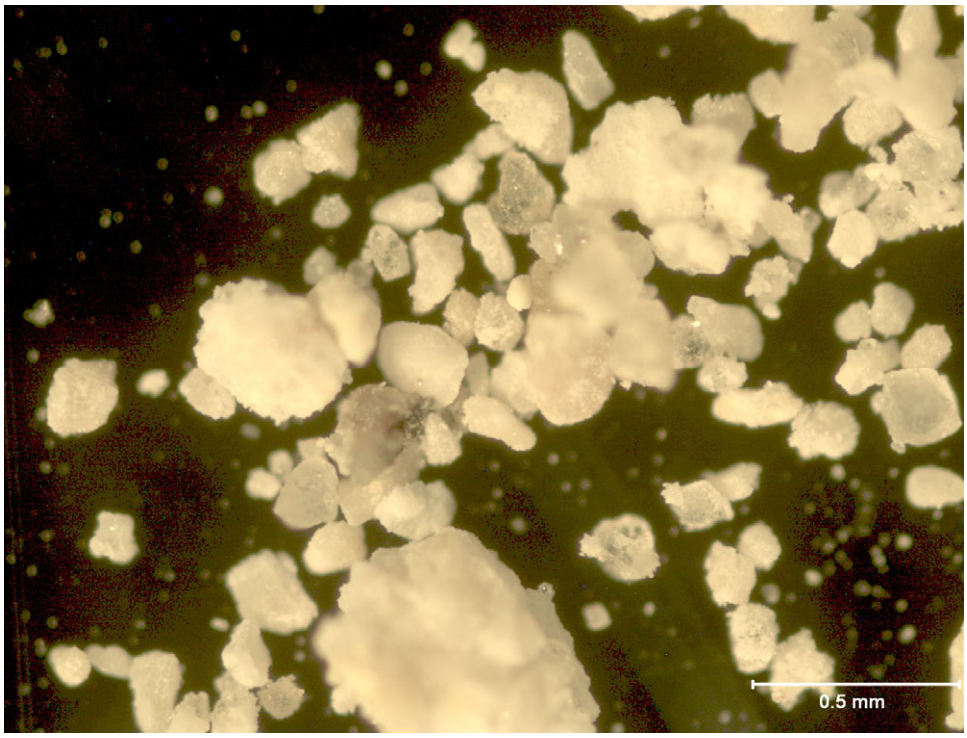


DEAHS59: Summary data and plots and cuttings photographs.

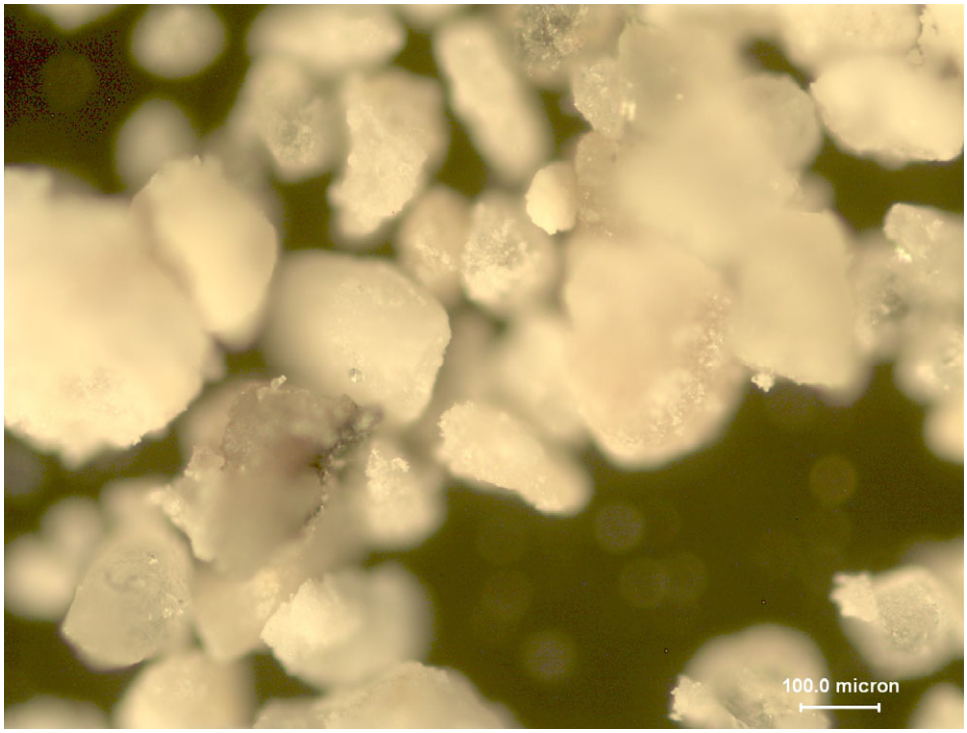
Test	Hole OD	Hole ID	Volts	Amps	RPM	WOB	Volume Removal	ROP	S. E. Rotation	S. E. WOB	Total S. E.	Total S. E.	ROP	
Date	(in)	(In)	(v)	(a)	(rpm)	(gms)	(in3/sec)	(in/sec)	(ft-lbs/in3)	(ft-lbs/in3)	(ft-lbs/in3)	(Joules/m3)	(ft/hr)	(in/rev)
11/21/2005	0.846	0.550	121.3	1.7995	15256	3000	0.0523	0.1610	3081.46	1.70	3083.16	2.55E+08	48.30	0.00063







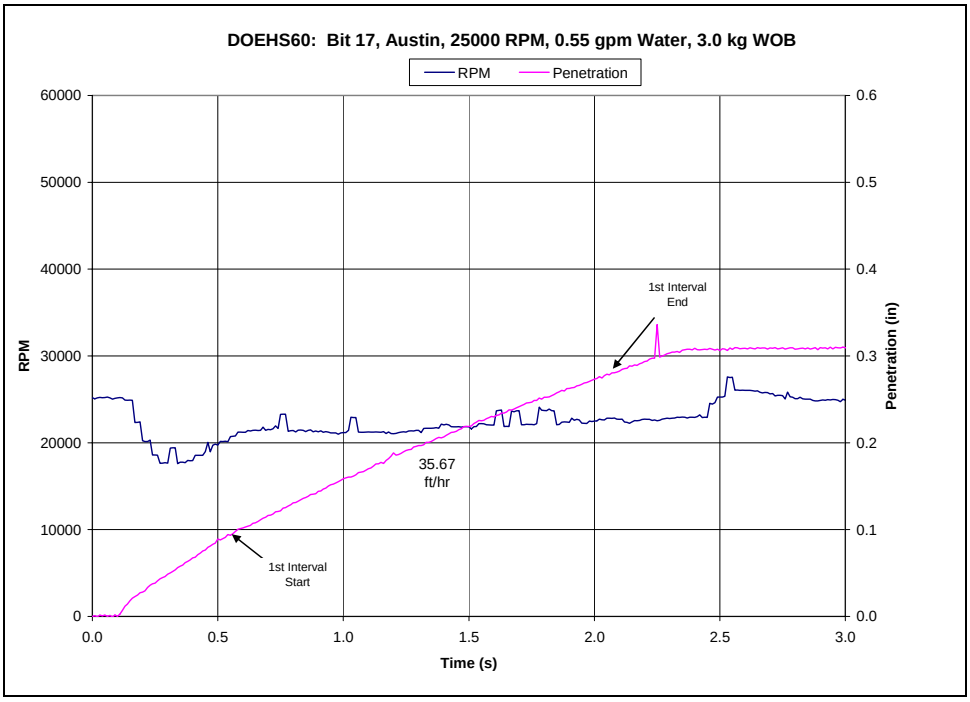
Test DOEH59 Austin cuttings 20,000 RPM

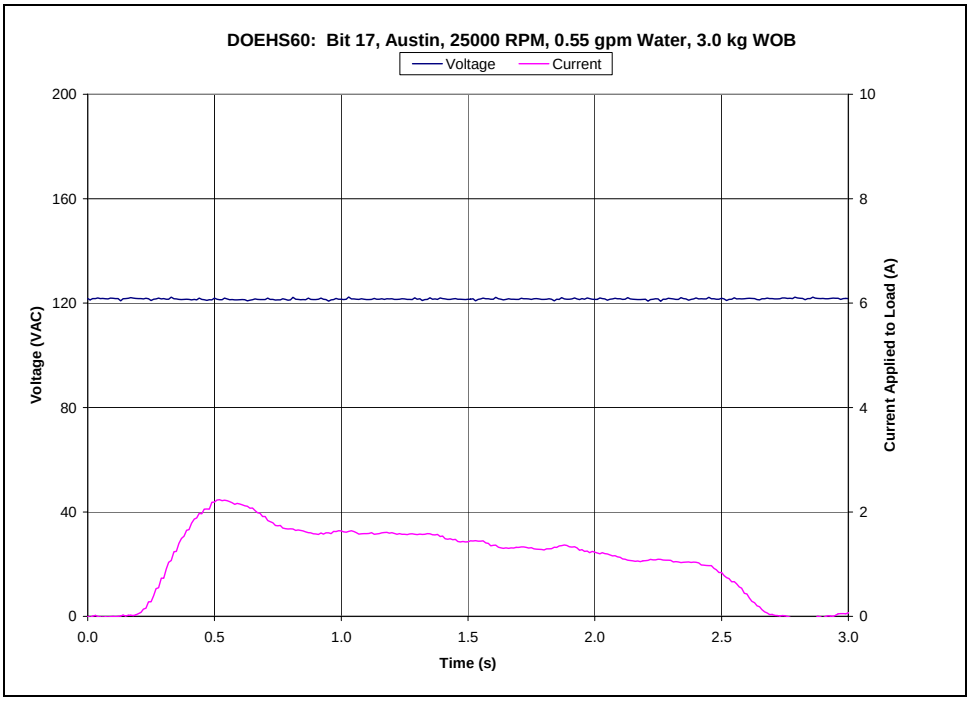


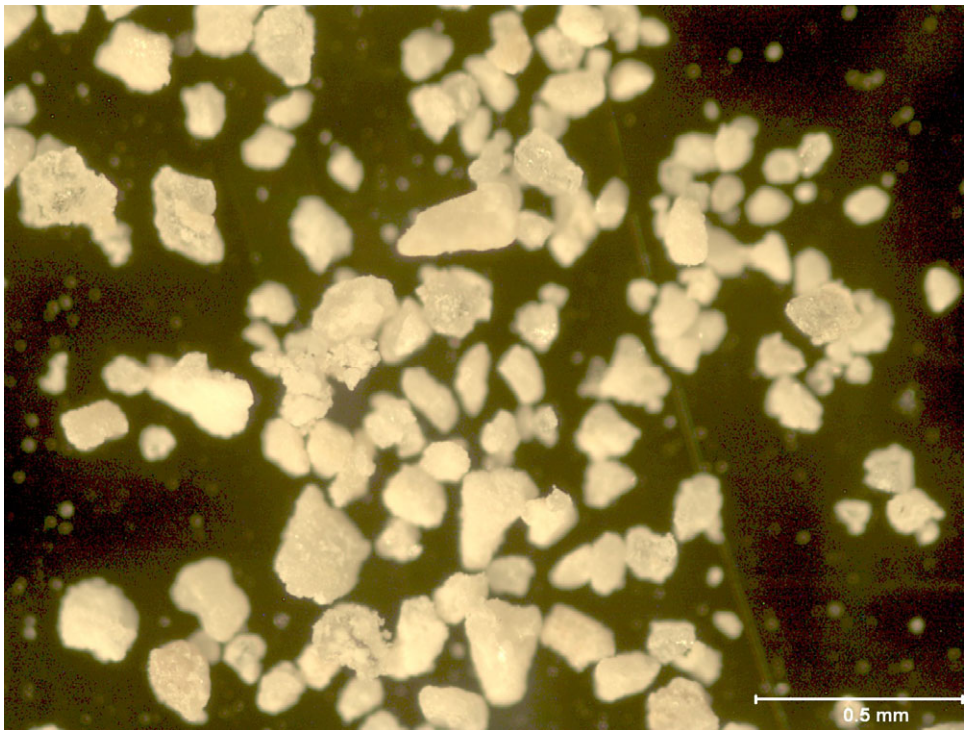
Test DOEH59 Austin cuttings 20,000 RPM

DEAHS60: Summary data and plots and cuttings photographs.

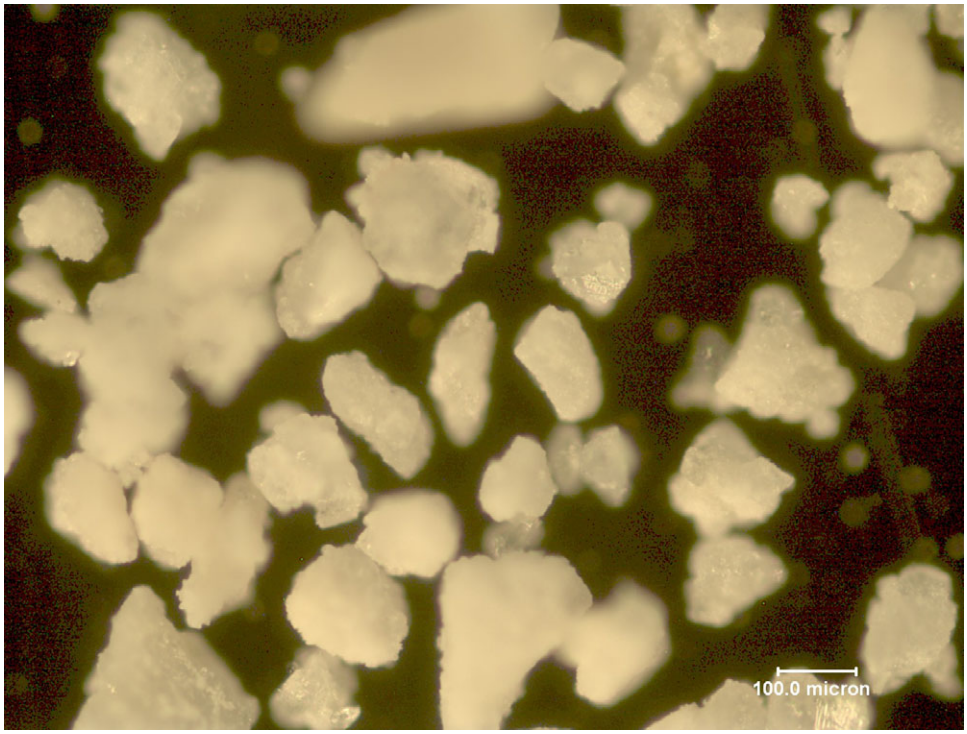
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/21/2005	0.852	0.549	121.5	1.4787	22020	3000	0.0396	0.1189	3343.03	1.65	3344.68	2.76E+08	35.67	0.00032







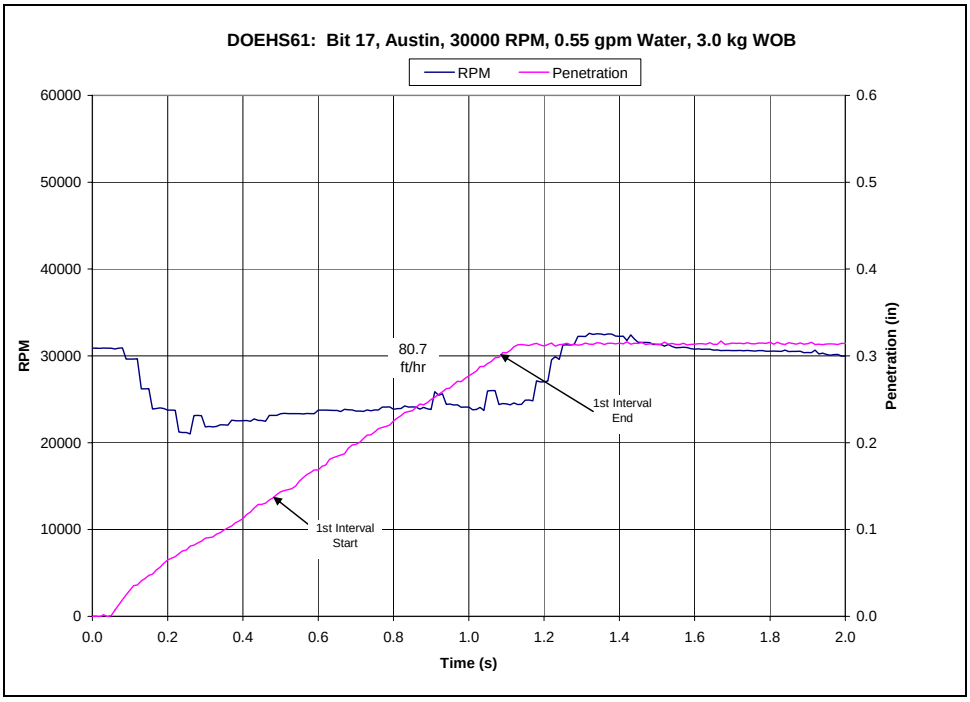
Test DOEH60 Austin cuttings 25,000 RPM

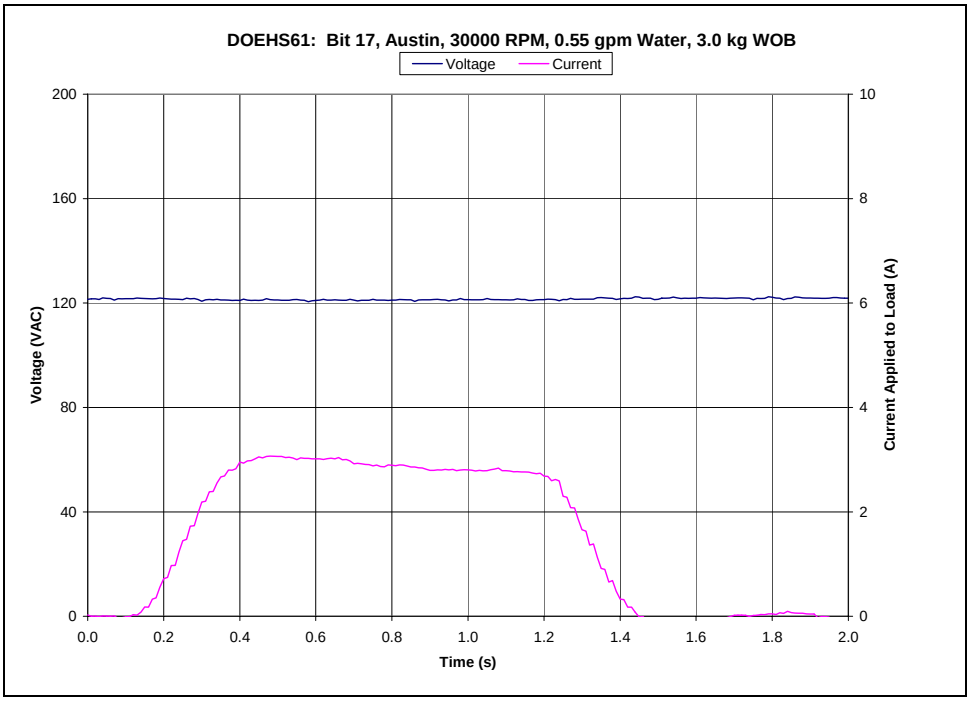


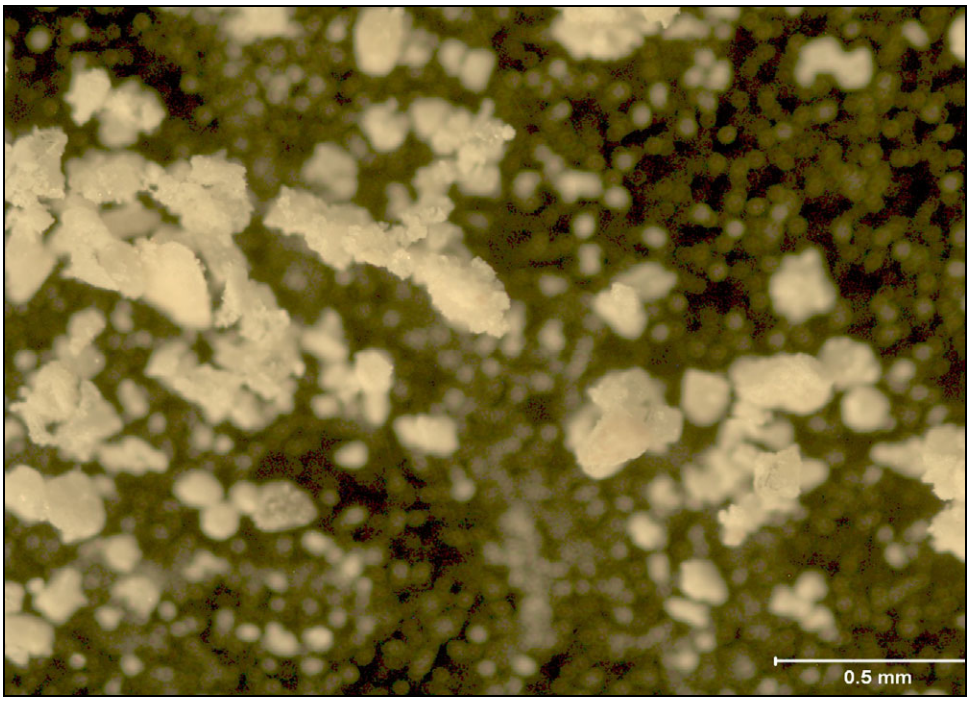
Test DOEH60 Austin cuttings 25,000 RPM

DEAHS61: Summary data and plots and cuttings photographs.

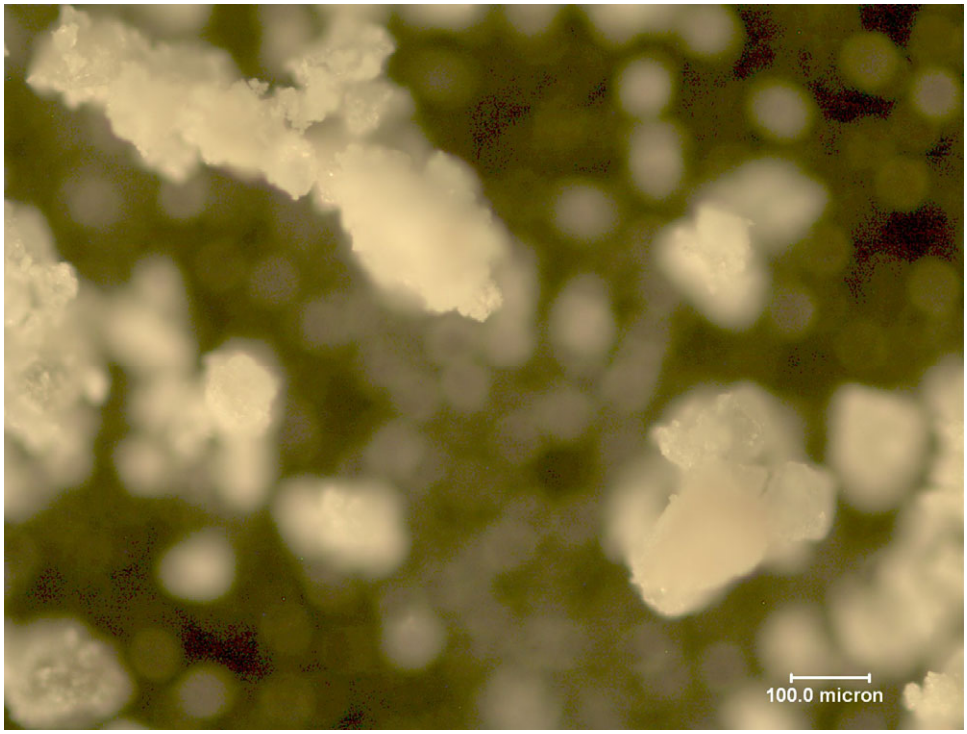
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/21/2005	0.857	0.538	131.2	2.9013	24033	3000	0.0940	0.2690	2986.45	1.58	2988.03	2.47E+08	80.70	0.00067







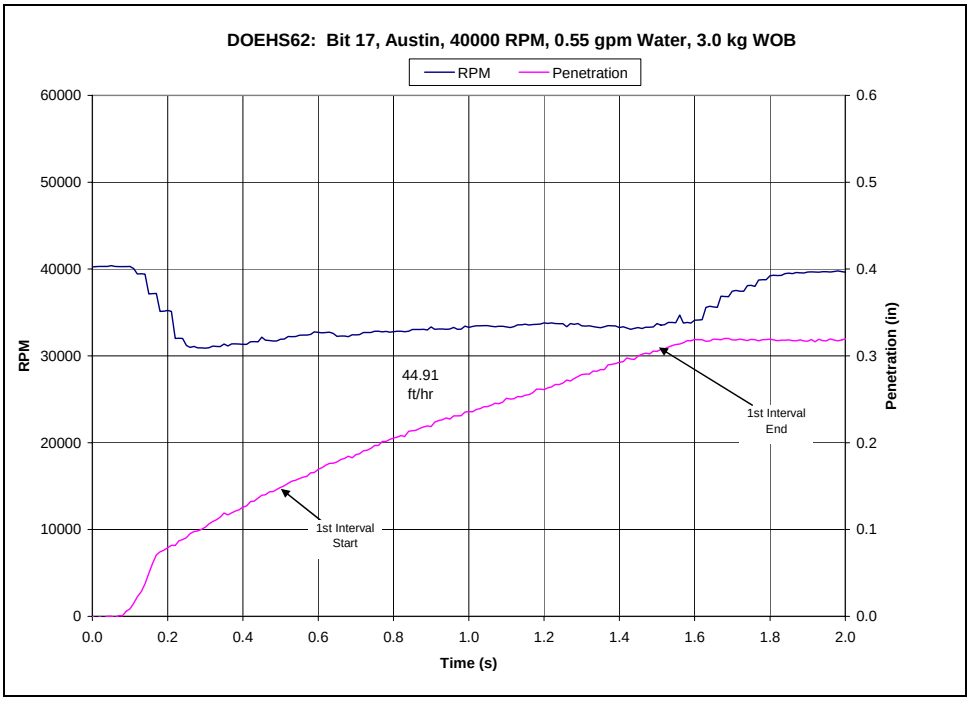
Test DOEH61 Austin cuttings 30,000 RPM

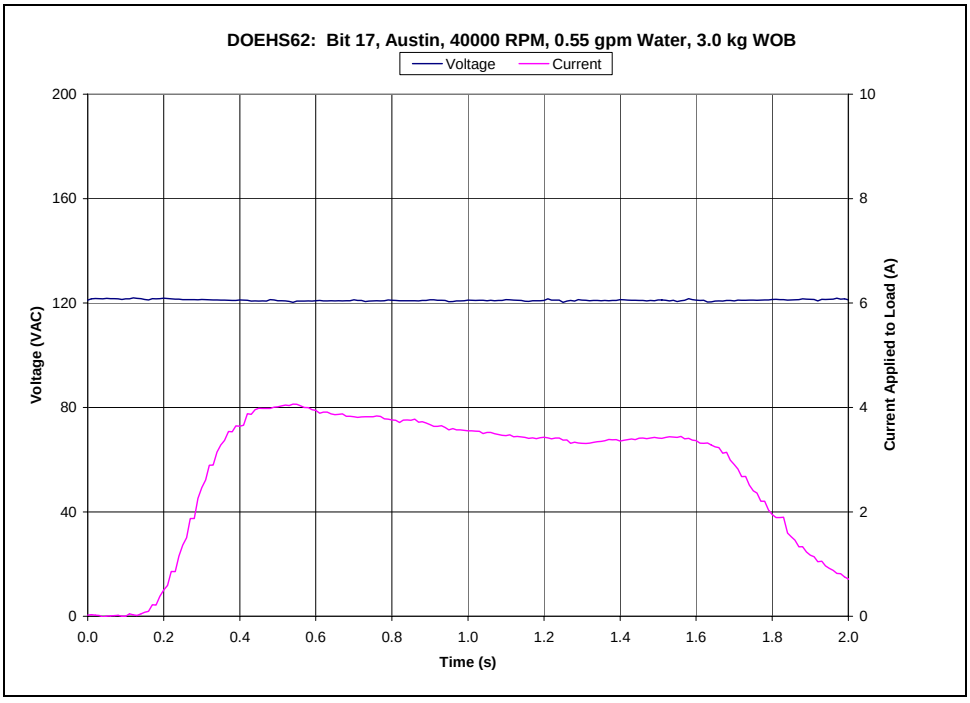


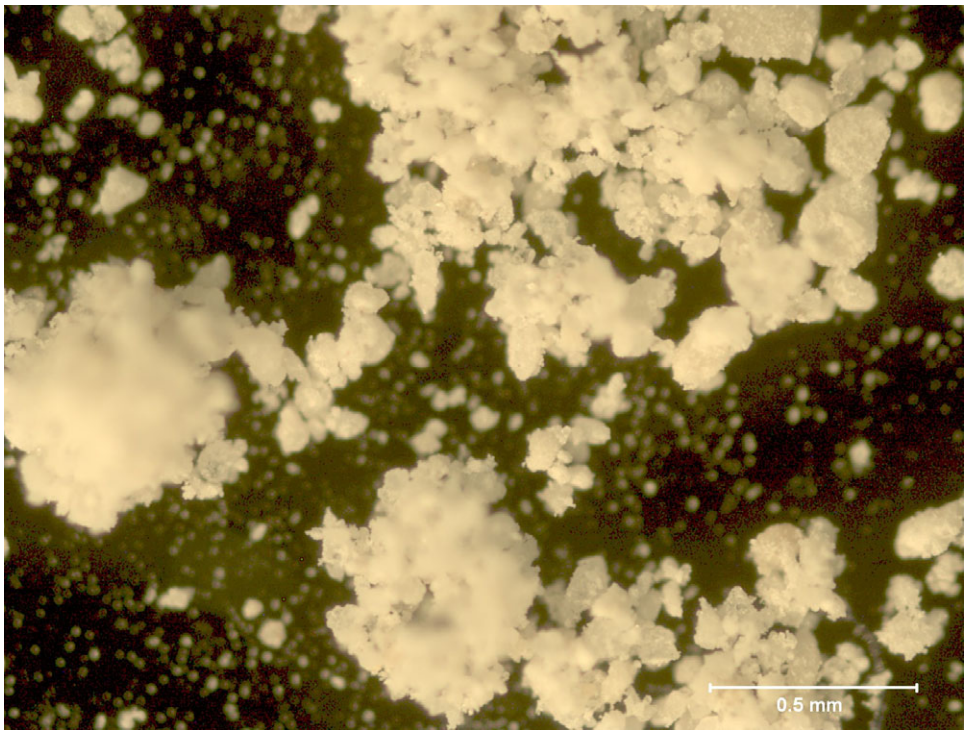
Test DOEH61 Austin cuttings 30,000 RPM

DEAHS62: Summary data and plots and cuttings photographs.

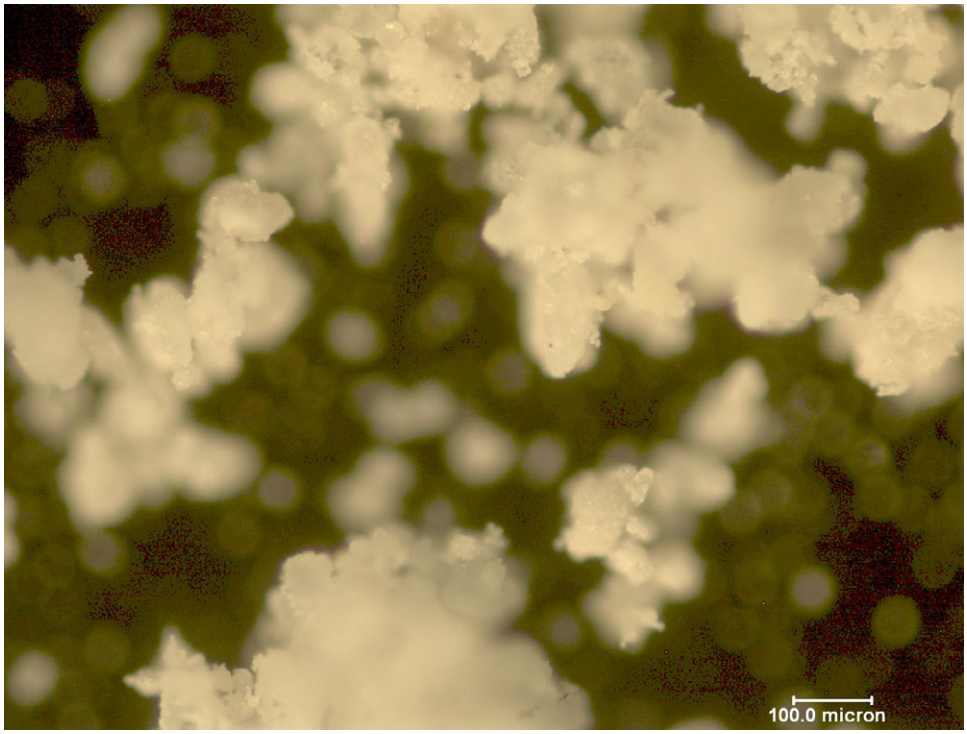
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/21/2005	0.850	0.557	121.0	3.5786	33189	3000	0.0485	0.1497	6589.64	1.70	6591.34	5.45E+08	44.91	0.00027







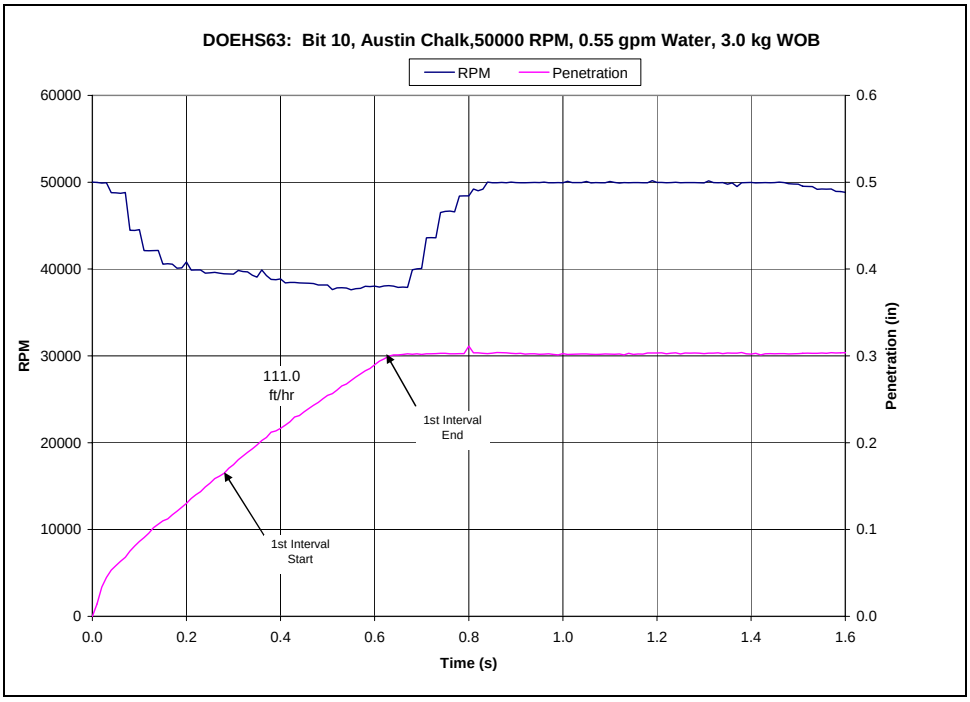
Test DOEH62 Austin cuttings 40,000 RPM

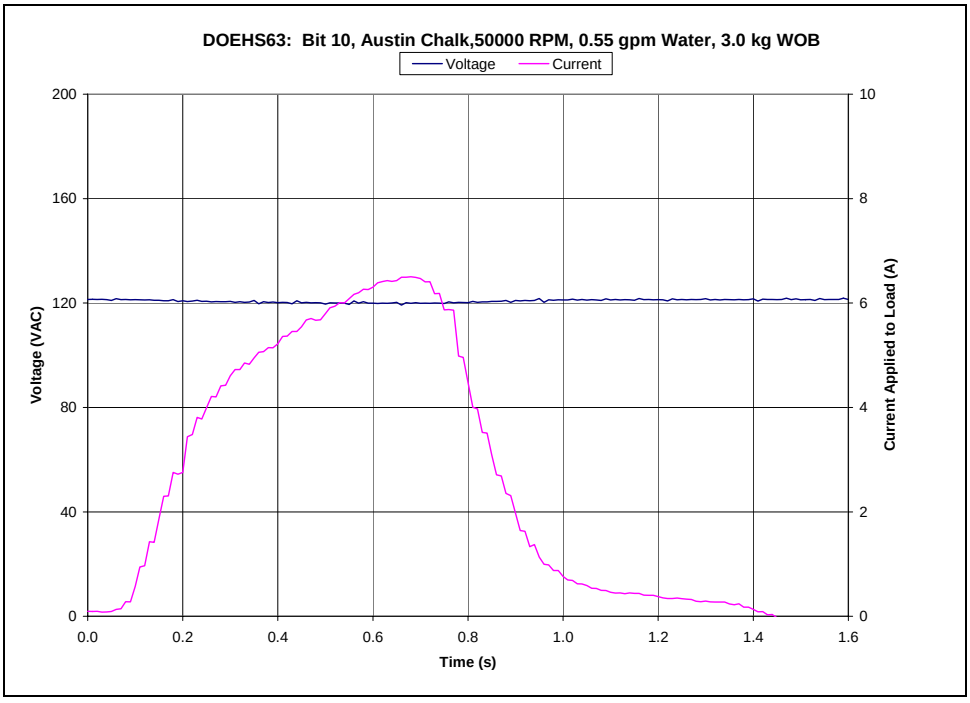


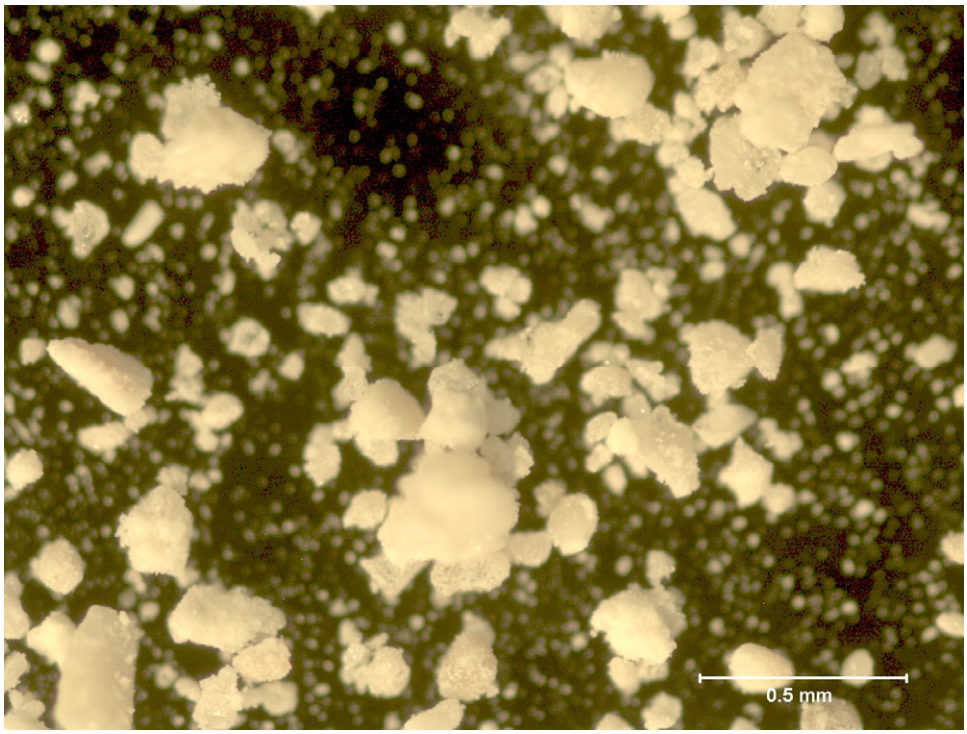
Test DOEH62 Austin cuttings 40,000 RPM

DEAHS63: Summary data and plots and cuttings photographs.

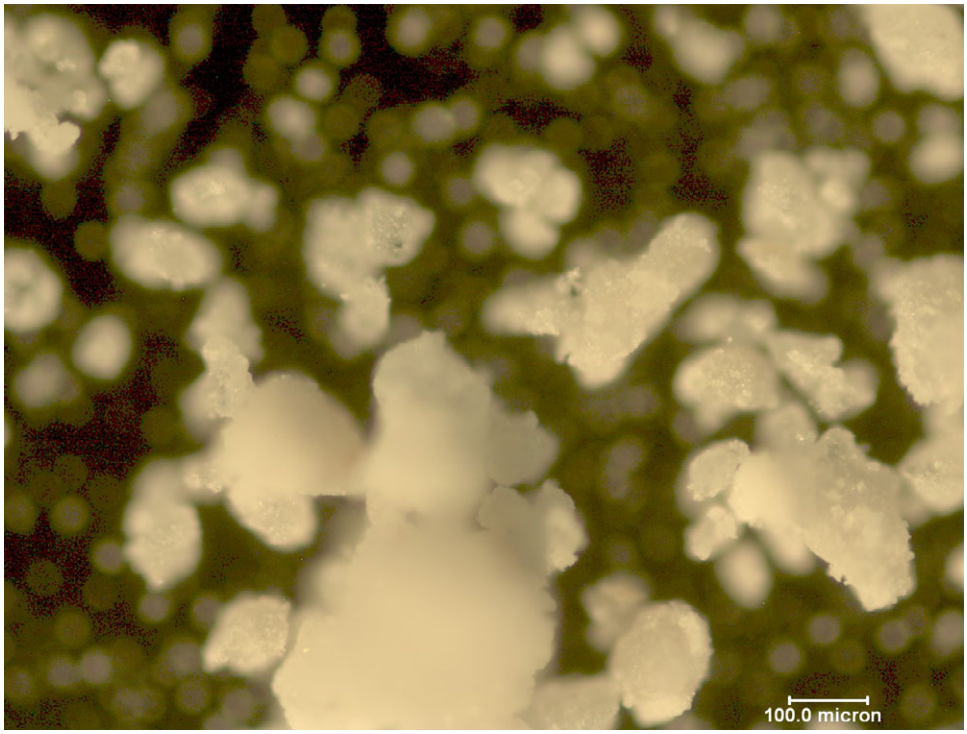
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/21/2005	0.871	0.528	120.2	5.6230	38465	3000	0.1394	0.3700	3574.40	1.46	3575.87	2.96E+08	111.00	0.00058







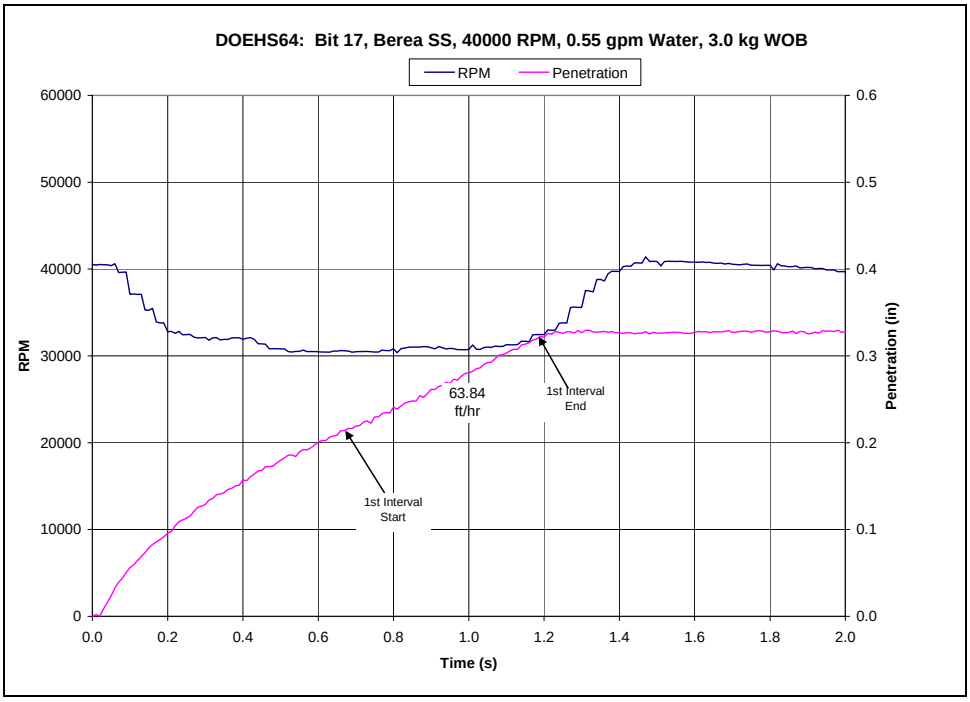
Test DOEH63 Austin cuttings 50,000 RPM

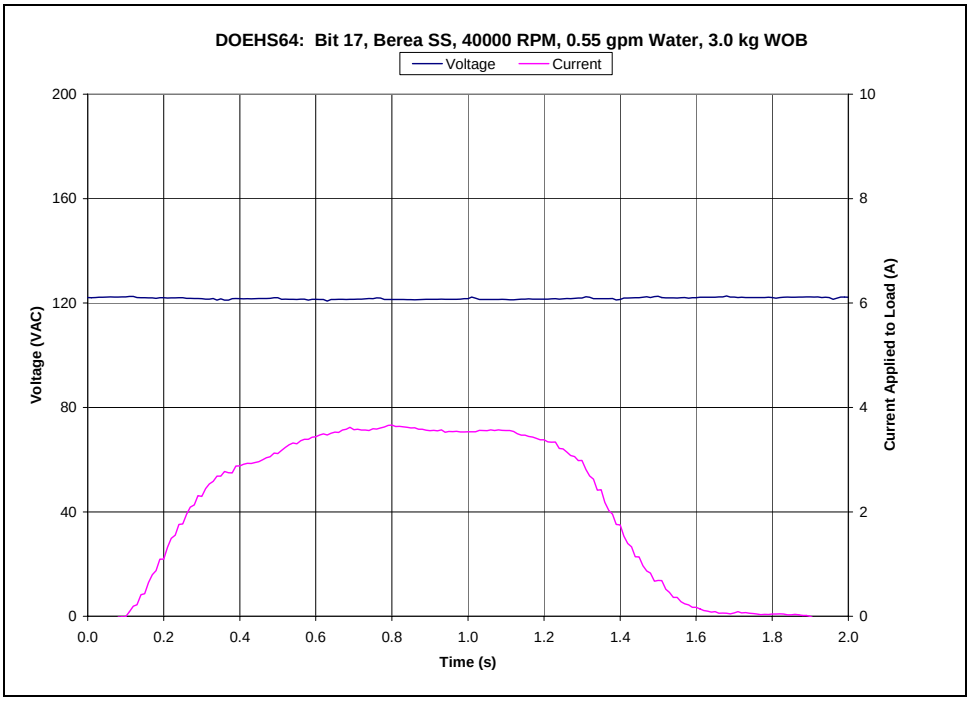


Test DOEH63 Austin cuttings 50,000 RPM

DEAHS64: Summary data and plots and cuttings photographs.

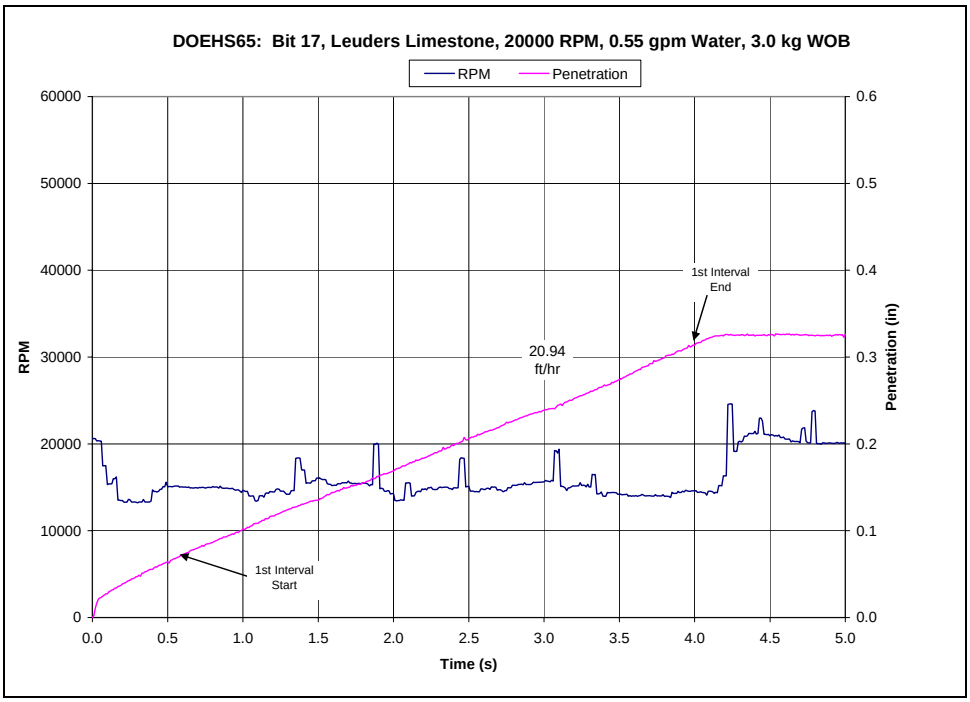
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/21/2005	0.846	0.548	121.5	3.5571	30978	3000	0.0694	0.2128	4591.64	1.69	4593.33	3.80E+08	63.84	0.00041

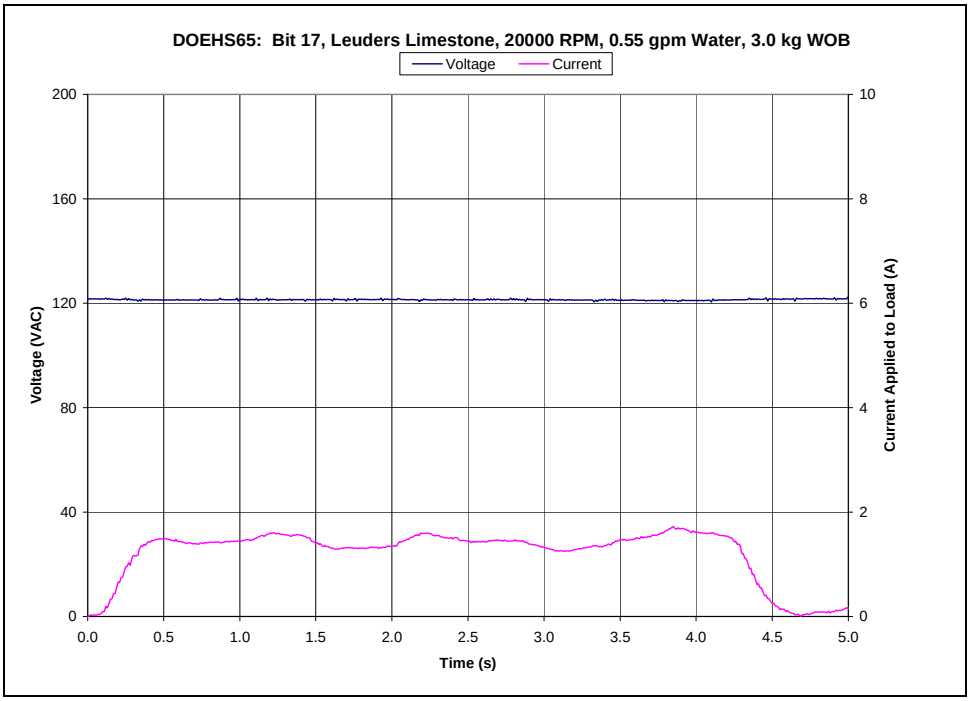


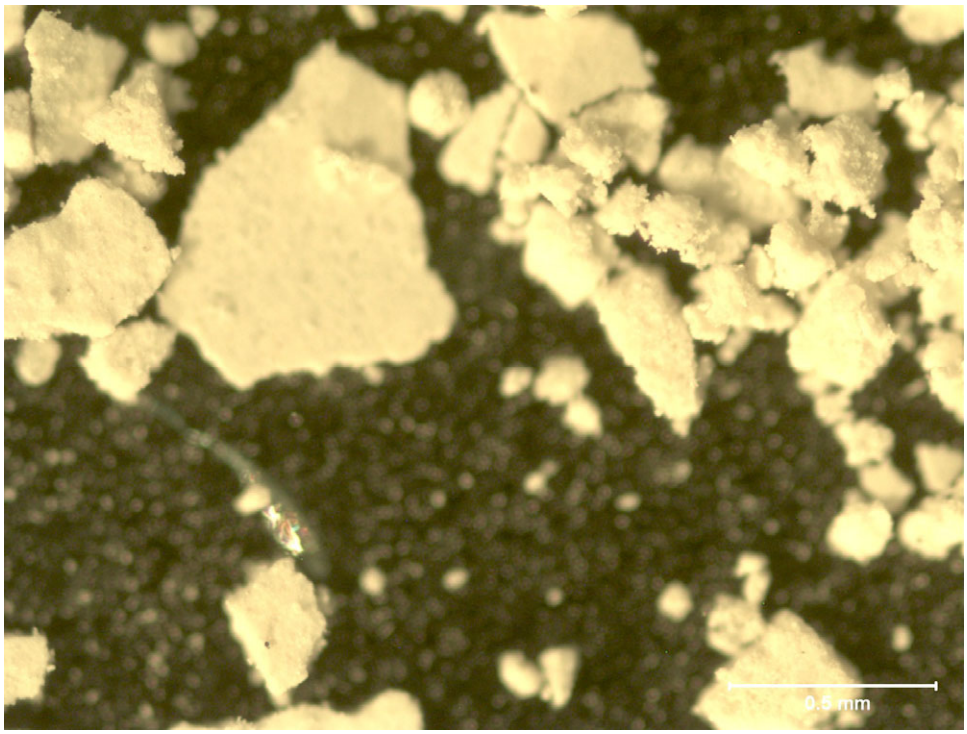


DEAHS65: Summary data and plots and cuttings photographs.

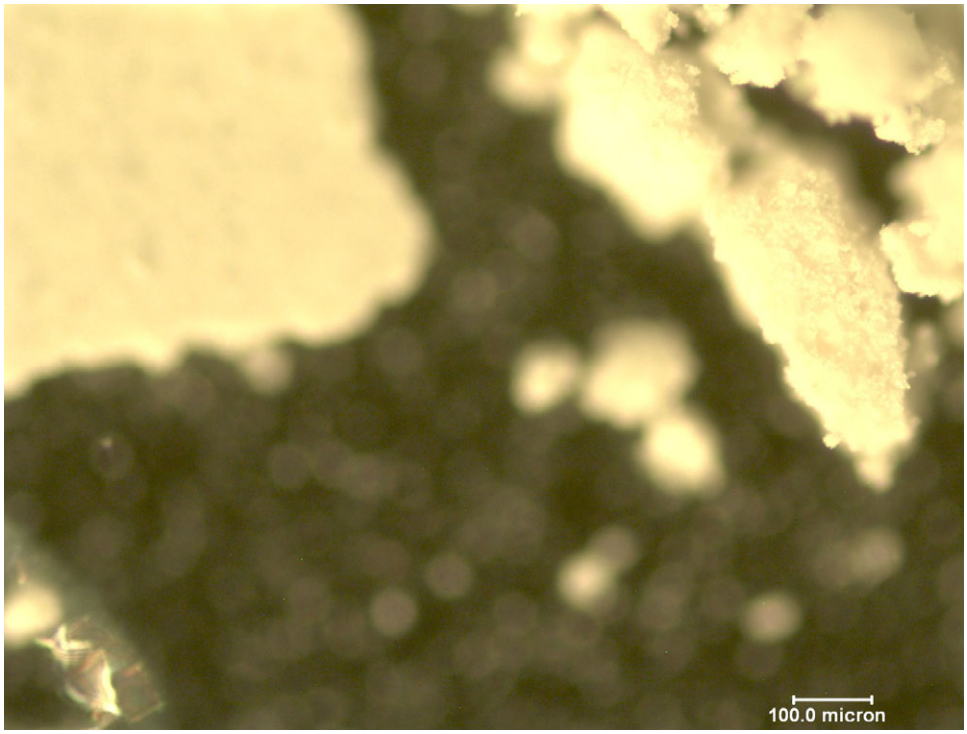
Test	Hole OD	Hole ID	Volts	Amps	RPM	WOB	Volume Removal	ROP	S. E. Rotation	S. E. WOB	Total S. E.	Total S. E.	ROP	
Date	(in)	(In)	(v)	(a)	(rpm)	(gms)	(in3/sec)	(in/sec)	(ft-lbs/in3)	(ft-lbs/in3)	(ft-lbs/in3)	(Joules/m3)	(ft/hr)	(in/rev)
11/22/2005	0.838	0.555	121.3	1.4426	15012	3000	0.0216	0.0698	5973.31	1.78	5975.10	4.94E+08	20.94	0.00028







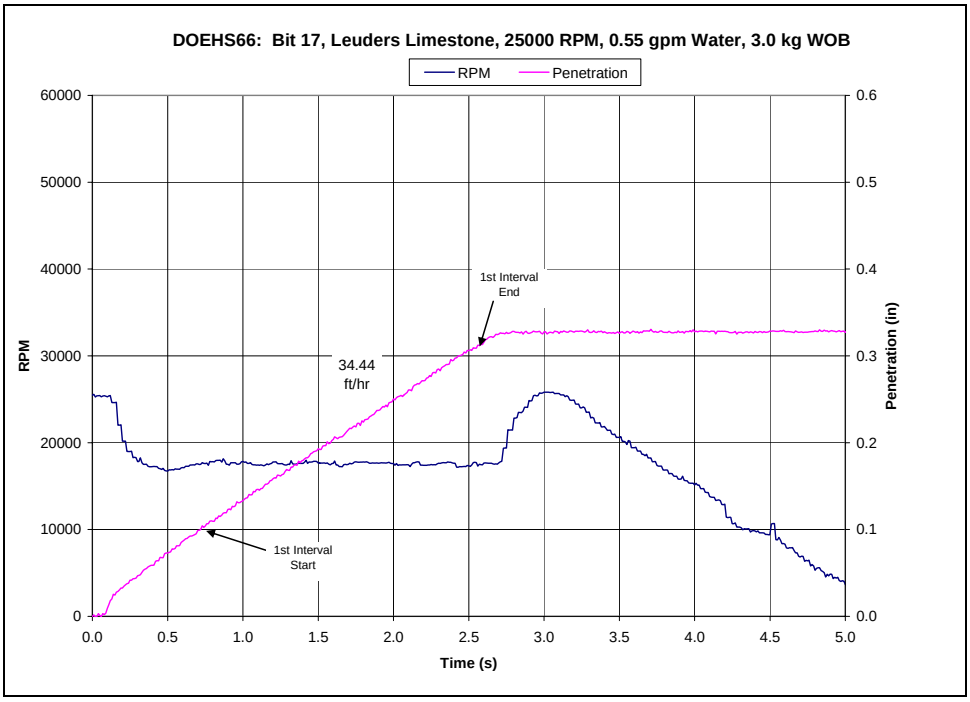
Test DOEH65 Austin cuttings 20,000 RPM

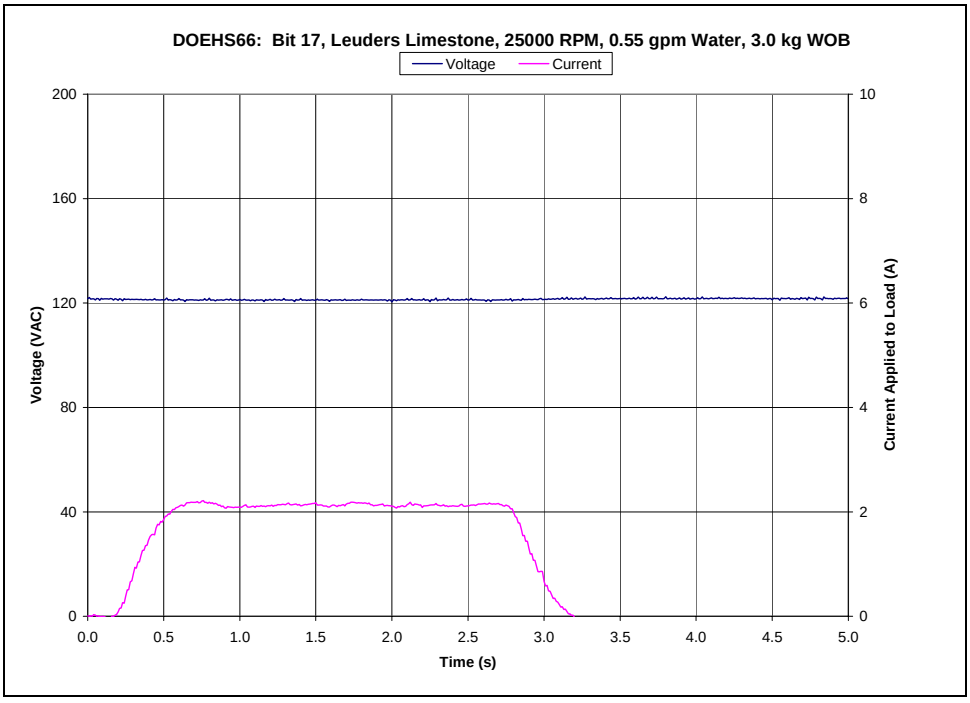


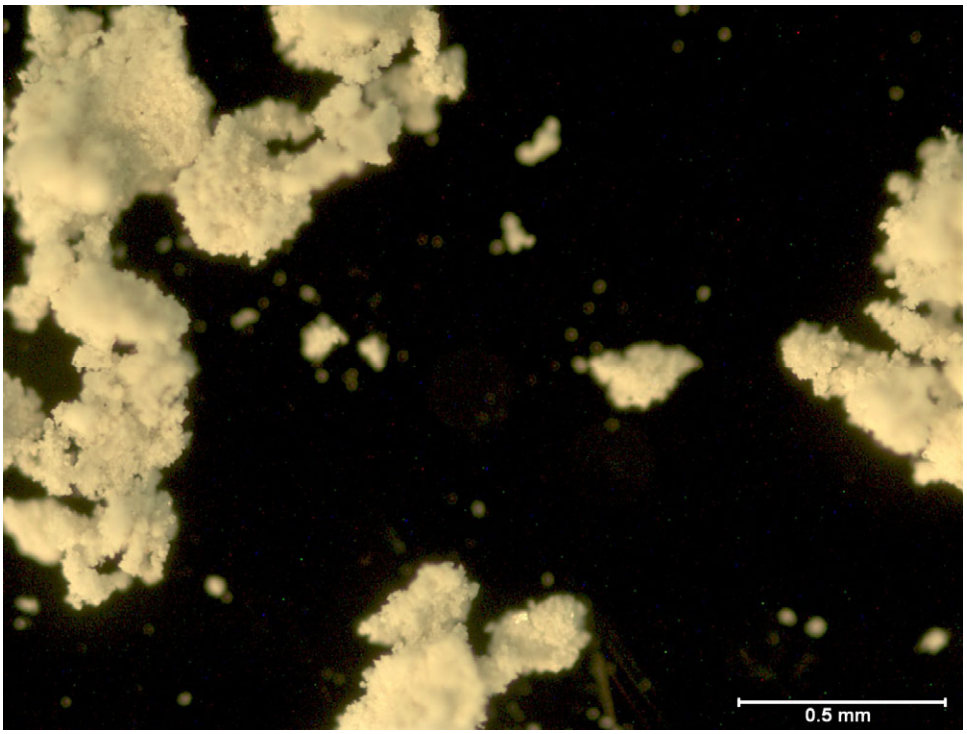
Test DOEH65 Austin cuttings 20,000 RPM

DEAHS66: Summary data and plots and cuttings photographs.

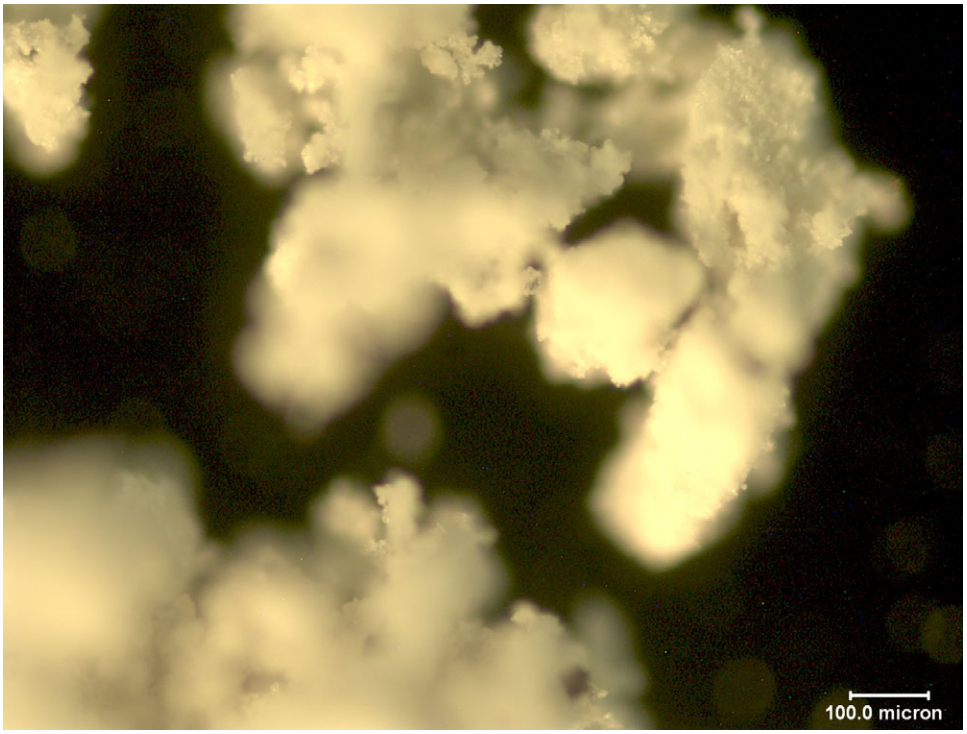
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/22/2005	0.838	0.555	121.2	2.1282	17593	3000	0.0355	0.1148	5352.43	1.78	5354.21	4.43E+08	34.44	0.00039







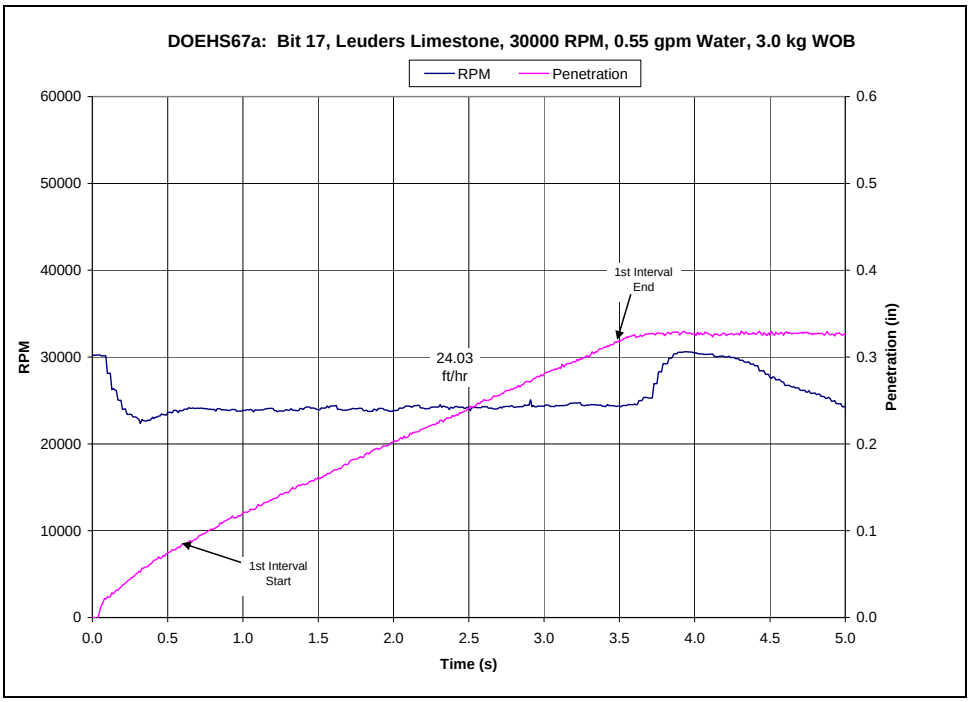
Test DOEH66 Austin cuttings 25,000 RPM

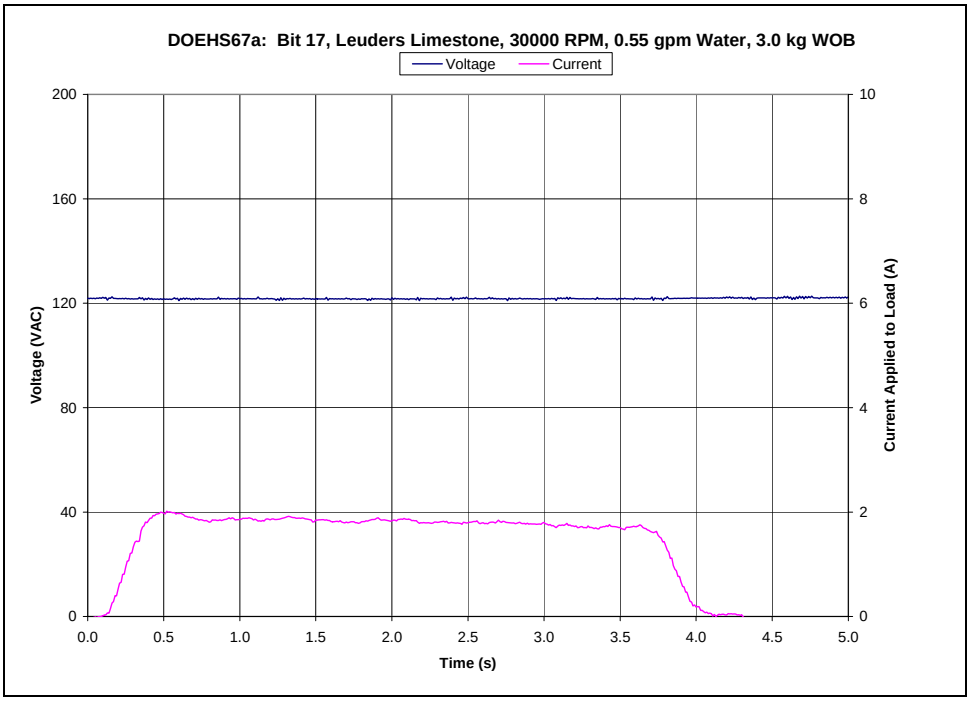


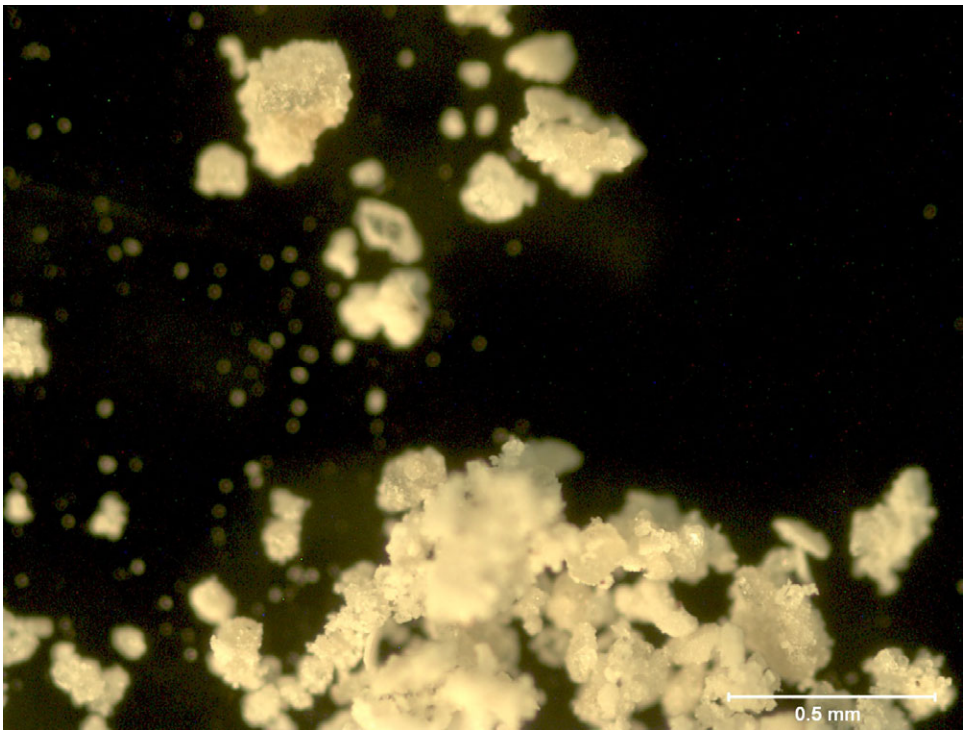
Test DOEH66 Austin cuttings 25,000 RPM

DEAHS67a: Summary data and plots and cuttings photographs.

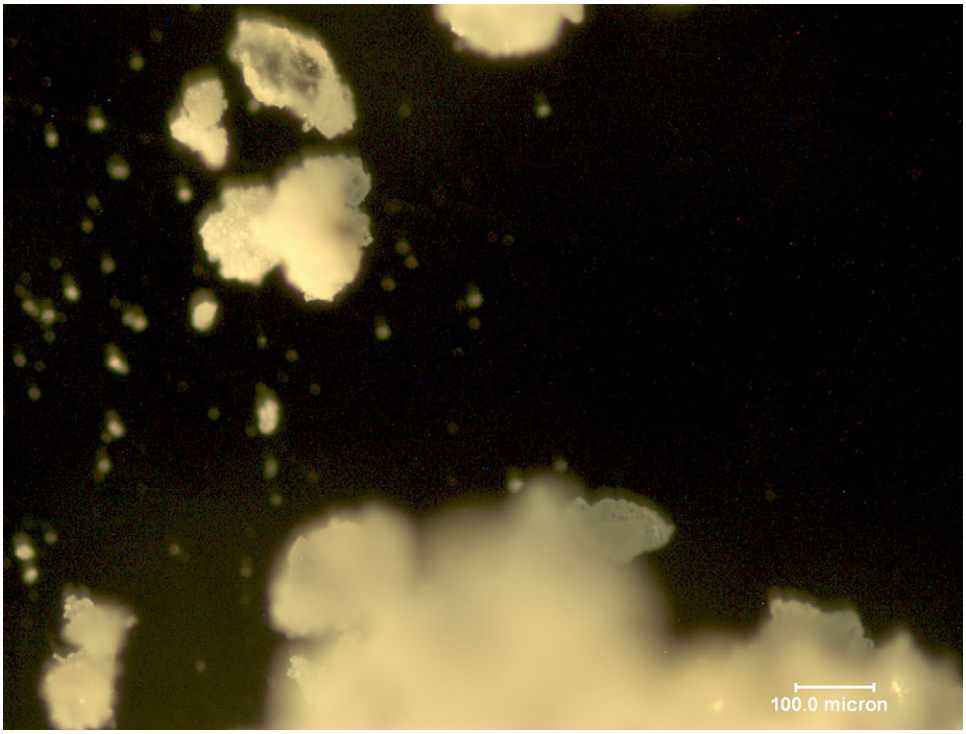
Test	Hole OD	Hole ID	Volts	Amps	RPM	WOB	Volume Removal	ROP	S. E. Rotation	S. E. WOB	Total S. E.	Total S. E.	ROP	
Date	(in)	(In)	(v)	(a)	(rpm)	(gms)	(in3/sec)	(in/sec)	(ft-lbs/in3)	(ft-lbs/in3)	(ft-lbs/in3)	(Joules/m3)	(ft/hr)	(in/rev)
11/22/2005	0.843	0.552	121.7	1.8145	24150	3000	0.0255	0.0801	6377.99	1.73	6379.72	5.27E+08	24.03	0.00020







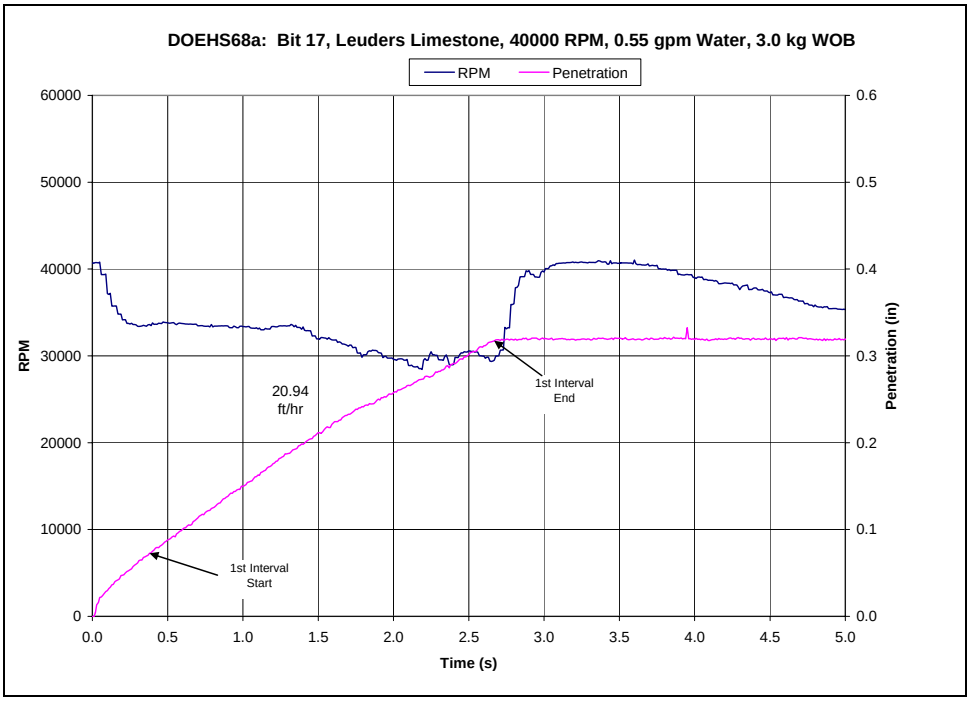
Test DOEH67a Austin cuttings 30,000 RPM

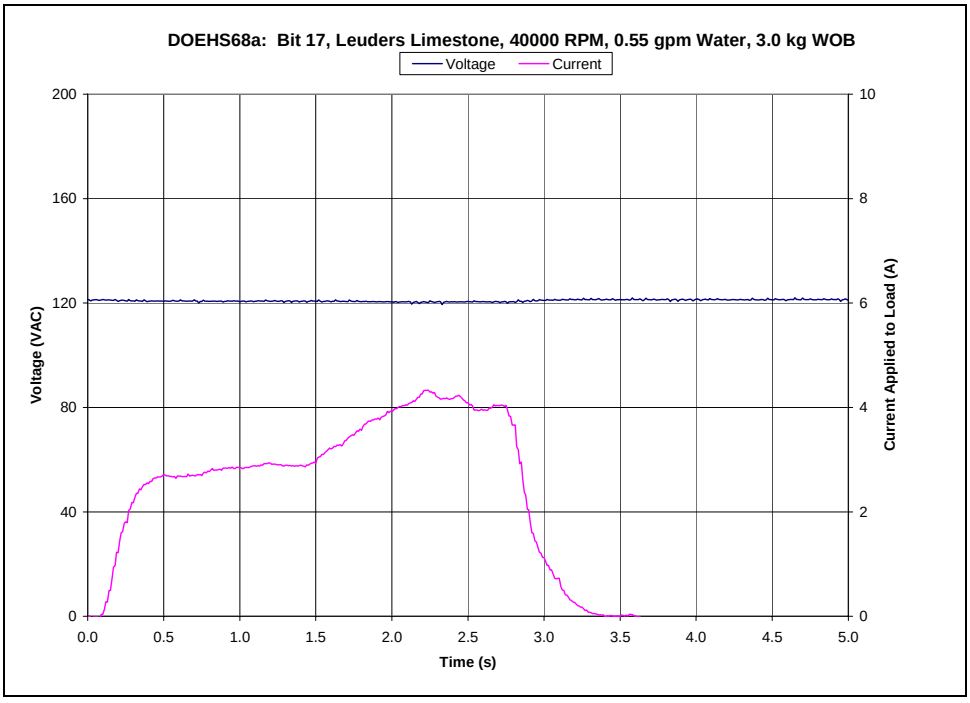


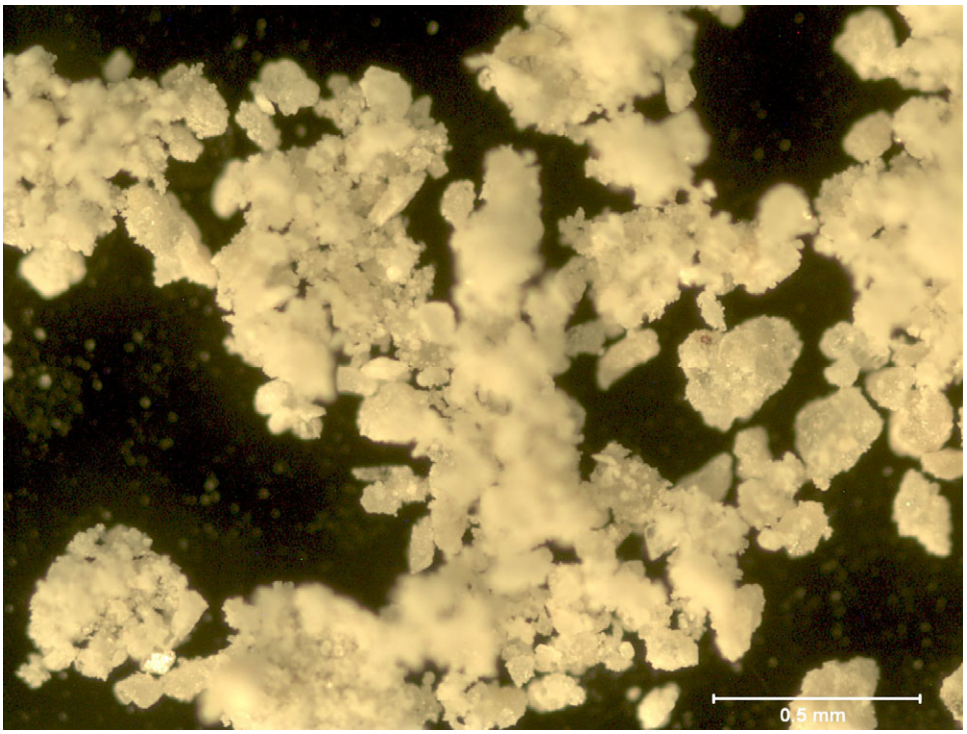
Test DOEH67a Austin cuttings 30,000 RPM

DEAHS68a: Summary data and plots and cuttings photographs.

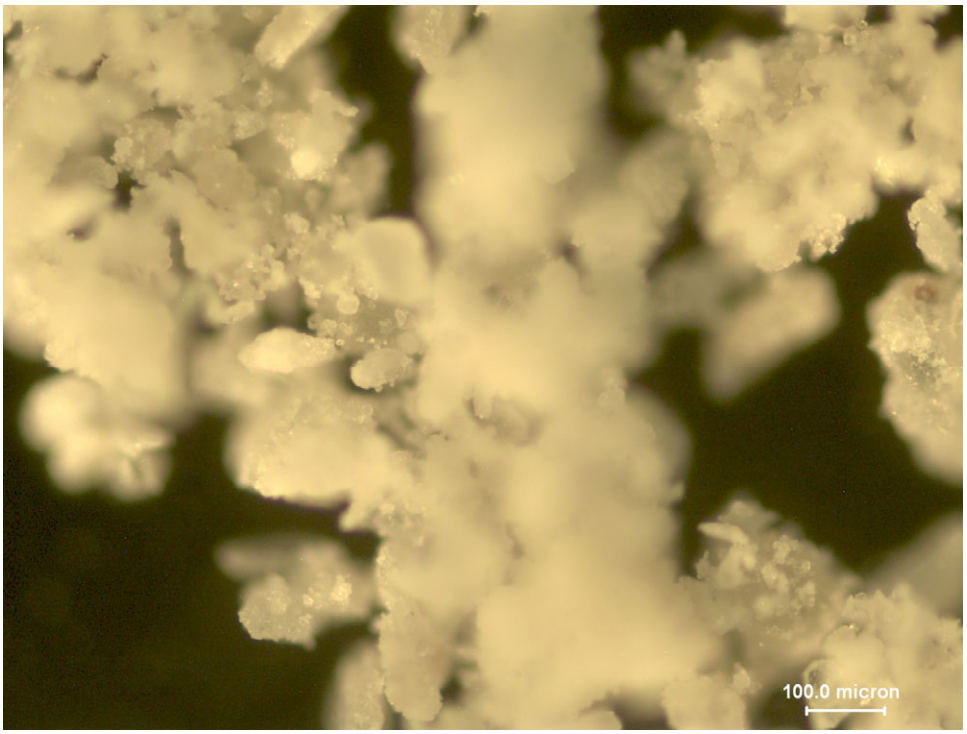
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/23/2005	0.841	0.554	120.6	3.3601	31696	3000	0.0331	0.1054	9020.39	1.75	9022.14	7.46E+08	31.62	0.00020







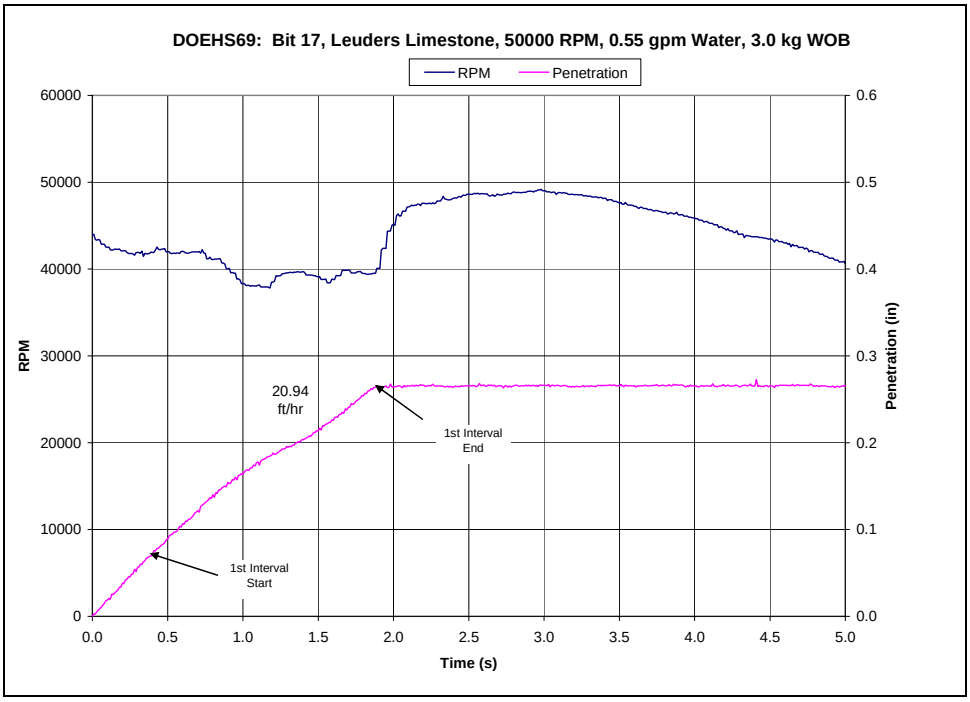
Test DOEH68a Austin cuttings 40,000 RPM

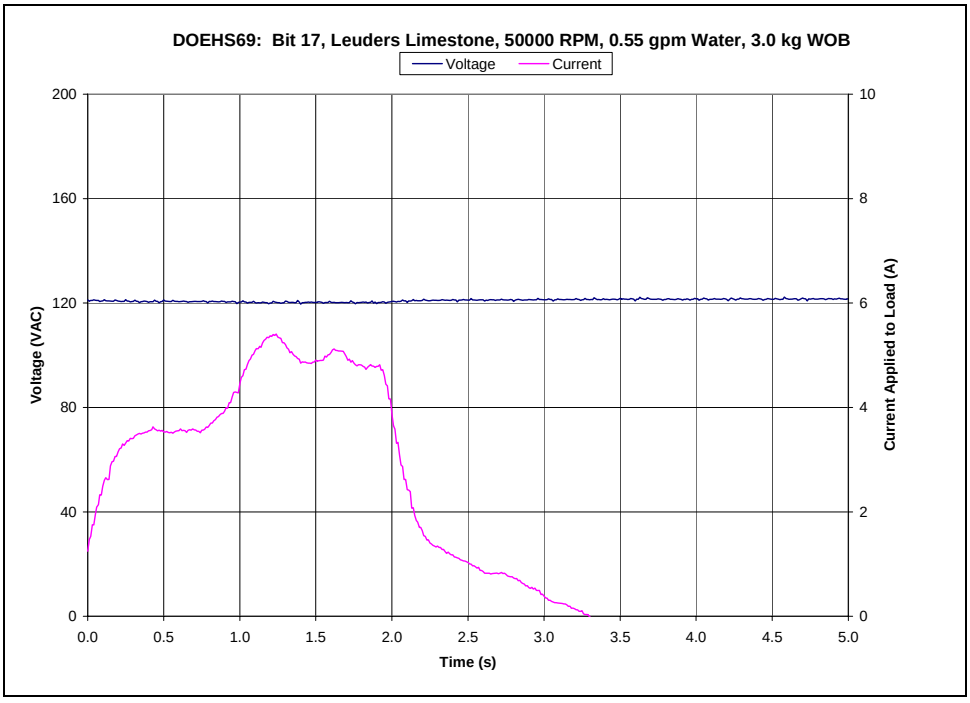


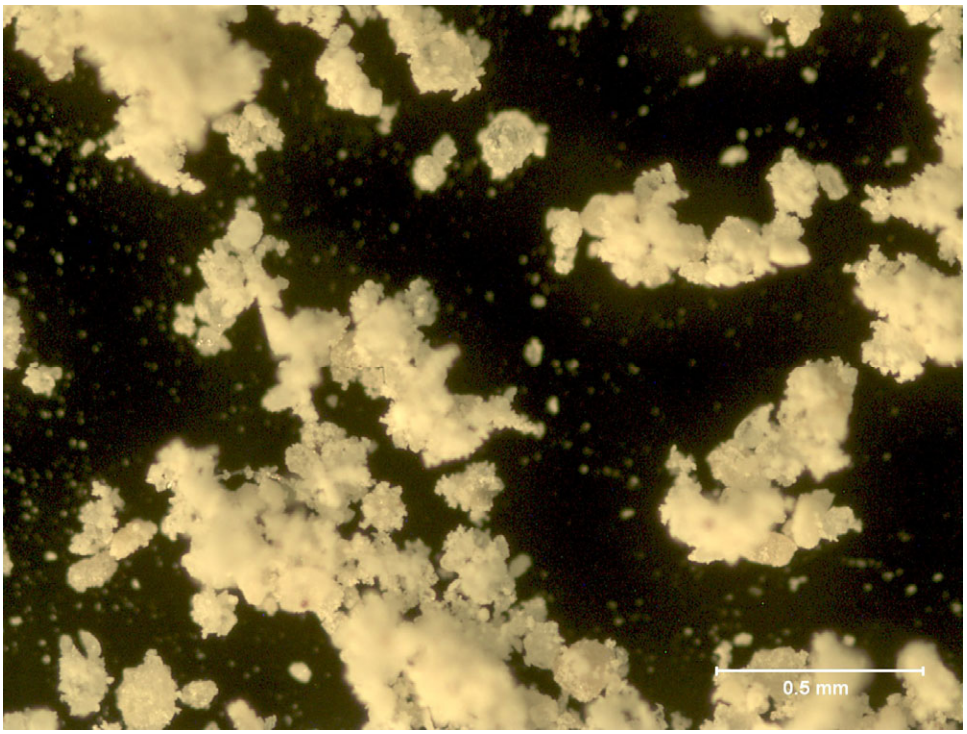
Test DOEH68a Austin cuttings 40,000 RPM

DEAHS69: Summary data and plots and cuttings photographs.

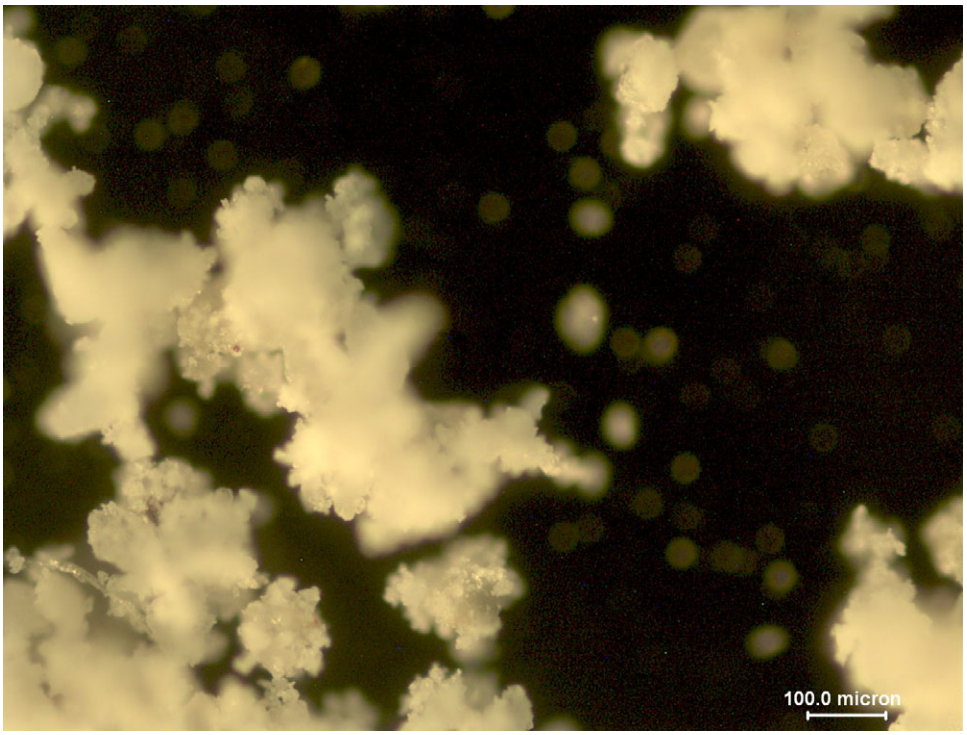
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/22/2005	0.839	0.556	120.4	4.4620	40049	3000	0.0379	0.1223	10449.37	1.78	10451.15	8.64E+08	36.69	0.00018







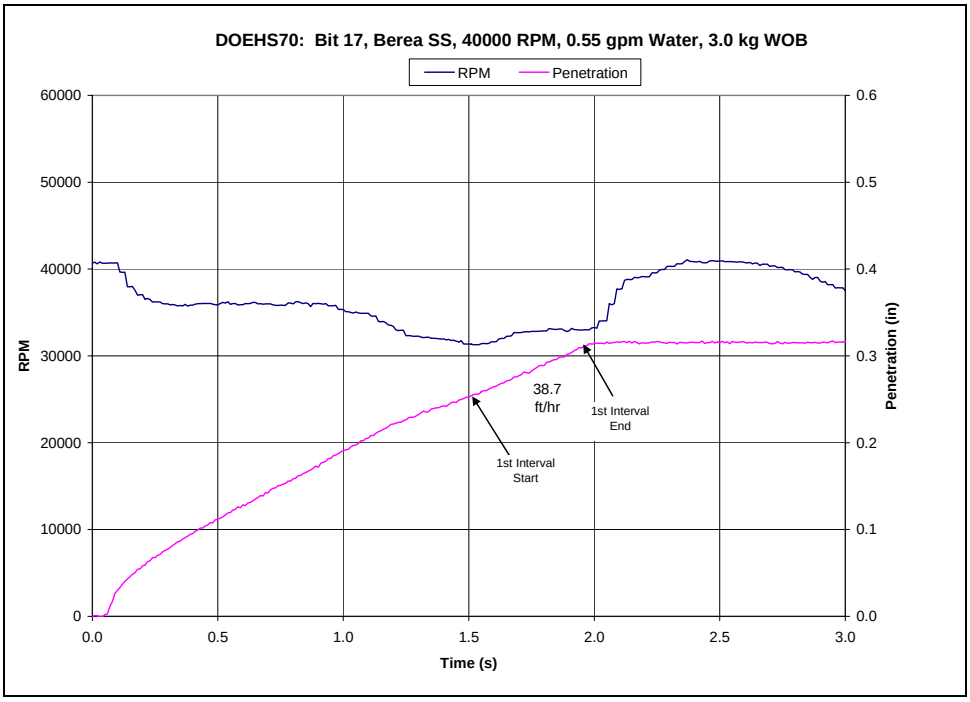
Test DOEH69 Austin cuttings 50,000 RPM

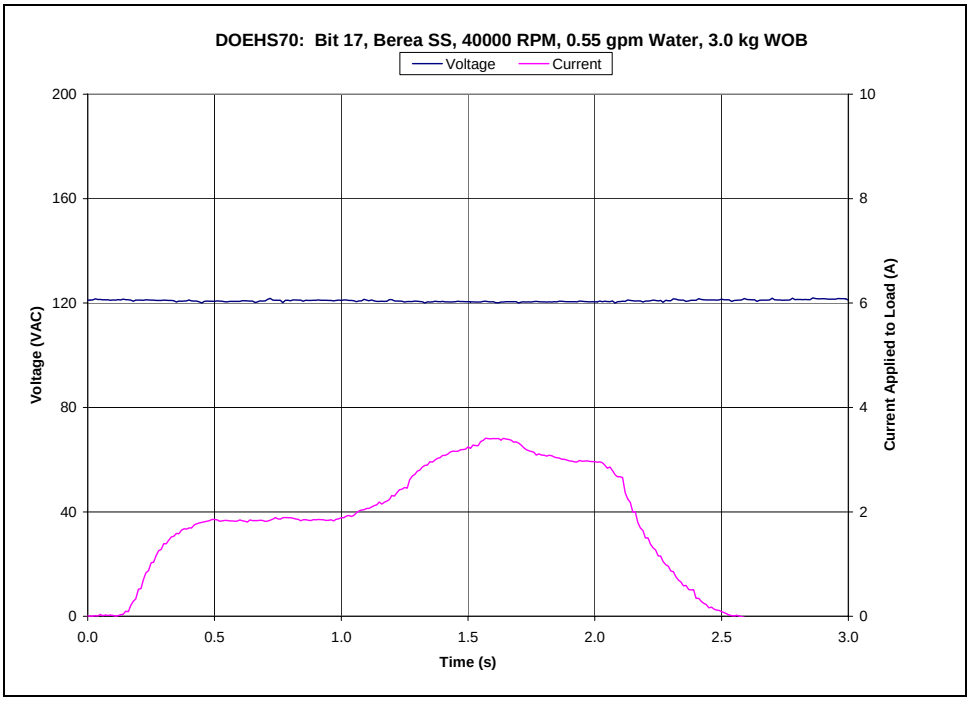


Test DOEH69 Austin cuttings 50,000 RPM

DEAHS70: Summary data and plots and cuttings photographs.

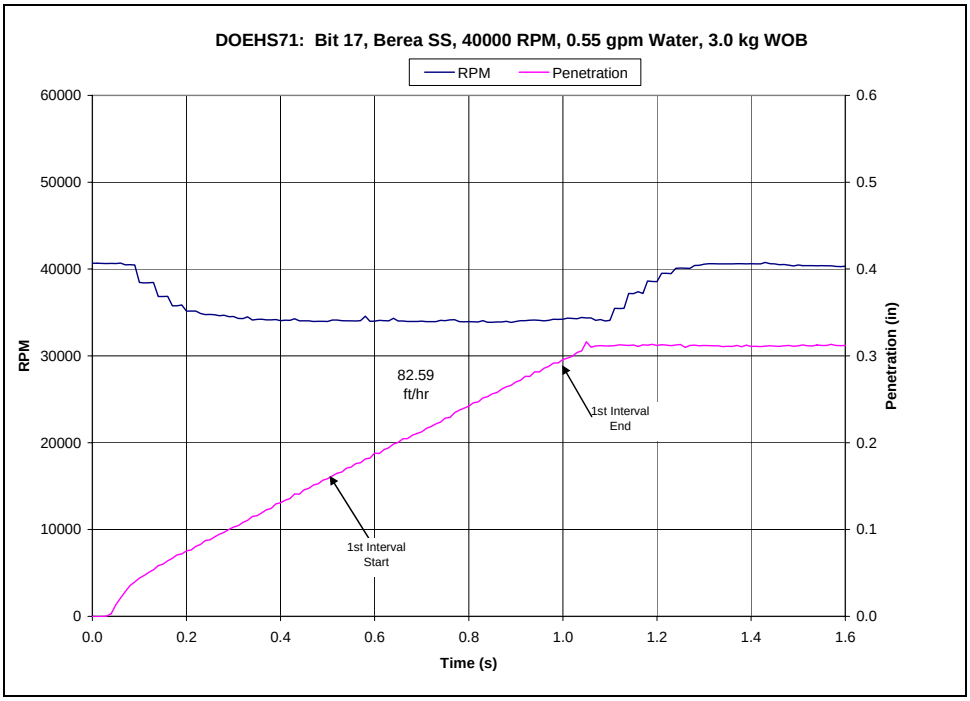
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/22/2005	0.839	0.553	120.4	3.2417	32415	3000	0.0402	0.1286	7162.44	1.76	7164.21	5.92E+08	38.58	0.00024

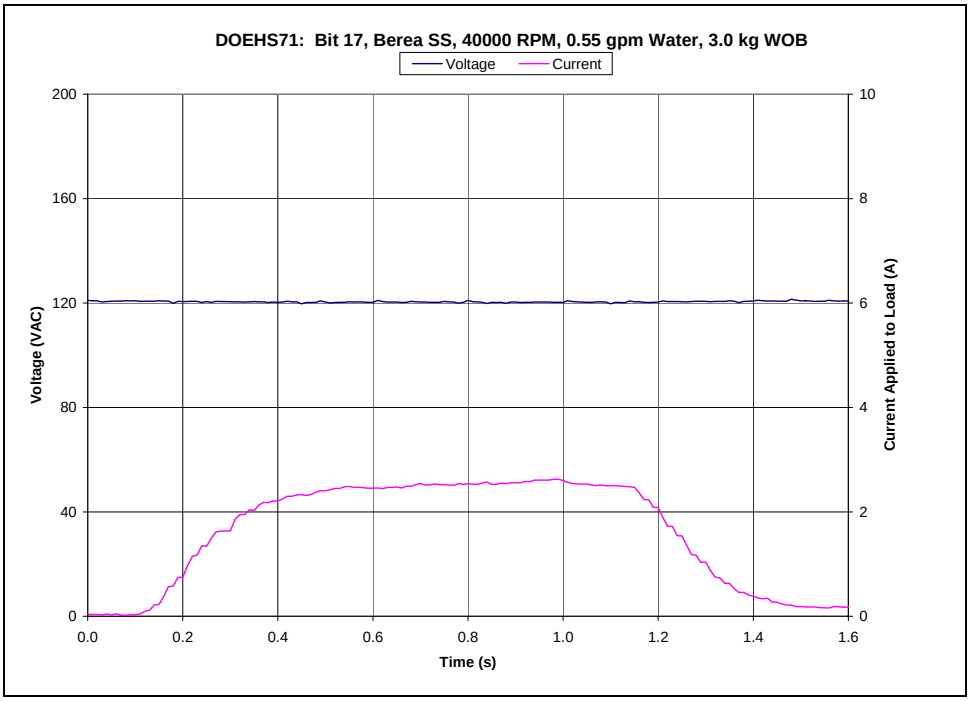




DEAHS71: Summary data and plots and cuttings photographs.

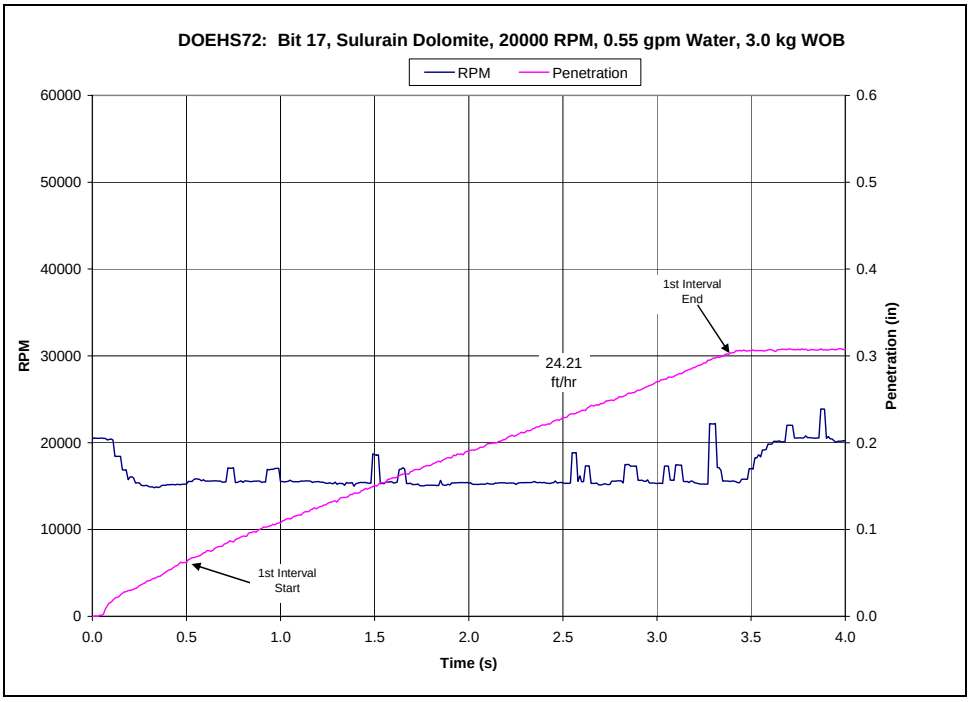
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/22/2005	0.841	0.554	120.4	2.5157	34045	3000	0.0866	0.2753	2580.37	1.75	2582.12	2.13E+08	82.59	0.00049

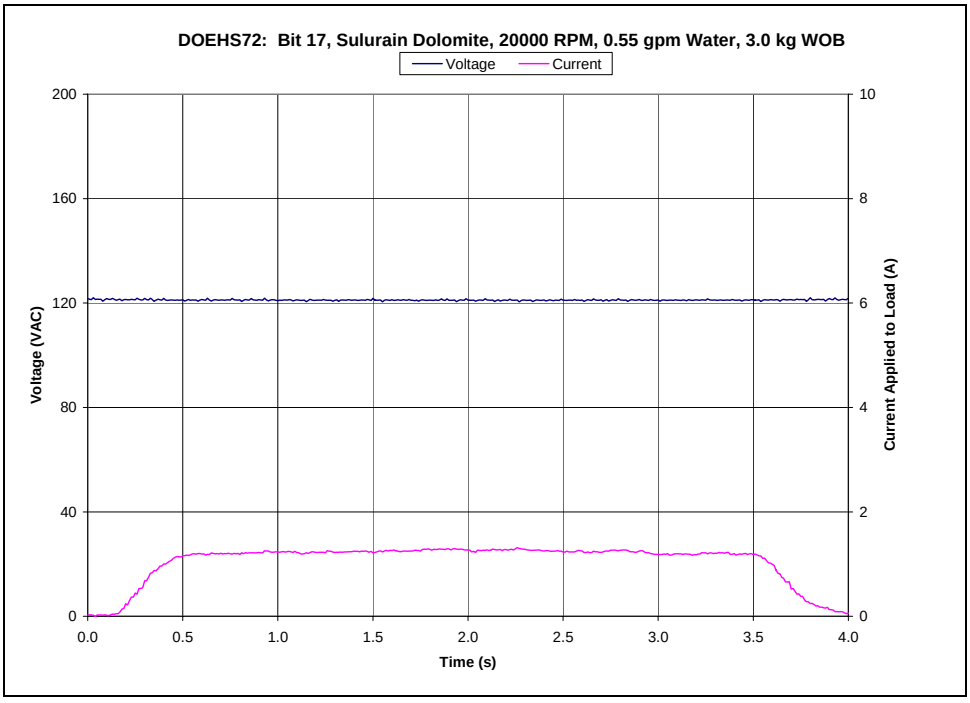


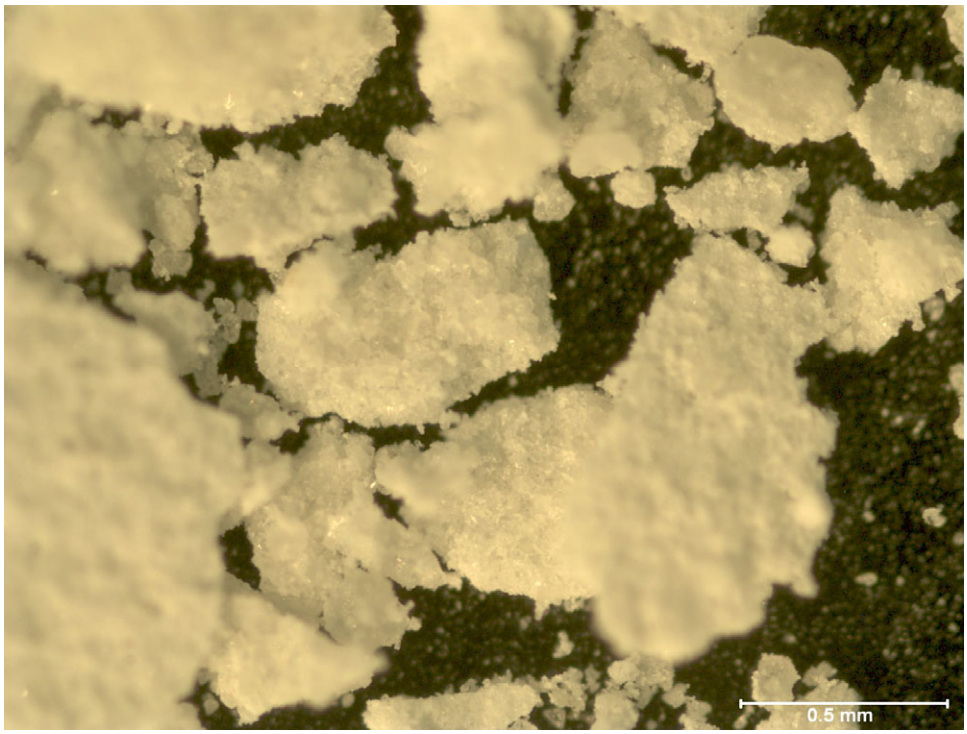


DEAHS72: Summary data and plots and cuttings photographs.

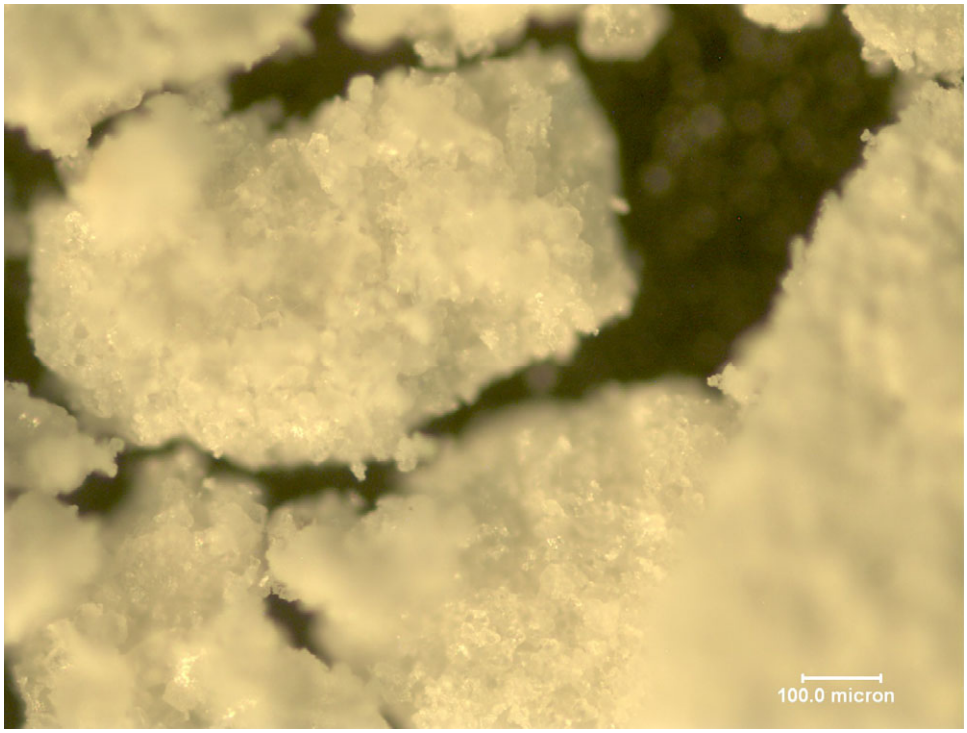
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/22/2005	0.839	0.556	121.1	1.2351	15795	3000	0.0250	0.0807	4409.53	1.78	4411.30	3.65E+08	24.21	0.00031







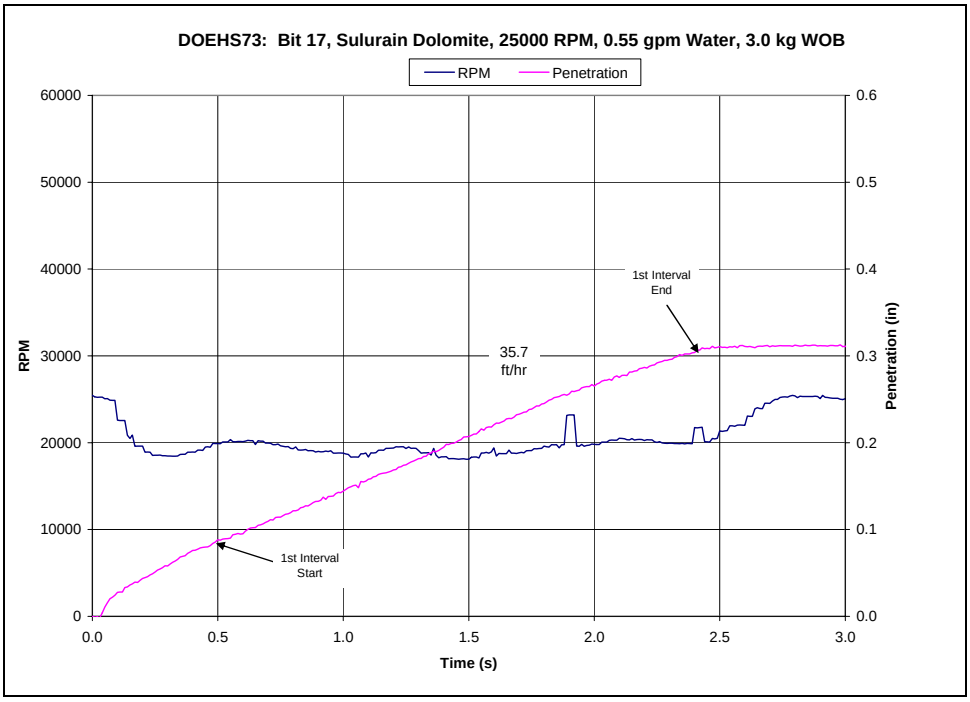
Test DOEH72 Sulurain Dolomite cuttings 20,000 RPM

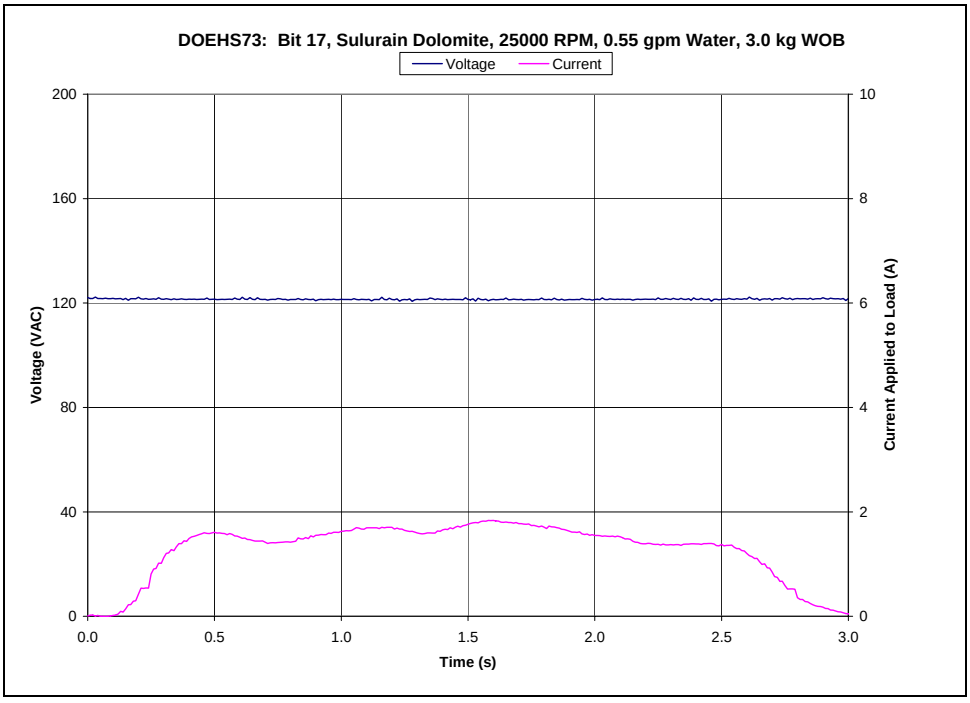


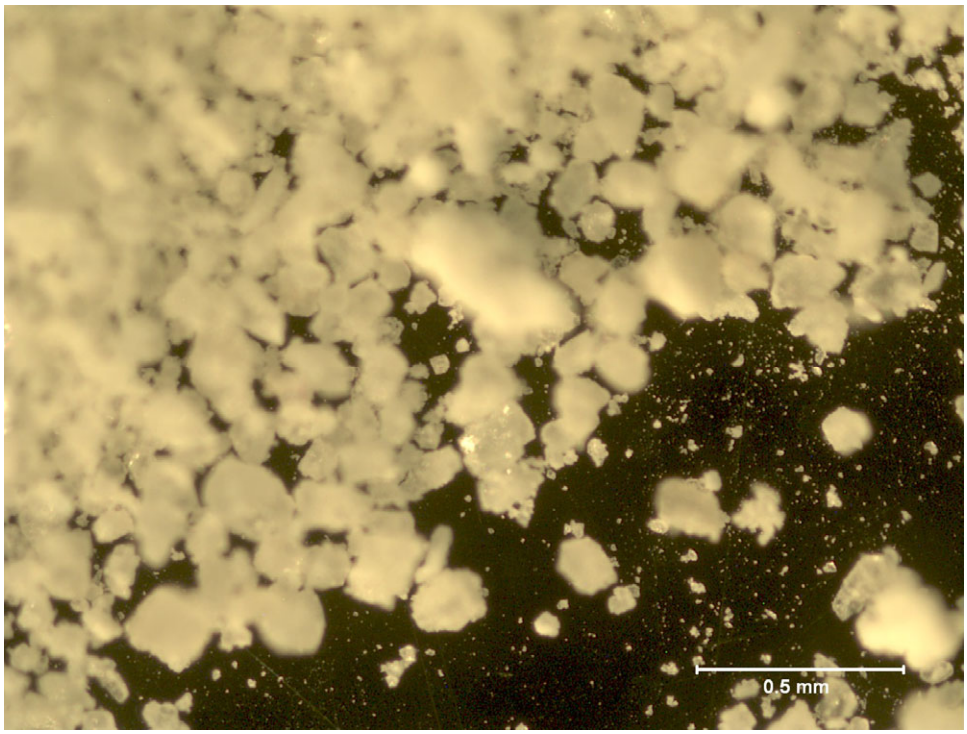
Test DOEH72 Sulurain Dolomite cuttings 20,000 RPM

DEAHS73: Summary data and plots and cuttings photographs.

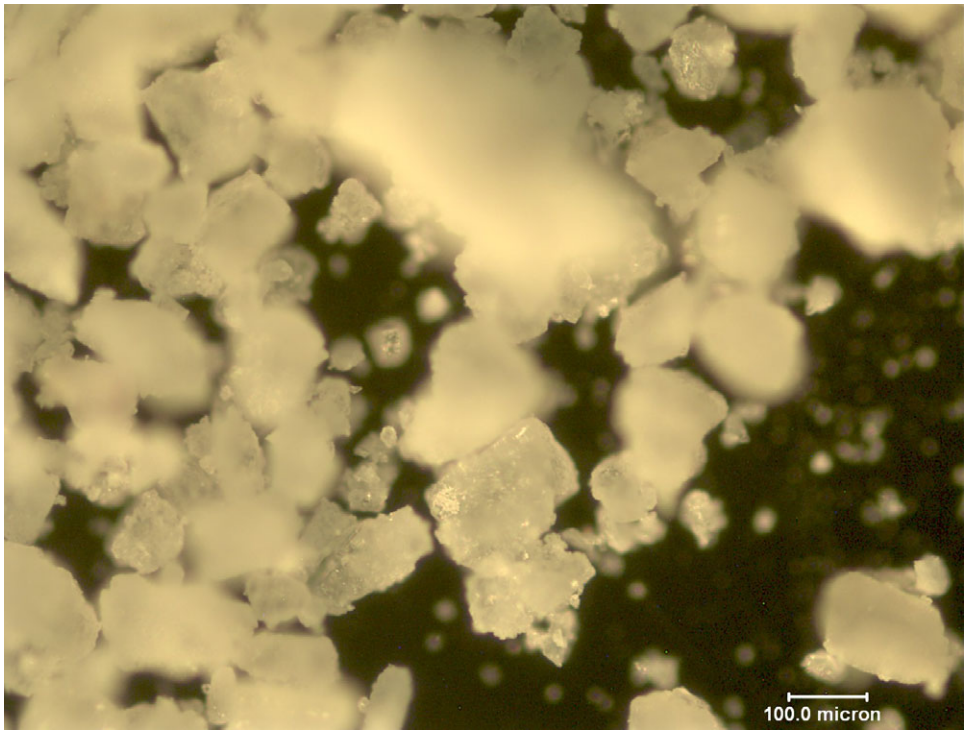
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/22/2005	0.840	0.555	121.4	1.5870	19473	3000	0.0372	0.1190	3825.35	1.77	3827.11	3.16E+08	35.70	0.00037







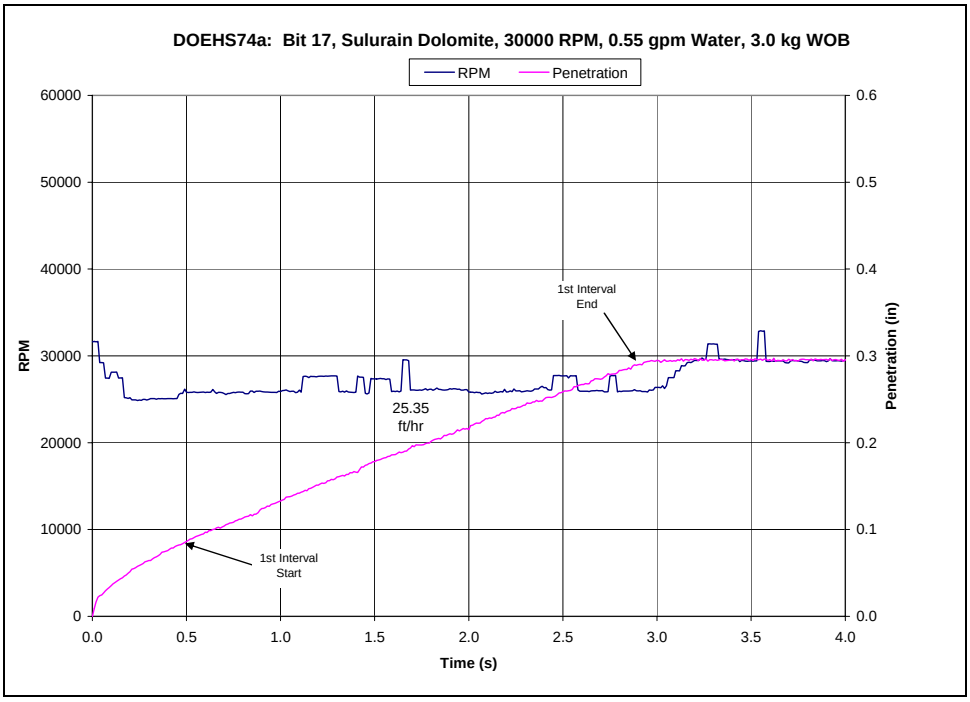
Test DOEH73 Sulurain Dolomite cuttings 25,000 RPM

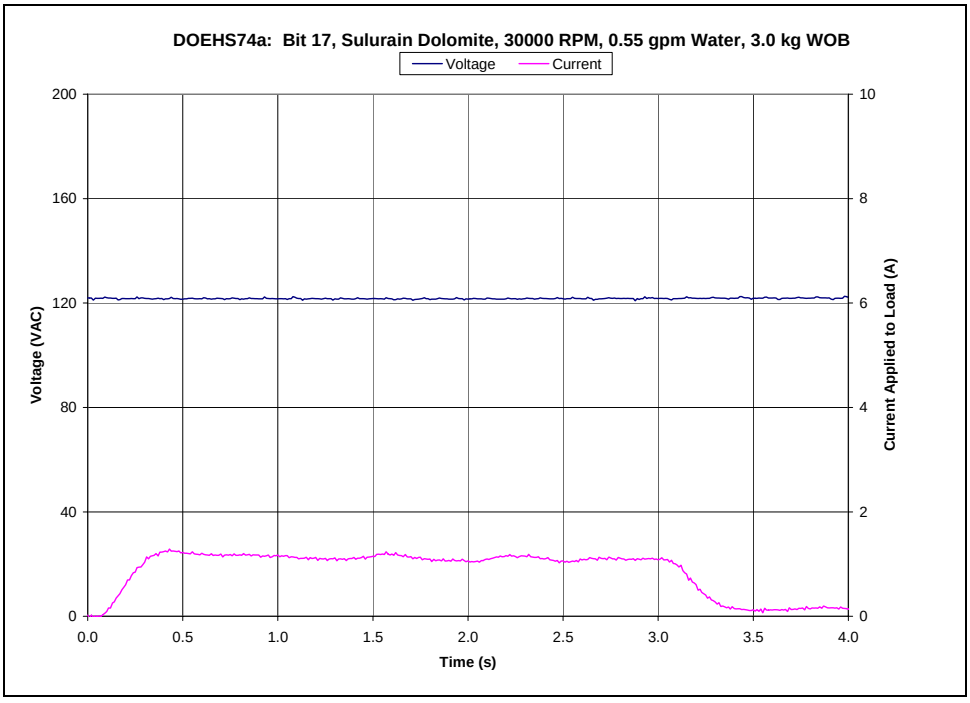


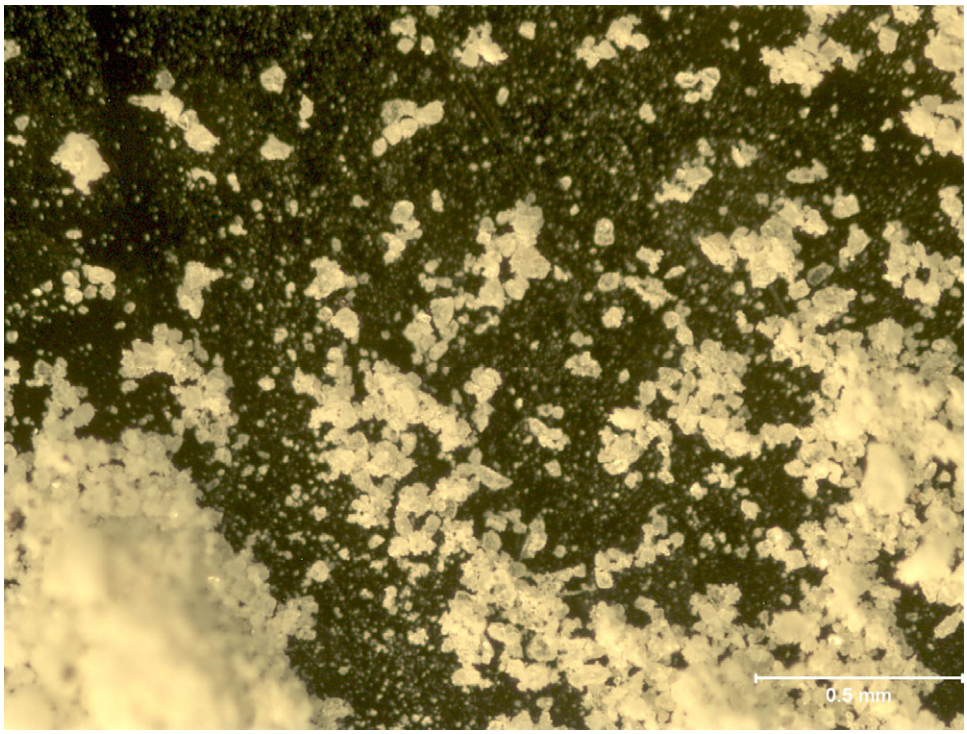
Test DOEH73 Sulurain Dolomite cuttings 25,000 RPM

DEAHS74a: Summary data and plots and cuttings photographs.

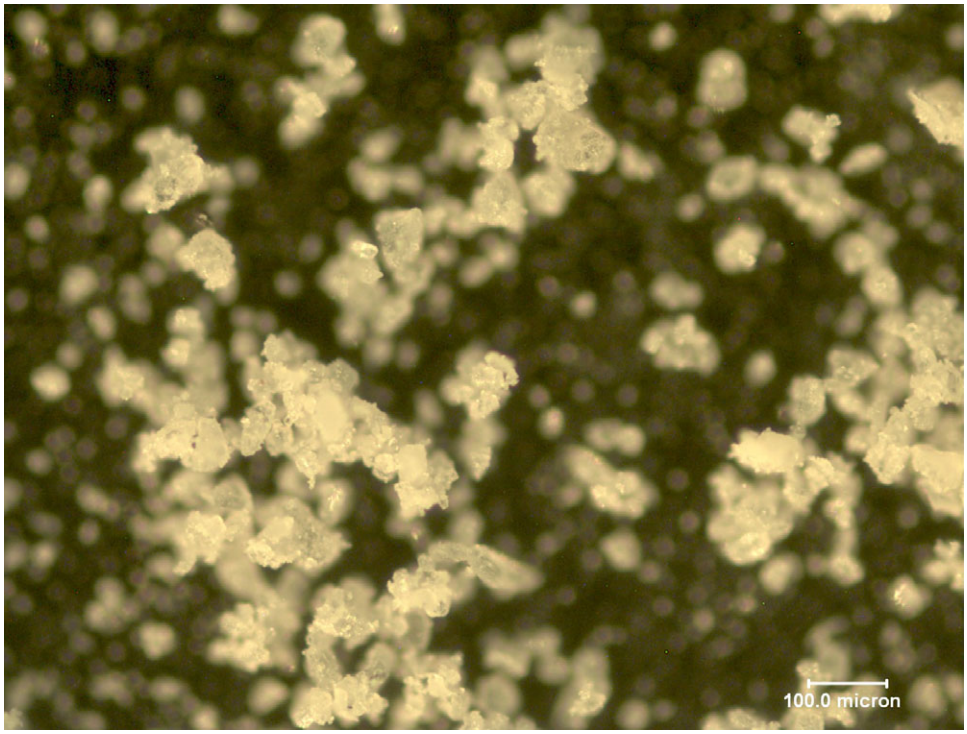
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/22/2005	0.846	0.548	121.7	1.1221	25770	3000	0.0276	0.0845	3652.52	1.69	3654.21	3.02E+08	25.35	0.00020







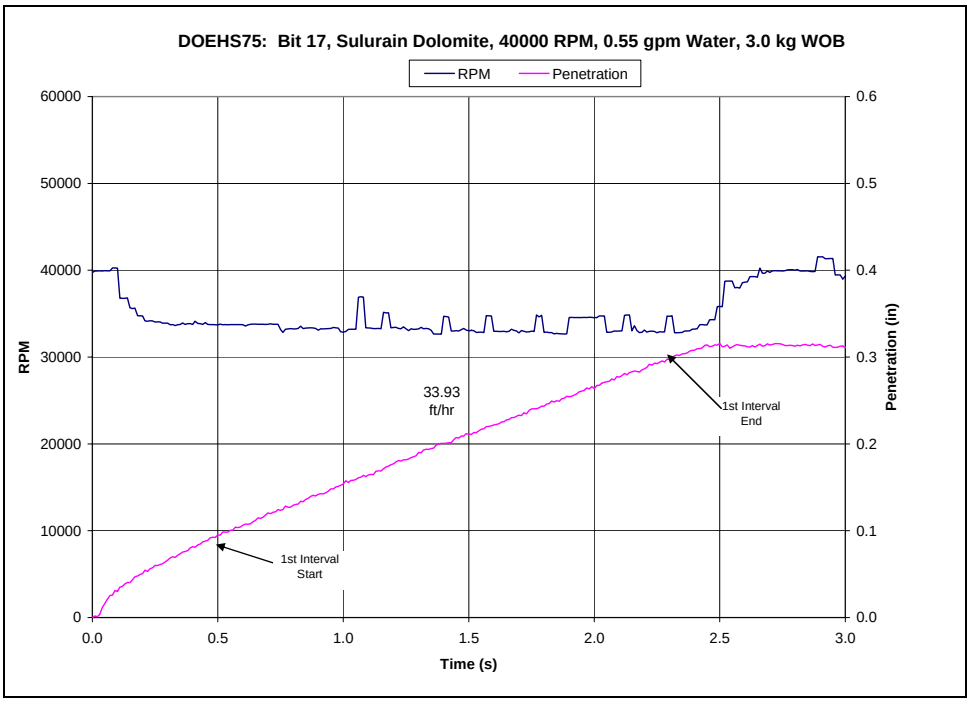
Test DOEH74a Sulurain Dolomite cuttings 30,000 RPM

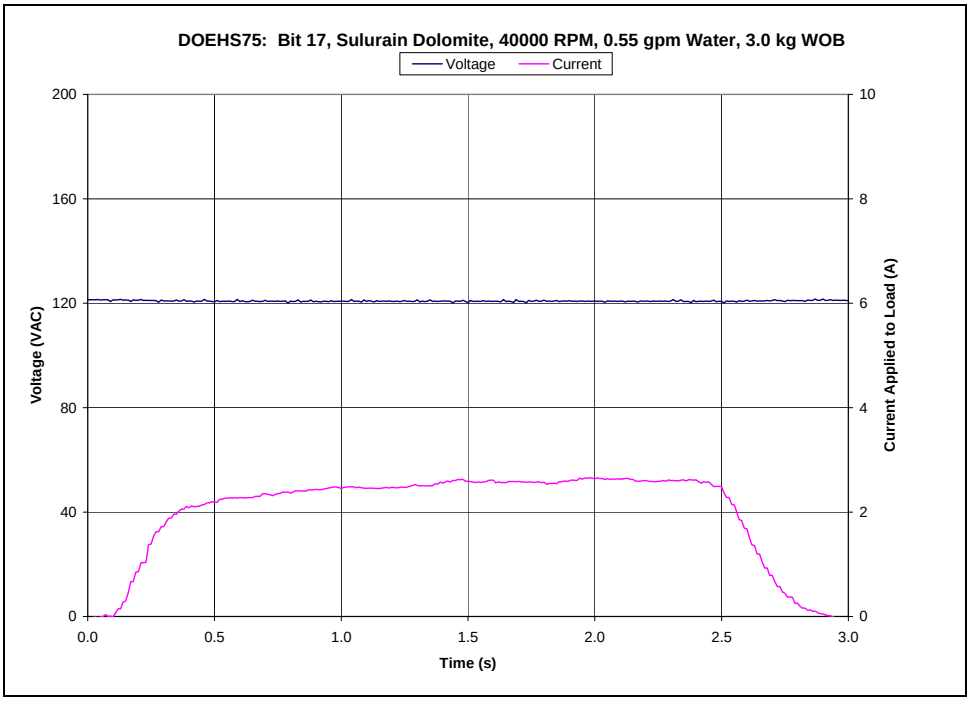


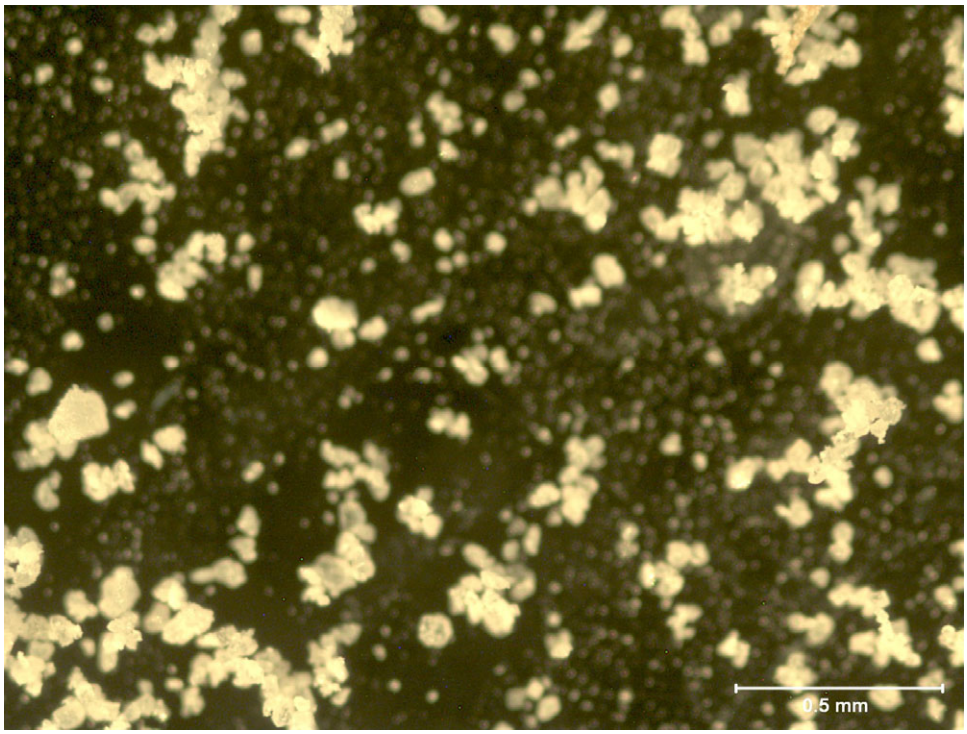
Test DOEH74a Sulurain Dolomite cuttings 30,000 RPM

DEAHS75: Summary data and plots and cuttings photographs.

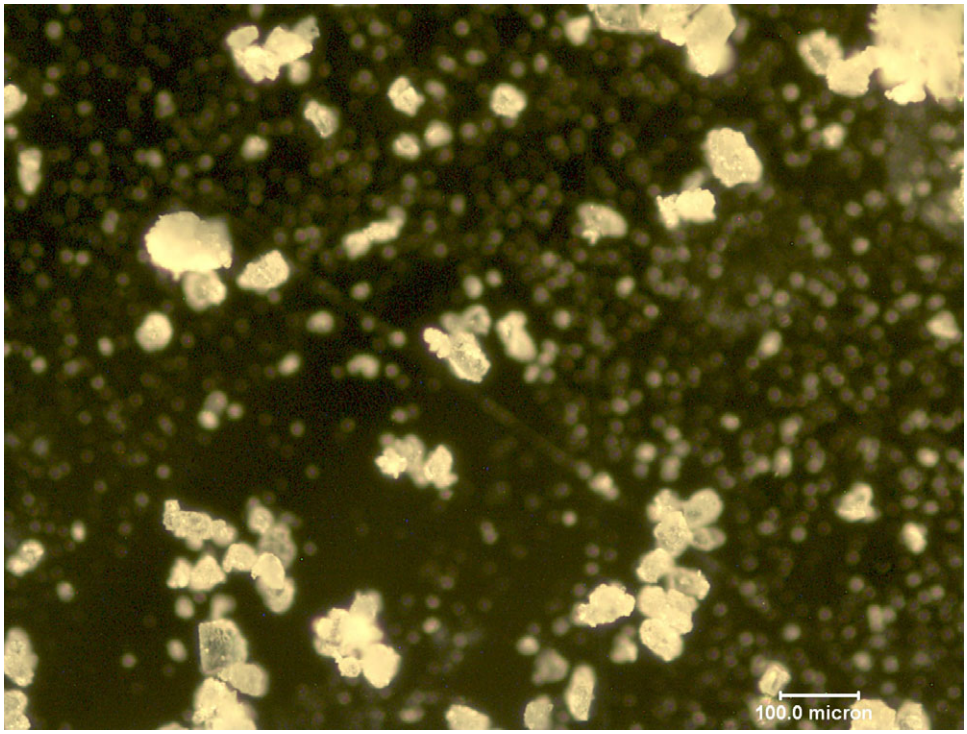
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/22/2005	0.841	0.550	120.8	2.5118	33511	3000	0.0360	0.1131	6224.63	1.73	6226.37	5.15E+08	33.93	0.00020







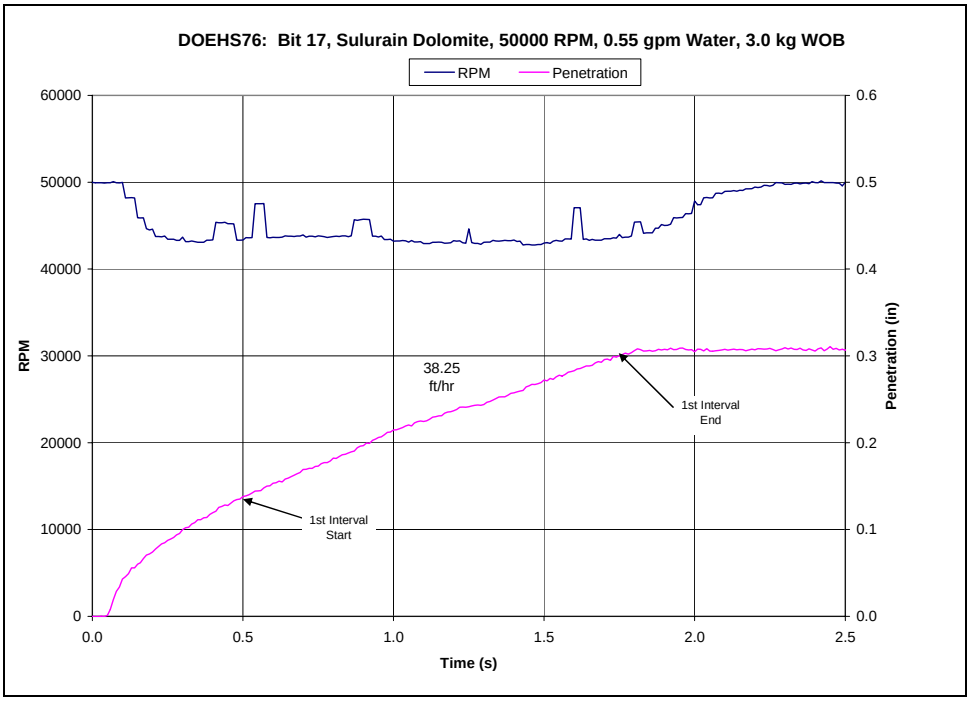
Test DOEH75 Sulurain Dolomite cuttings 40,000 RPM

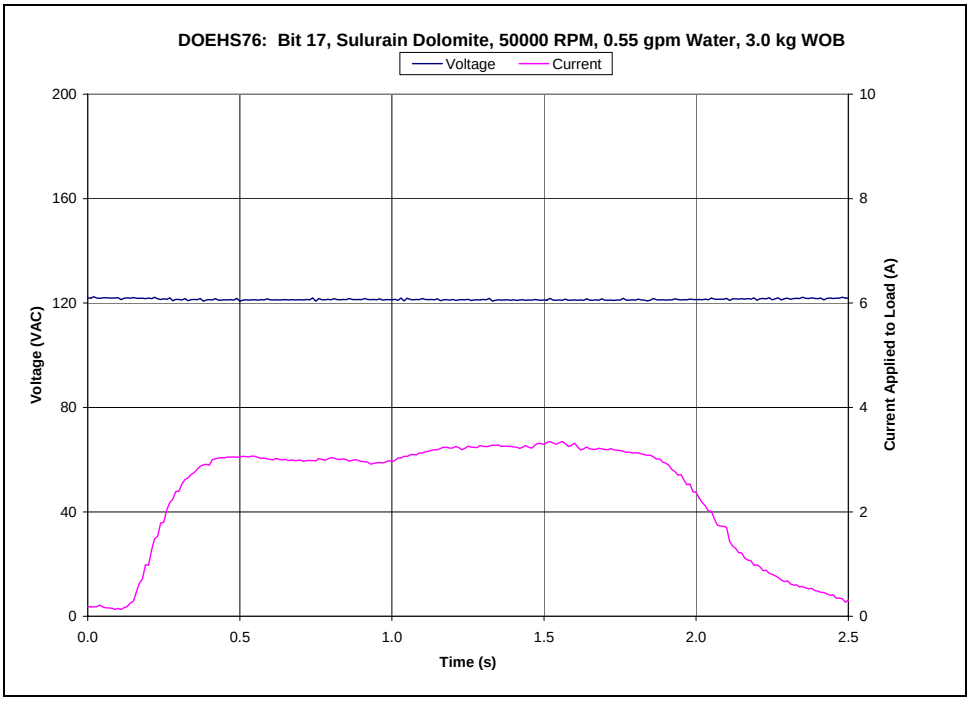


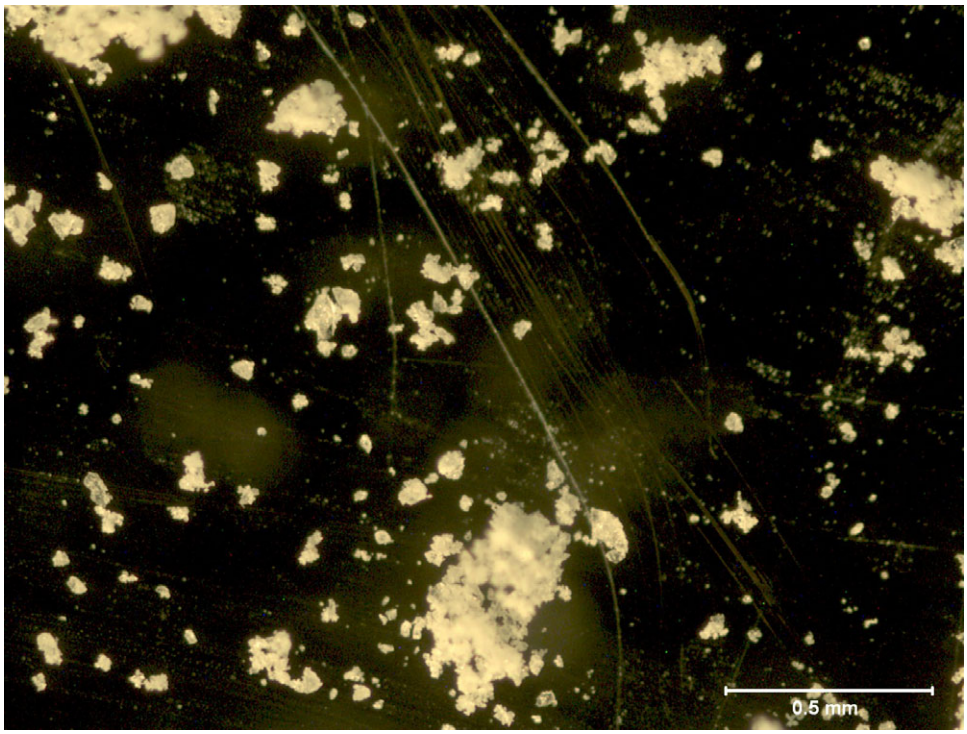
Test DOEH75 Sulurain Dolomite cuttings 40,000 RPM

DEAHS76: Summary data and plots and cuttings photographs.

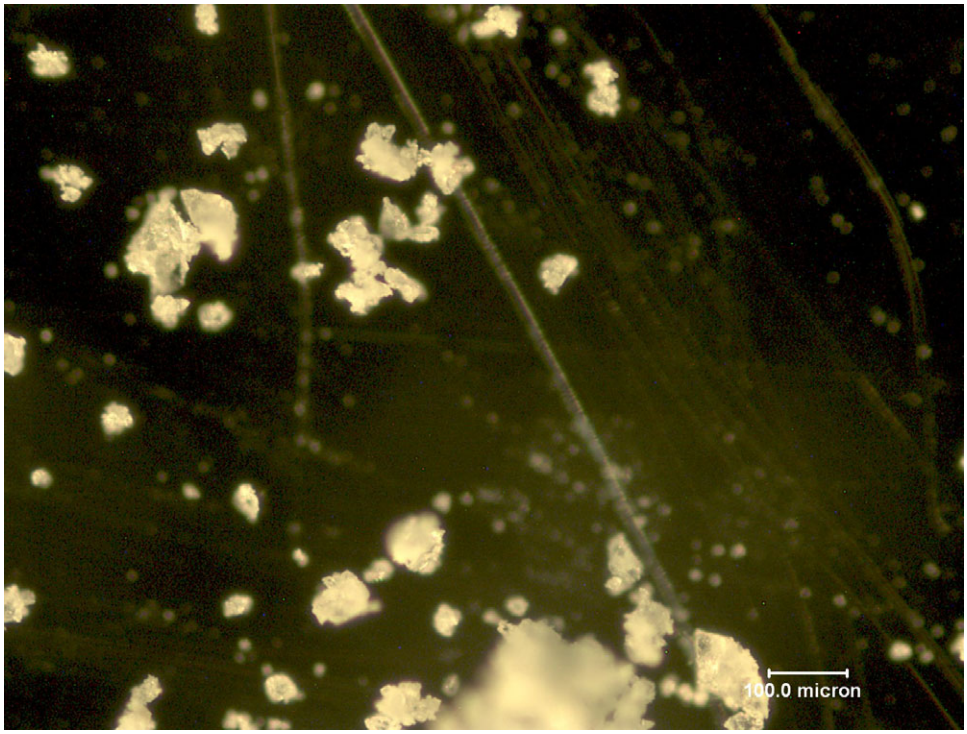
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/22/2005	0.846	0.554	121.3	3.1318	43707	3000	0.0409	0.1275	6843.37	1.72	6845.09	5.66E+08	38.25	0.00018







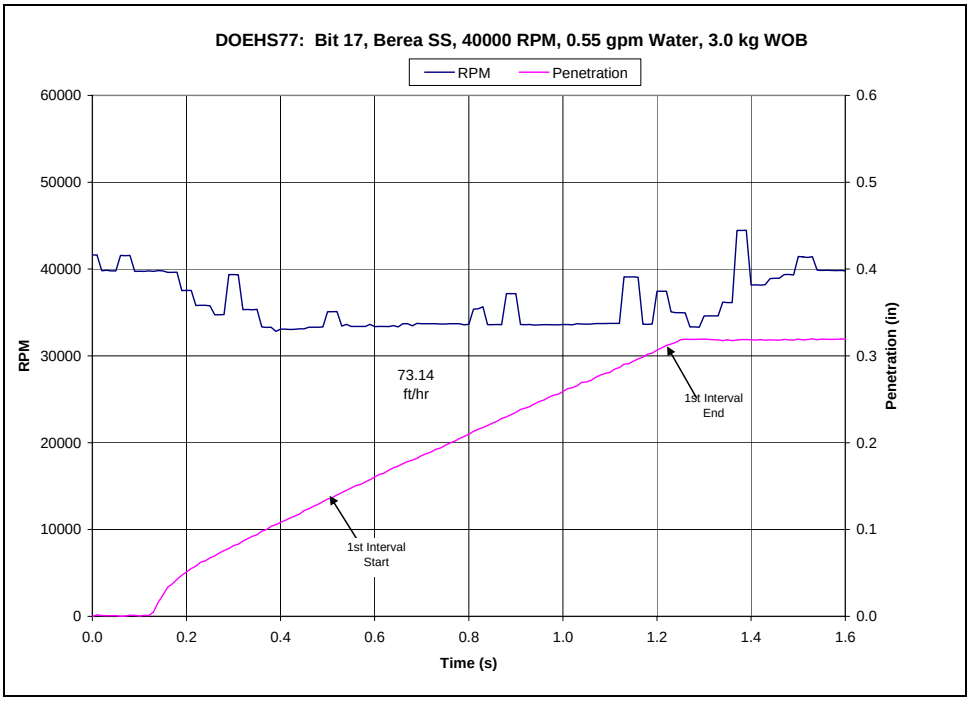
Test DOEH76 Sulurain Dolomite cuttings 50,000 RPM

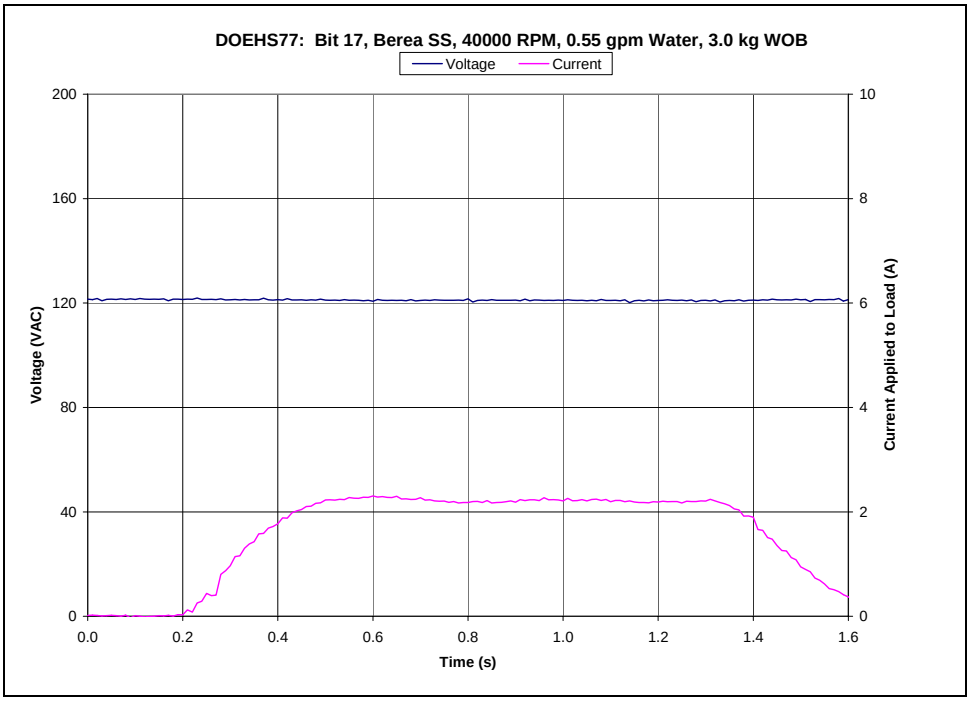


Test DOEH76 Sulurain Dolomite cuttings 50,000 RPM

DEAHS77: Summary data and plots and cuttings photographs.

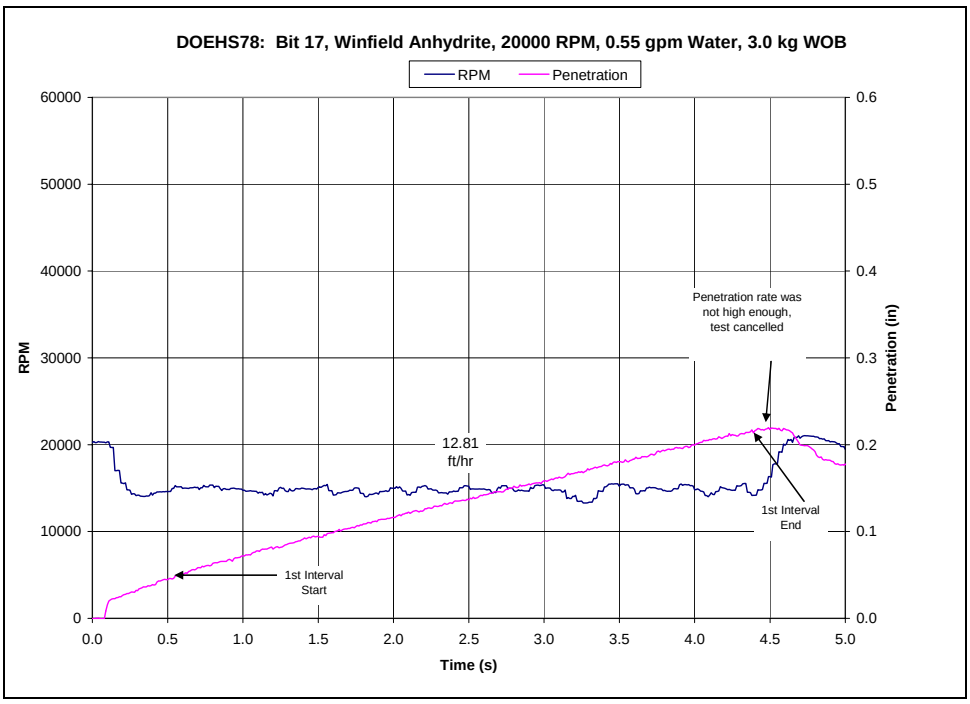
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/29/2005	0.840	0.555	121.0	2.2228	34285	3000	0.0761	0.2438	2606.76	1.77	2608.53	2.16E+08	73.14	0.00043

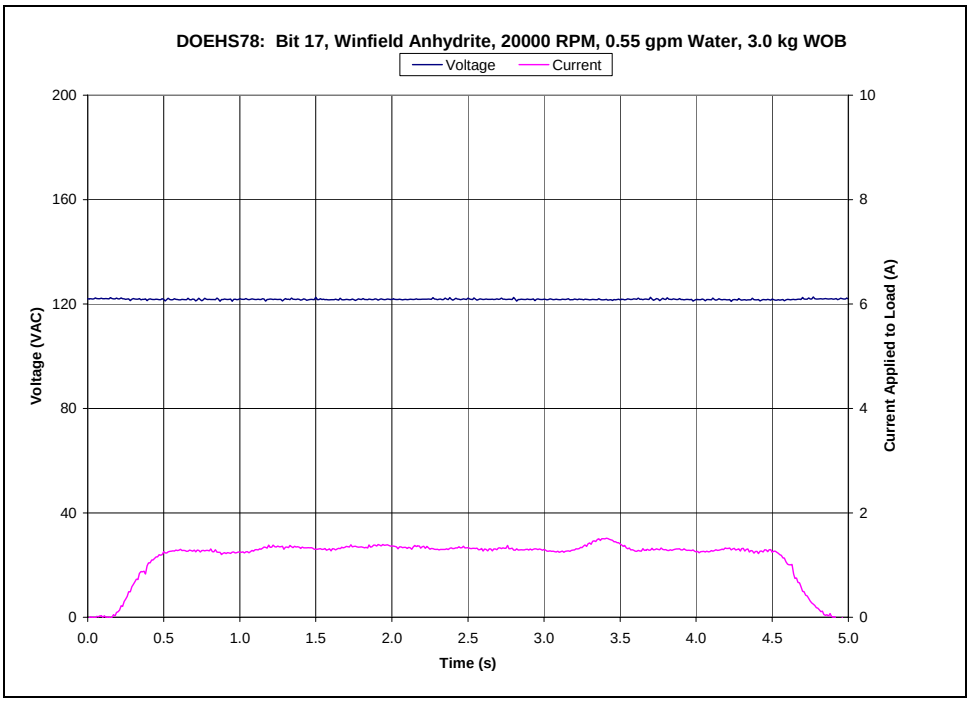


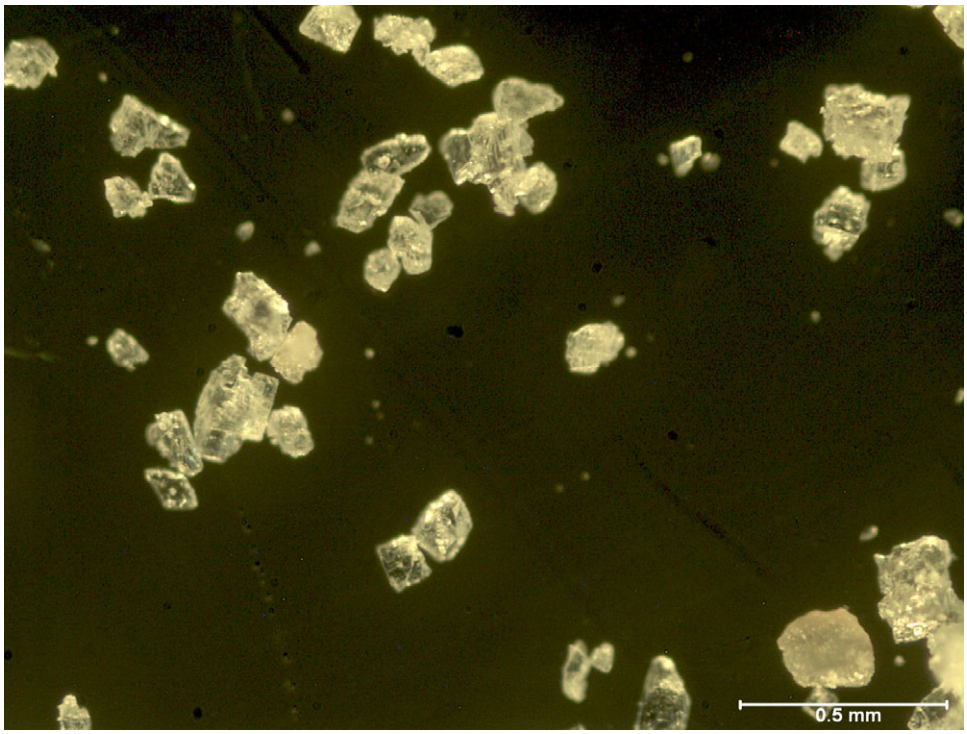


DEAHS78: Summary data and plots and cuttings photographs.

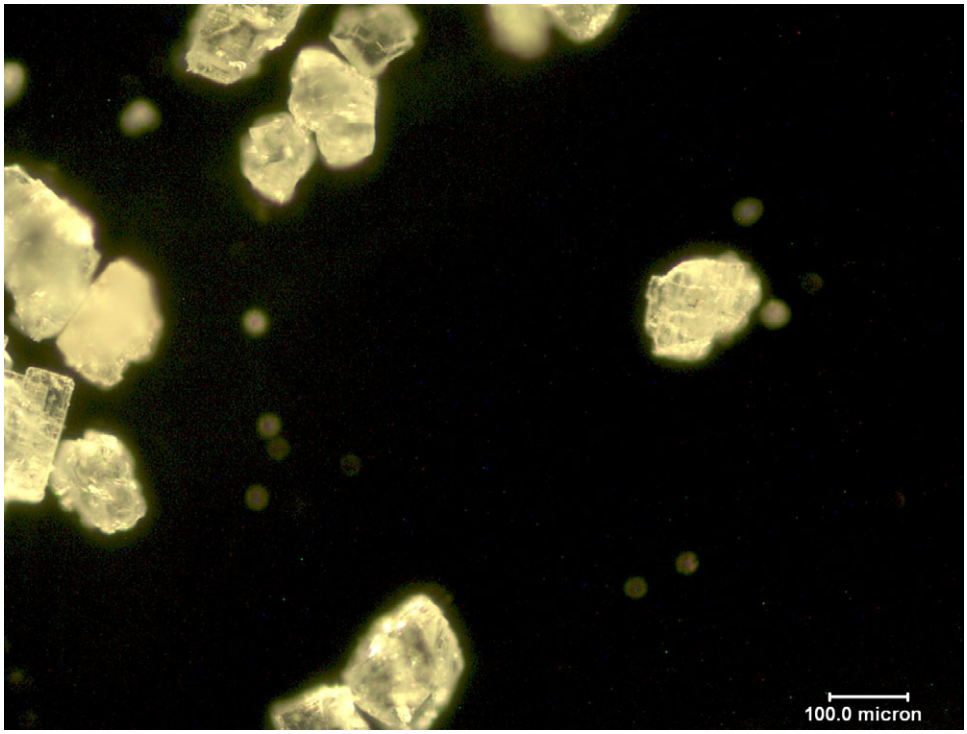
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/29/2005	0.840	0.555	121.8	1.3151	14767	3000	0.0133	0.0427	8859.69	1.77	8861.46	7.33E+08	12.81	0.00017







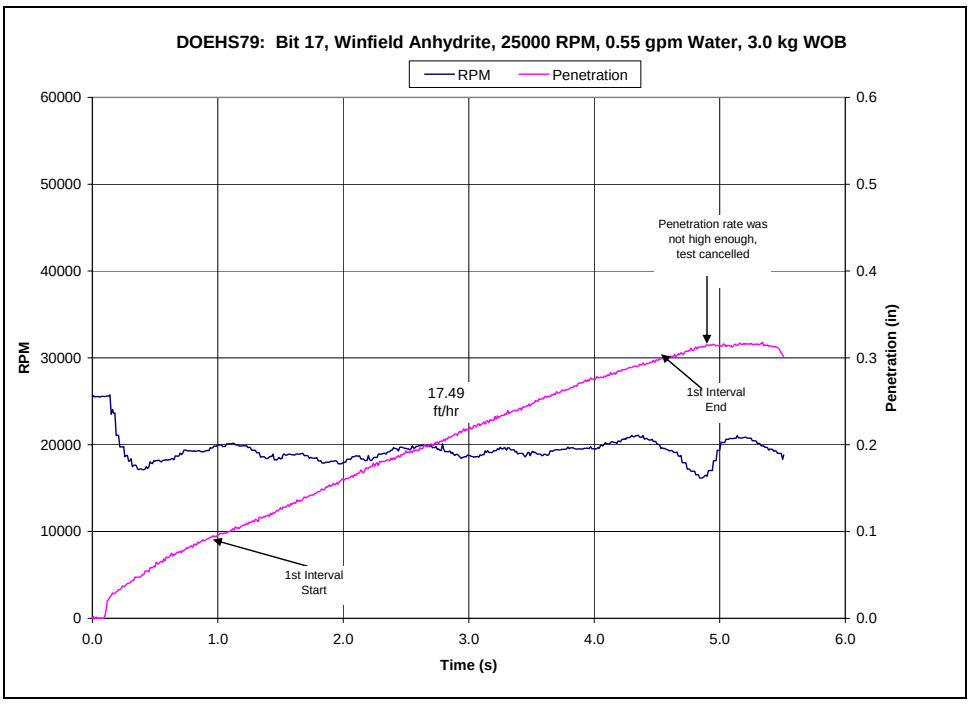
Test DOEH78 Winfield Anhydrite cuttings 20,000 RPM

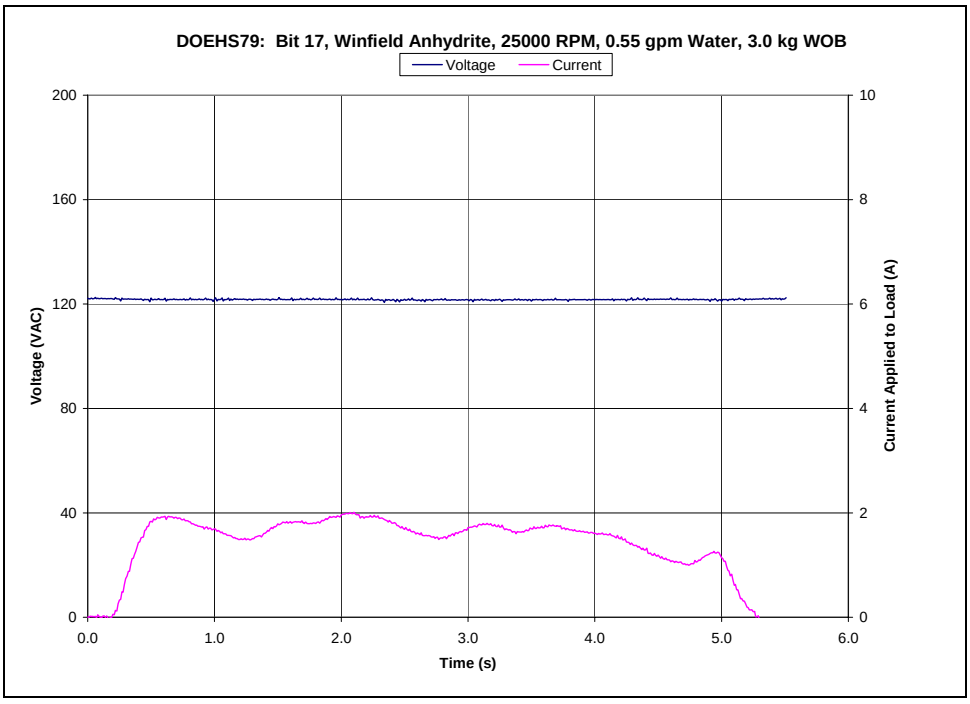


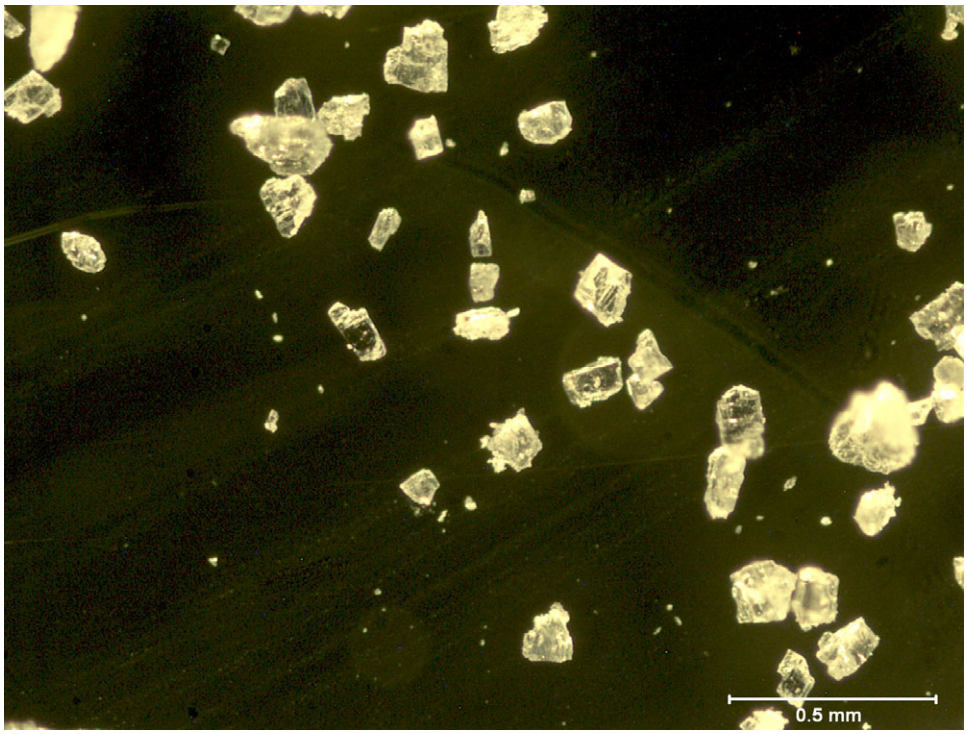
Test DOEH78 Winfield Anhydrite cuttings 20,000 RPM

DEAHS79: Summary data and plots and cuttings photographs.

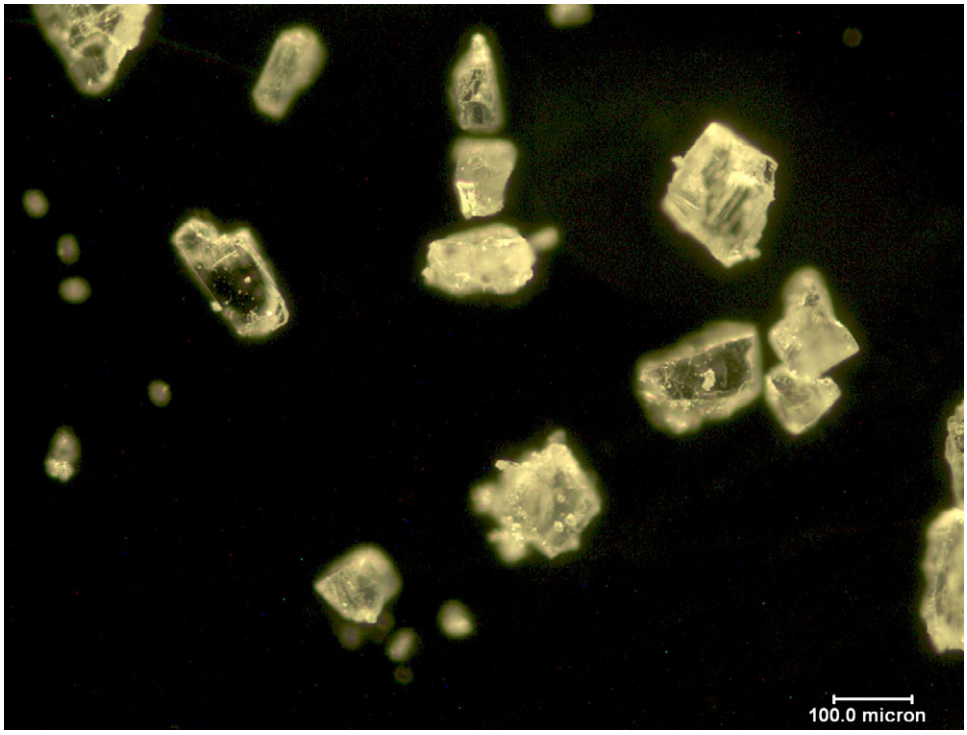
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/29/2005	0.843	0.553	121.7	1.6483	19279	3000	0.0185	0.0583	7981.75	1.73	7983.48	6.60E+08	17.49	0.00018







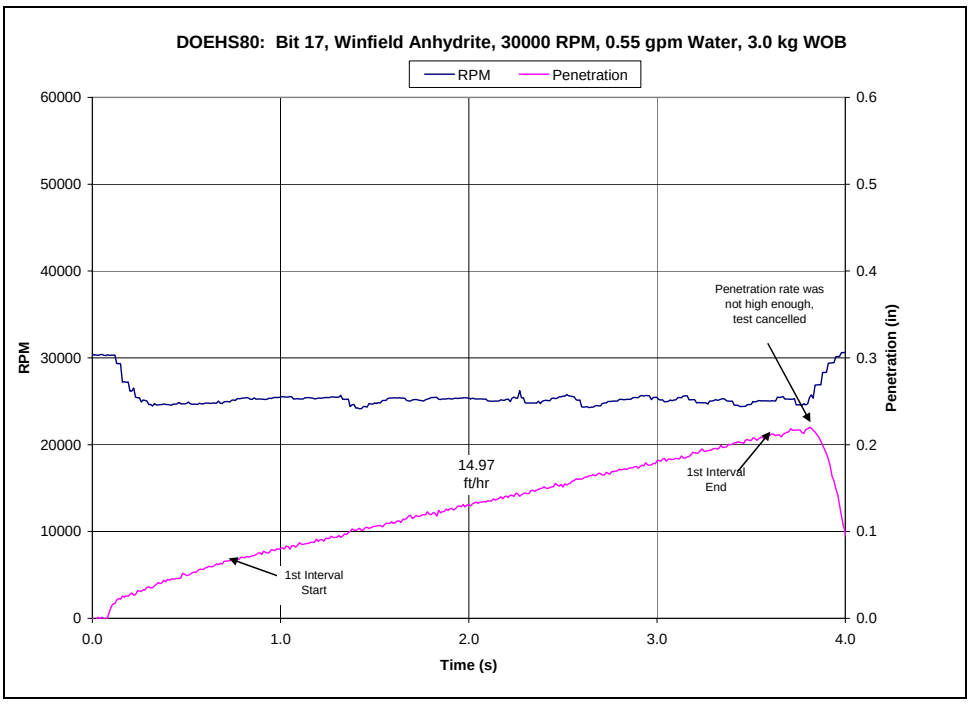
Test DOEH79 Winfield Anhydrite cuttings 25,000 RPM

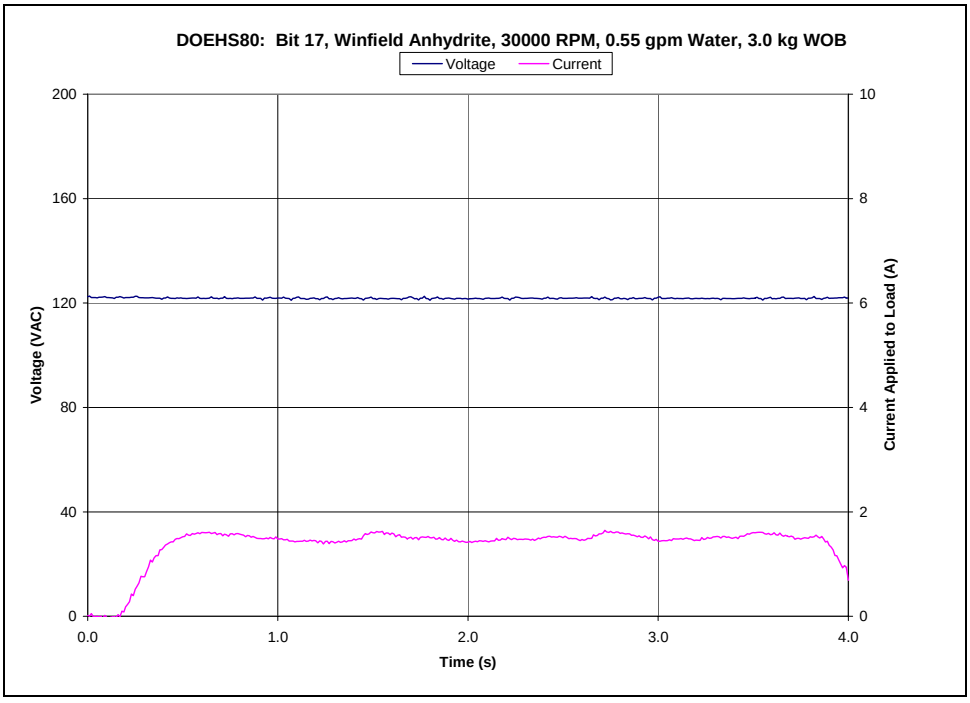


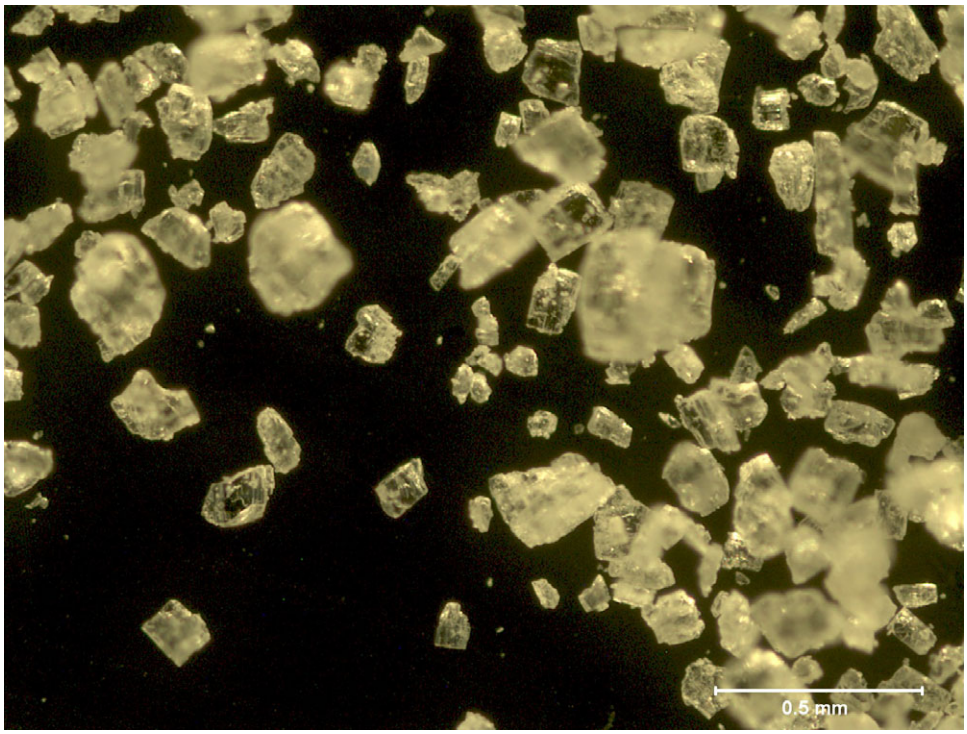
Test DOEH79 Winfield Anhydrite cuttings 25,000 RPM

DEAHS80: Summary data and plots and cuttings photographs.

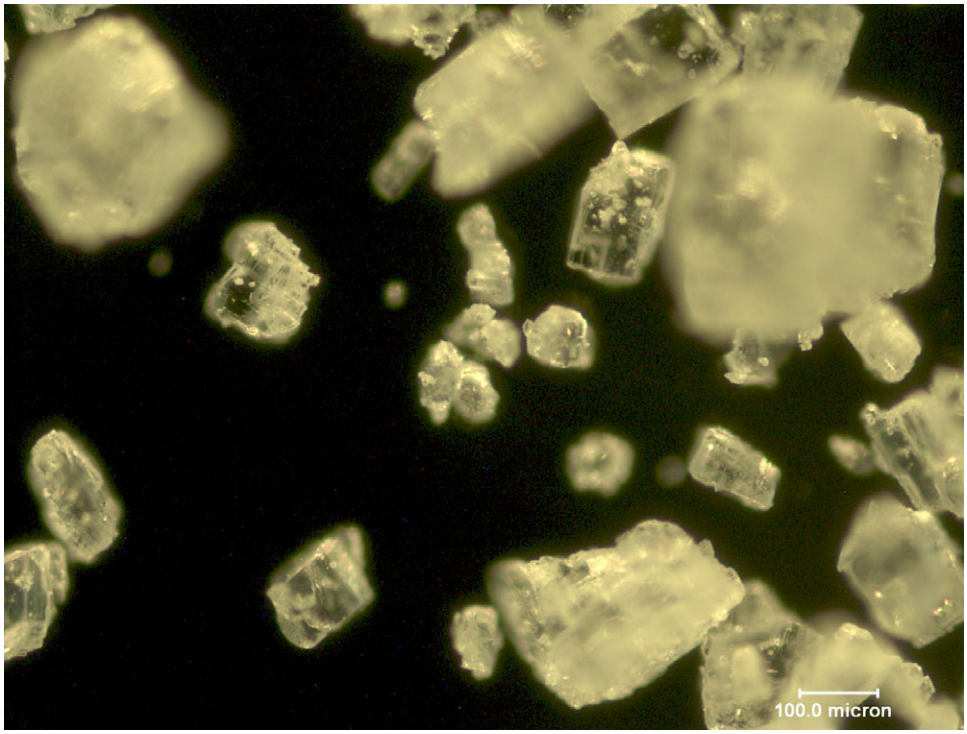
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/29/2005	0.841	0.549	121.8	1.5024	25146	3000	0.0159	0.0499	8484.77	1.73	8486.49	7.02E+08	14.97	0.00012







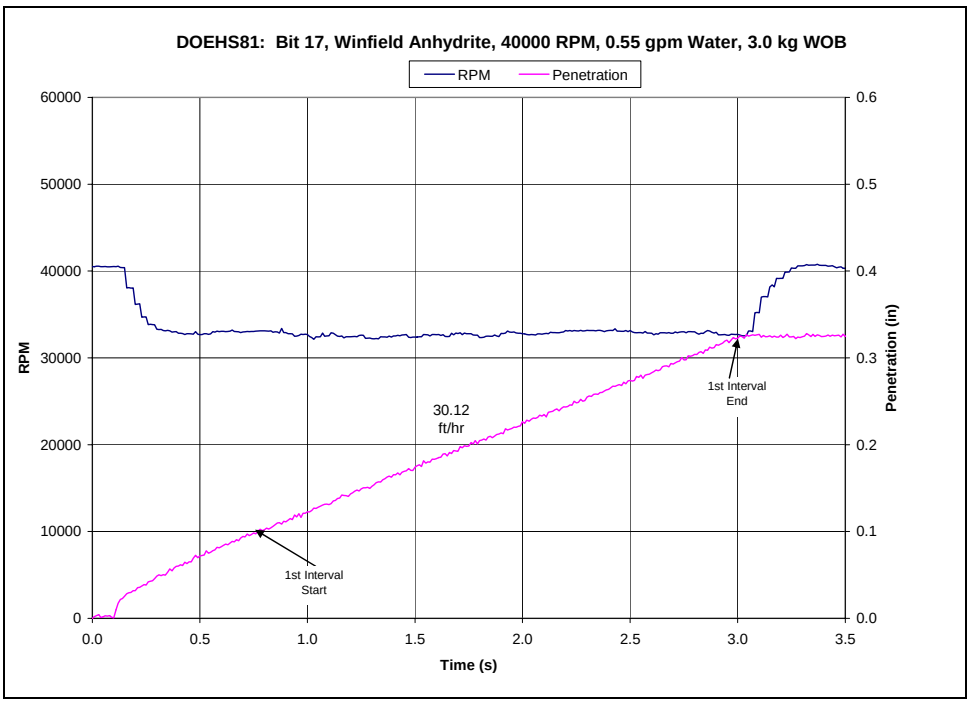
Test DOEH80 Winfield Anhydrite cuttings 30,000 RPM

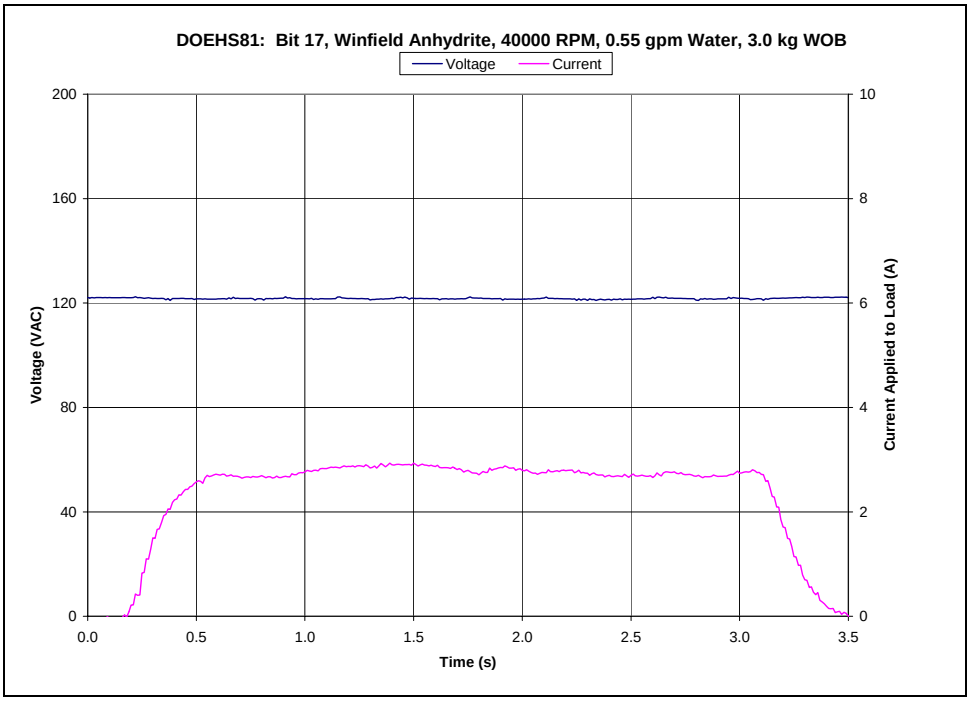


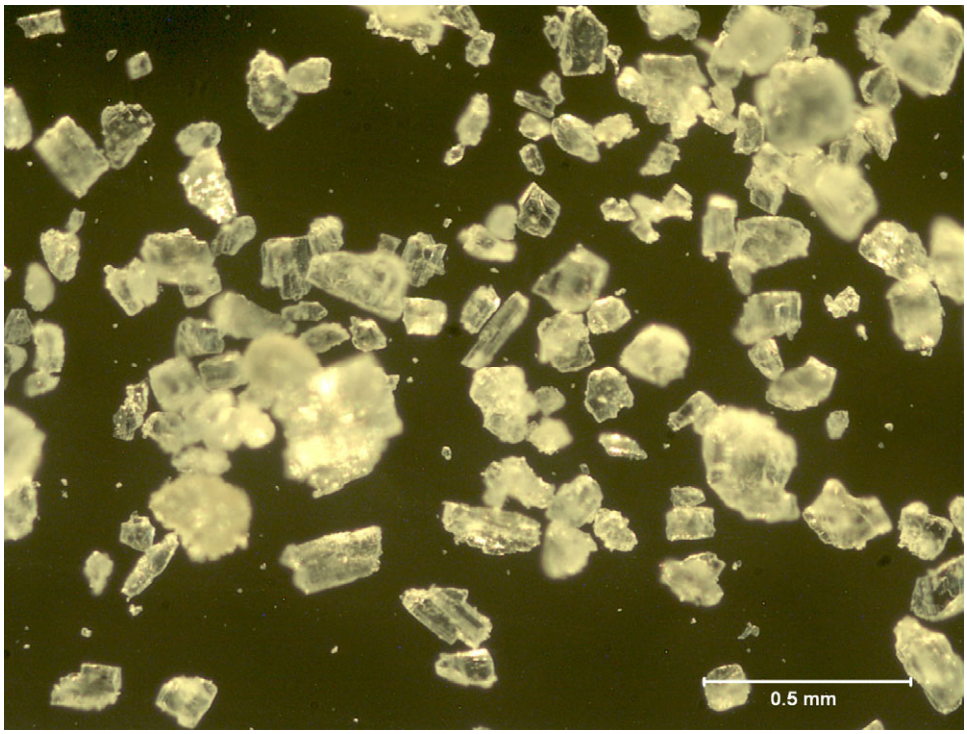
Test DOEH80 Winfield Anhydrite cuttings 30,000 RPM

DEAHS81: Summary data and plots and cuttings photographs.

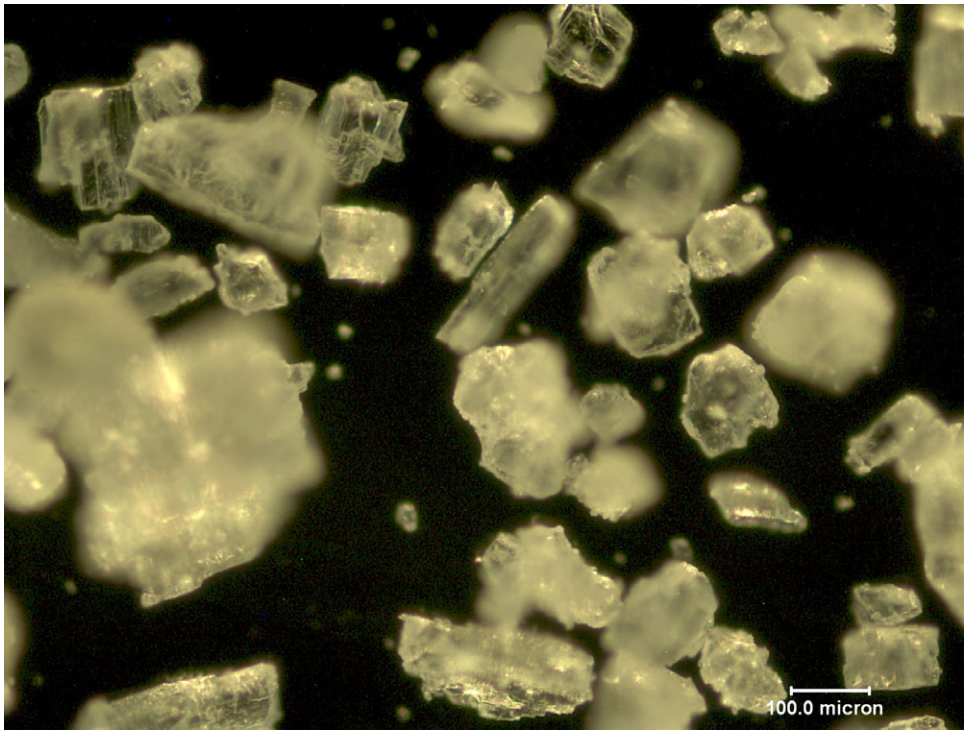
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/29/2005	0.840	0.551	121.7	2.7748	32766	3000	0.0317	0.1004	7855.23	1.75	7856.98	6.49E+08	30.12	0.00018







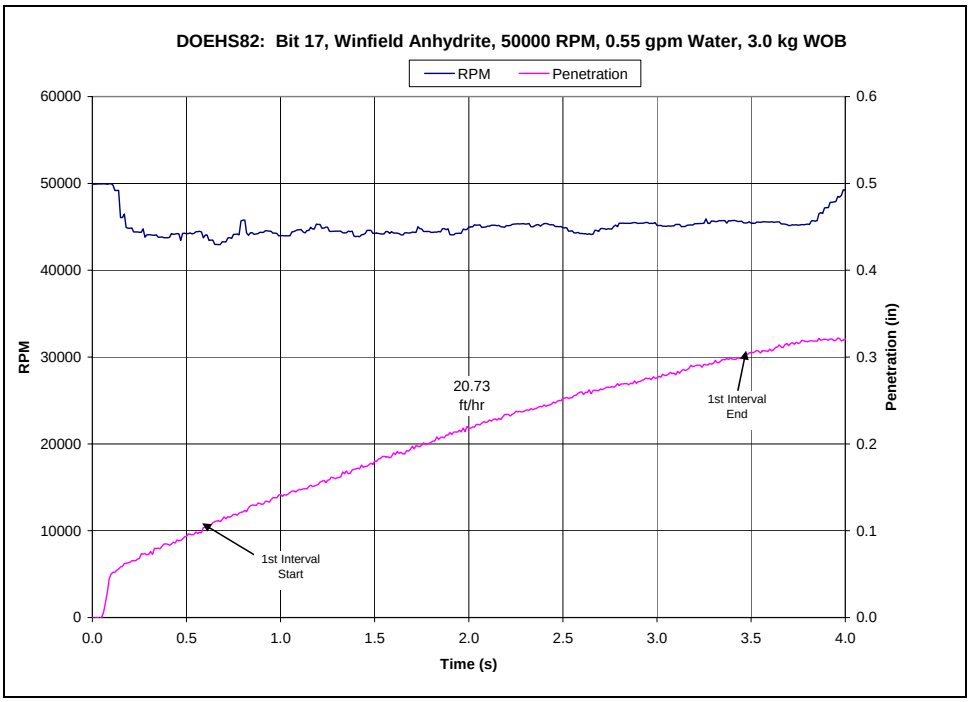
Test DOEH81 Winfield Anhydrite cuttings 40,000 RPM

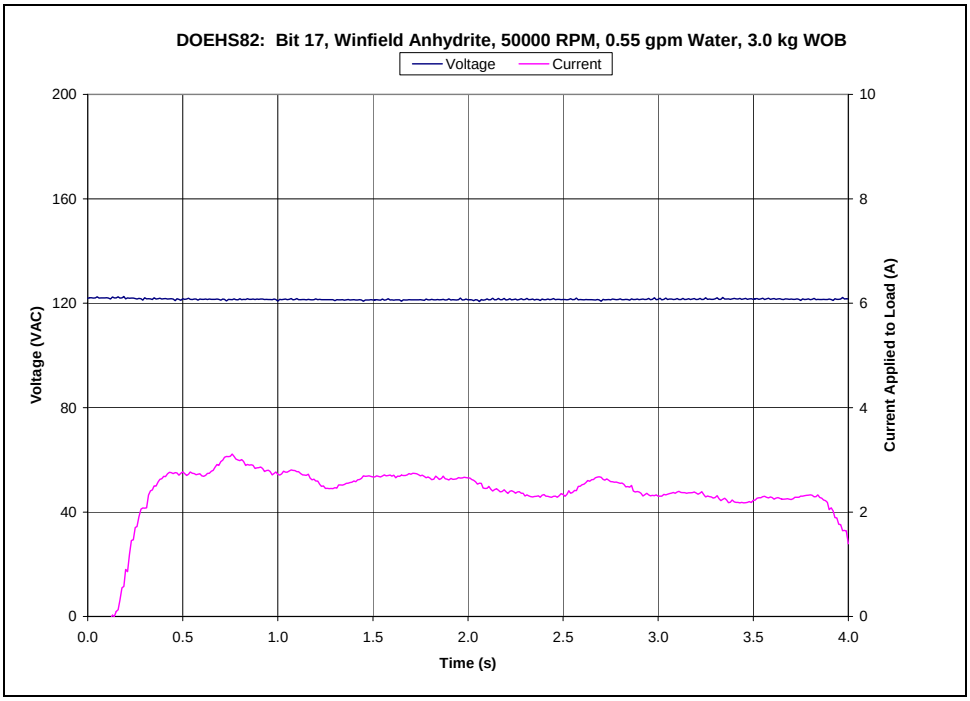


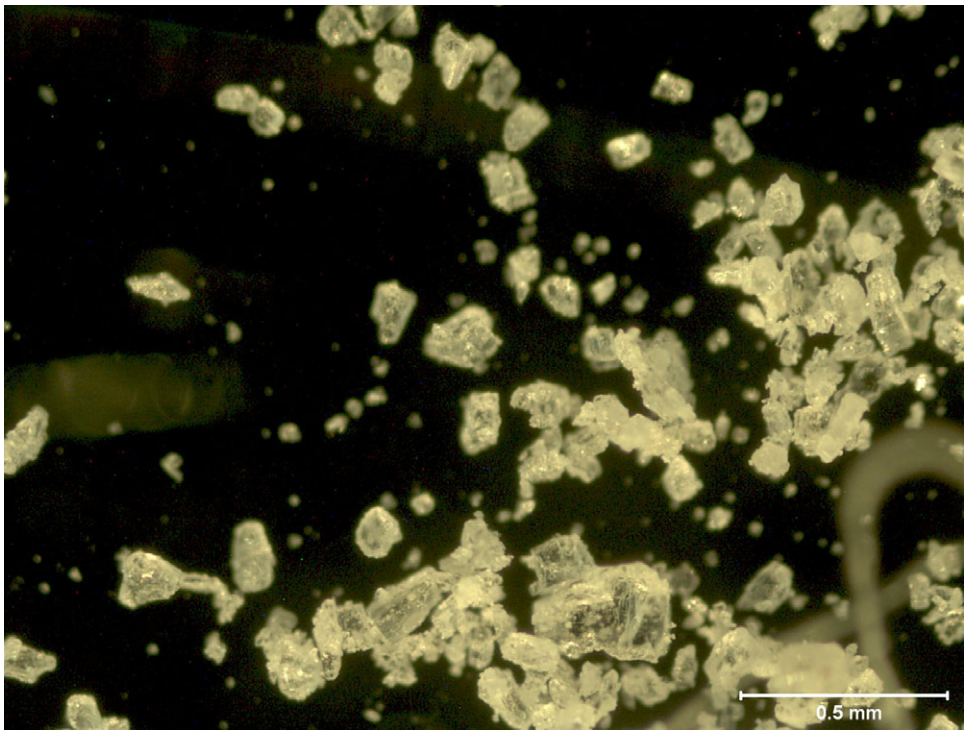
Test DOEH81 Winfield Anhydrite cuttings 40,000 RPM

DEAHS82: Summary data and plots and cuttings photographs.

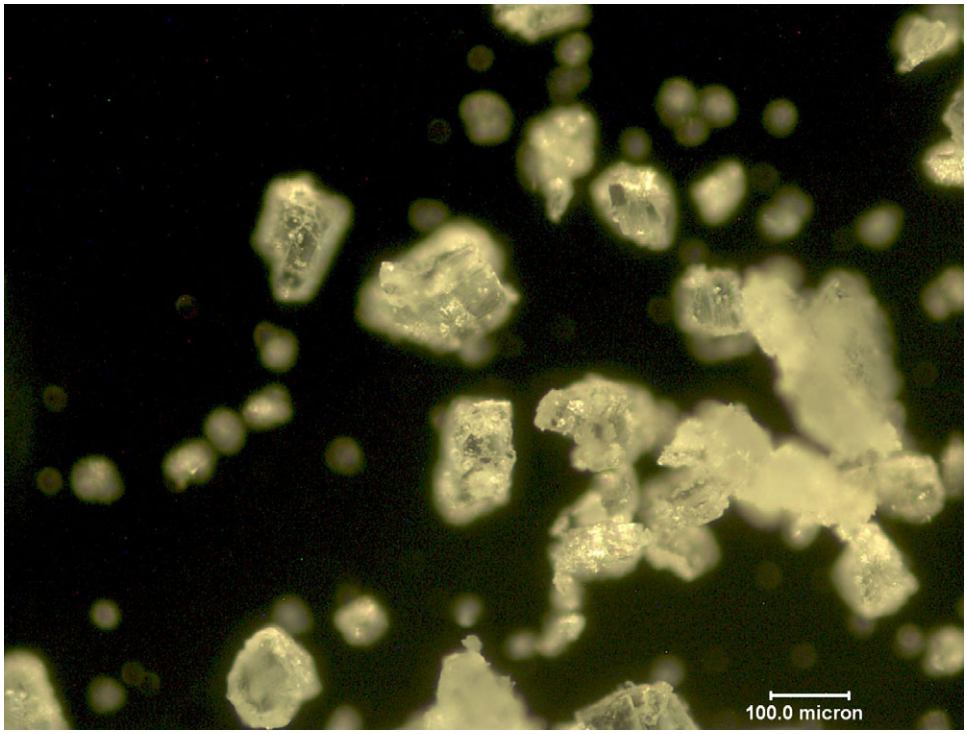
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/29/2005	0.847	0.553	121.5	2.5524	44748	3000	0.0223	0.0691	10236.38	1.71	10238.09	8.46E+08	20.73	0.00009







Test DOEH82 Winfield Anhydrite cuttings 50,000 RPM



Test DOEH82 Winfield Anhydrite cuttings 50,000 RPM

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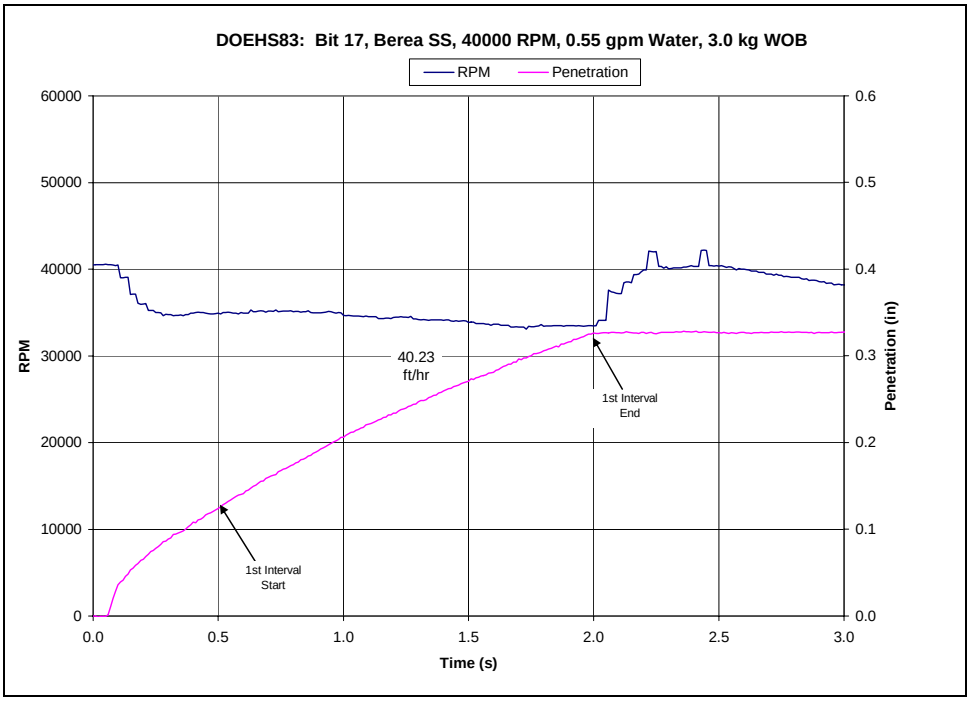
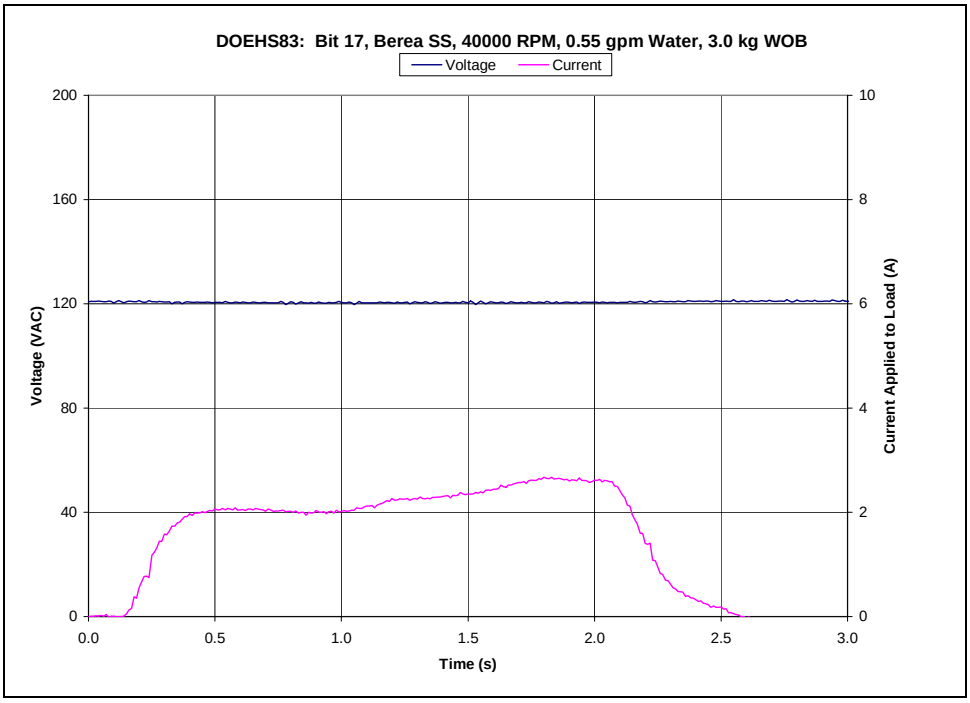
DEAHS83: Summary data and plots and cuttings photographs.

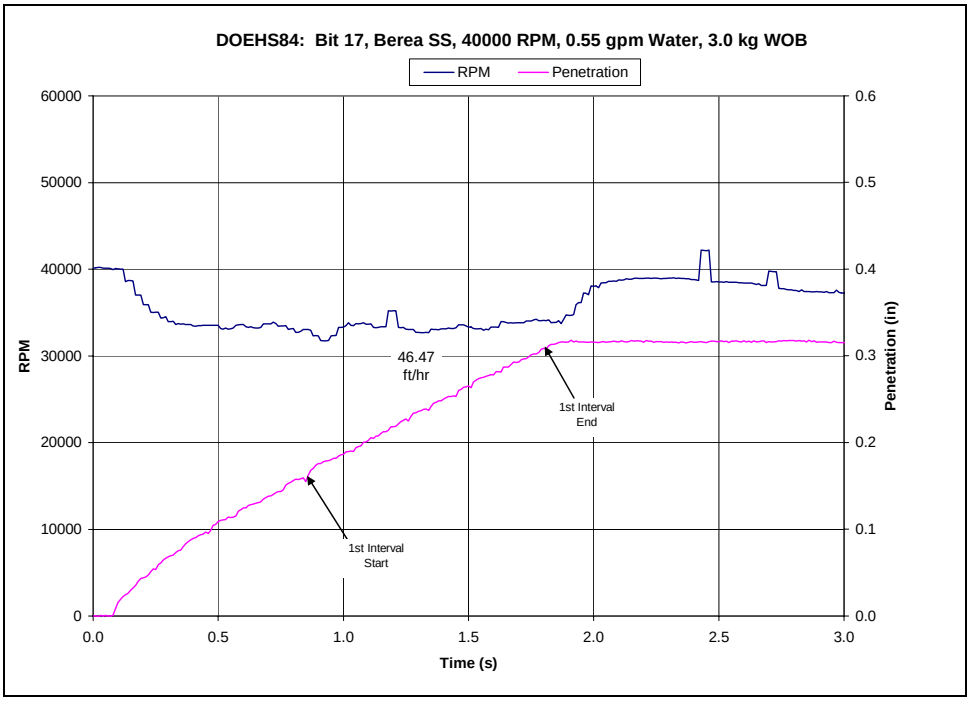
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/29/2005	0.842	0.558	120.5	2.2467	34340	3000	0.0419	0.1341	4768.24	1.77	4770.00	3.94E+08	40.23	0.00023

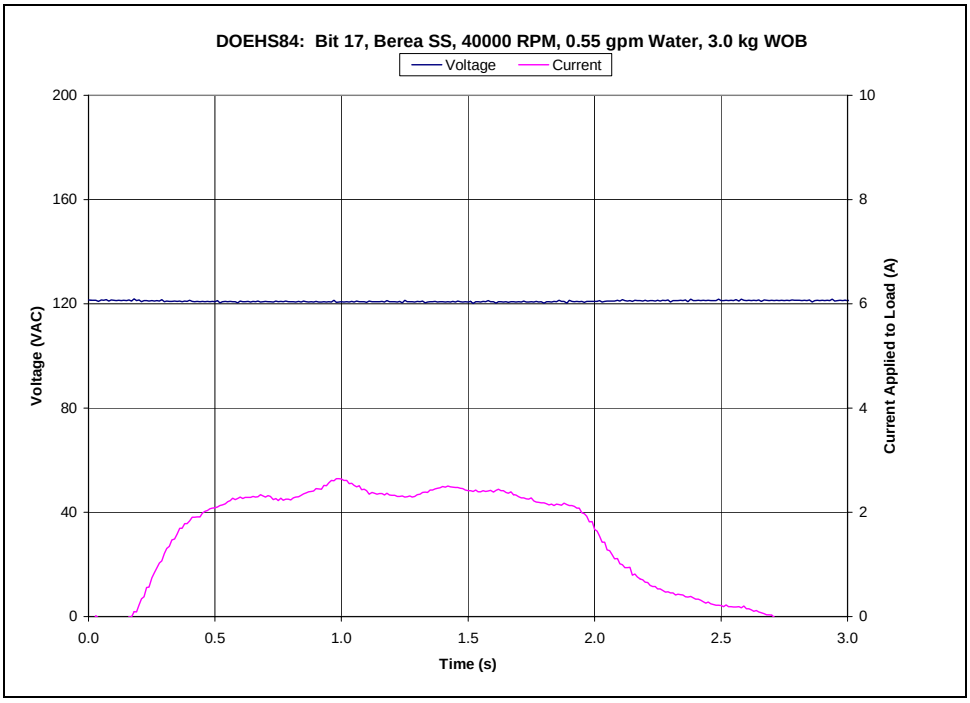




DEAHS84: Summary data and plots and cuttings photographs.

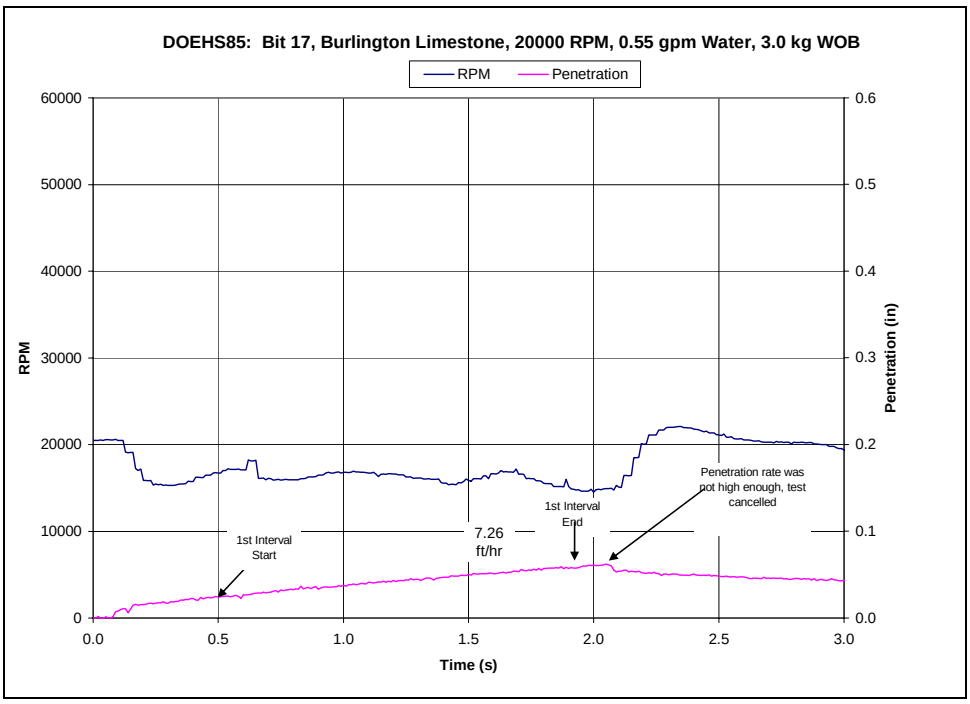
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/29/2005	0.842	0.558	120.8	2.3852	33342	3000	0.0484	0.1549	4393.66	1.77	4395.42	3.63E+08	46.47	0.00028

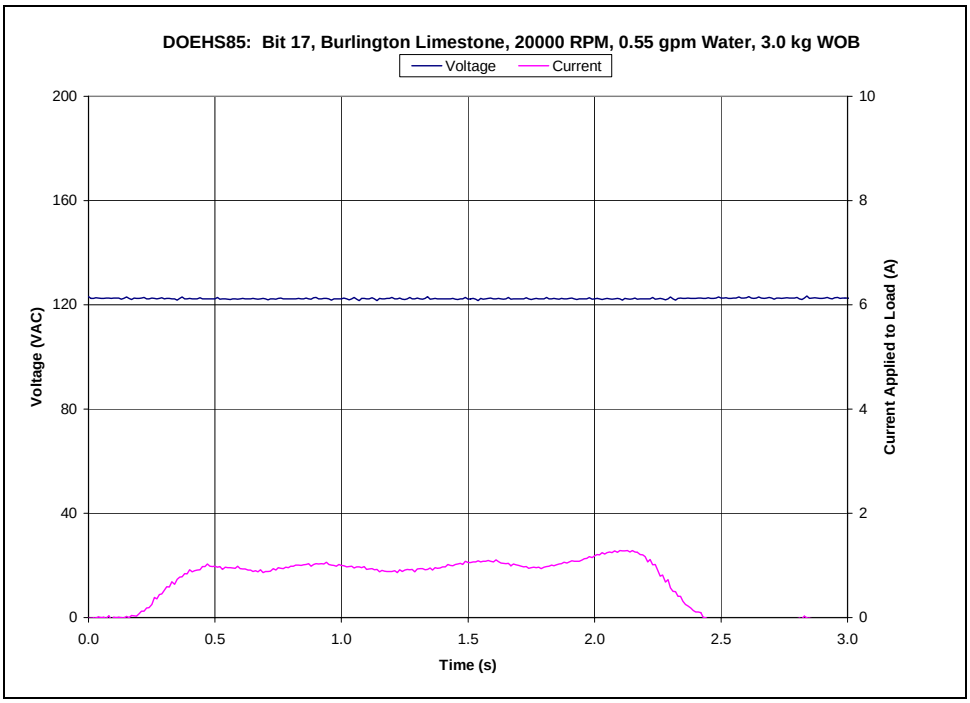


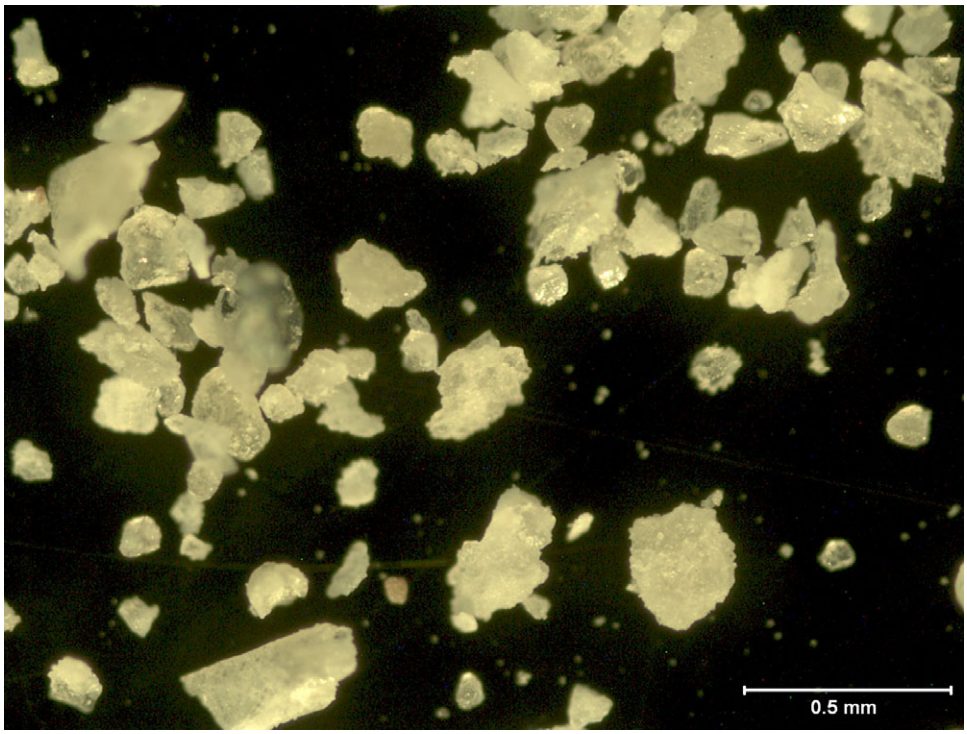


DEAHS85: Summary data and plots and cuttings photographs.

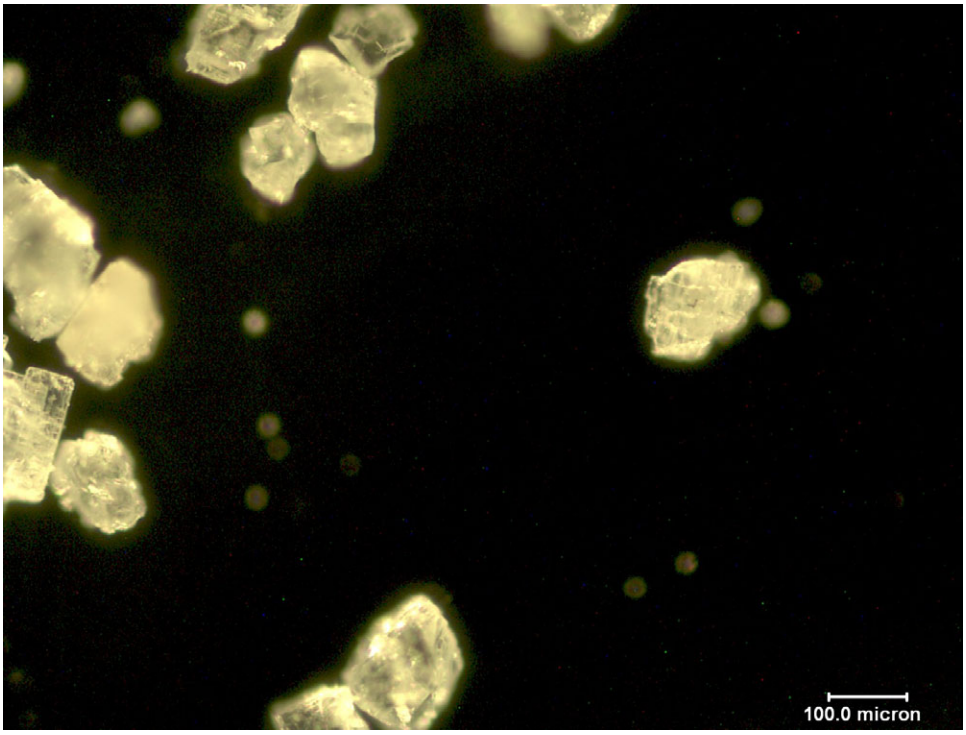
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/29/2005	0.818	0.554	122.3	0.9816	16266	3000	0.0069	0.0242	12866.49	1.94	12868.43	1.06E+09	7.26	0.00009







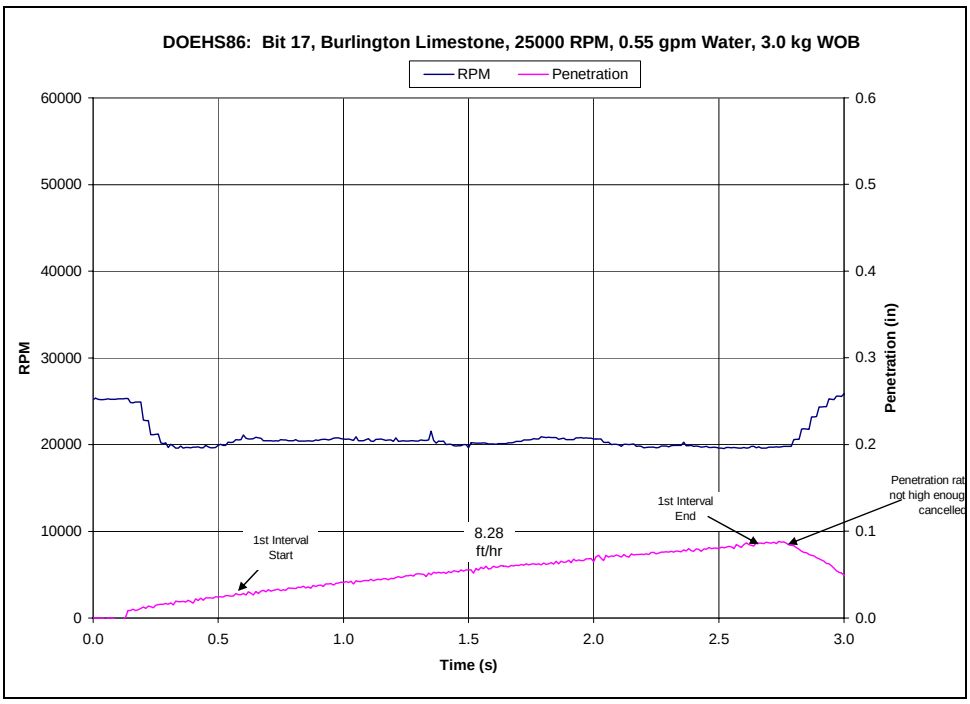
Test DOEH85 Burlington Limestone cuttings 20,000 RPM

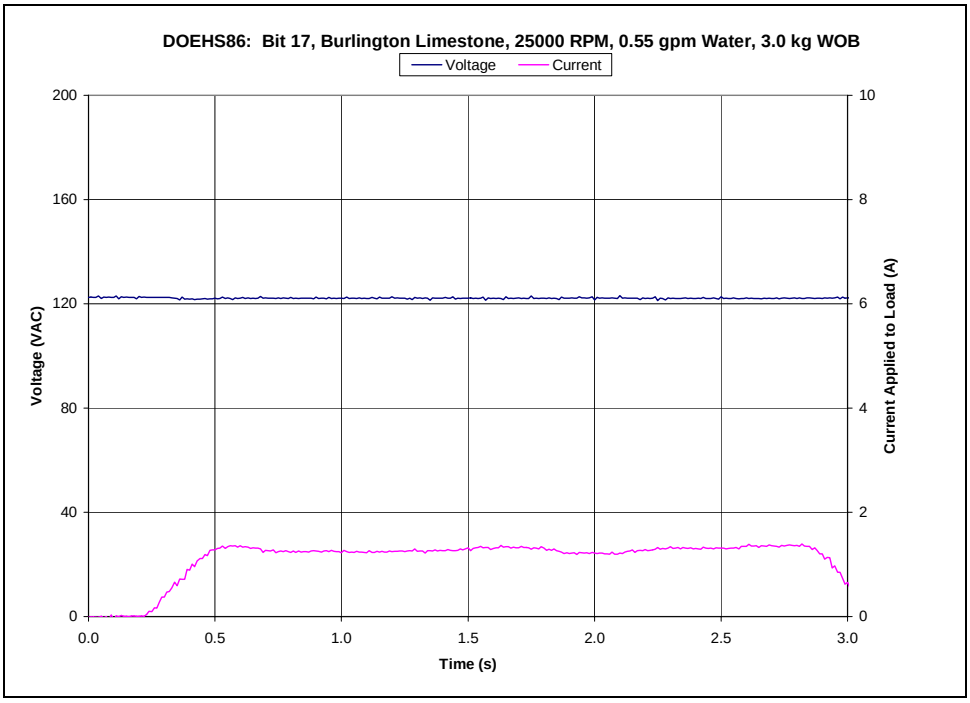


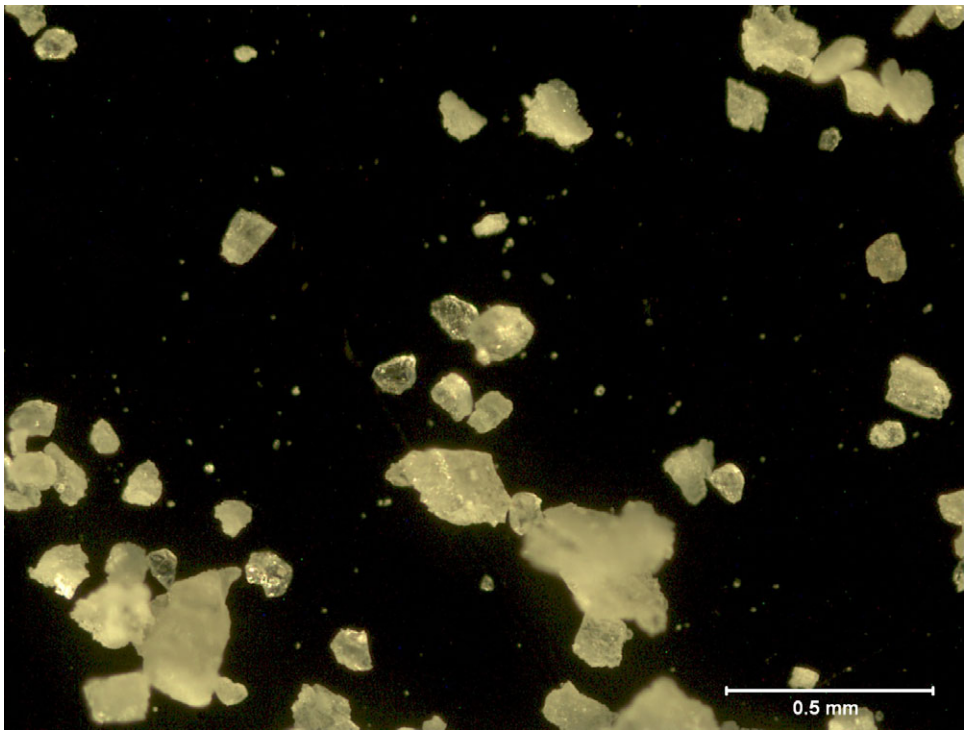
Test DOEH85 Burlington Limestone cuttings 20,000 RPM

DEAHS86: Summary data and plots and cuttings photographs.

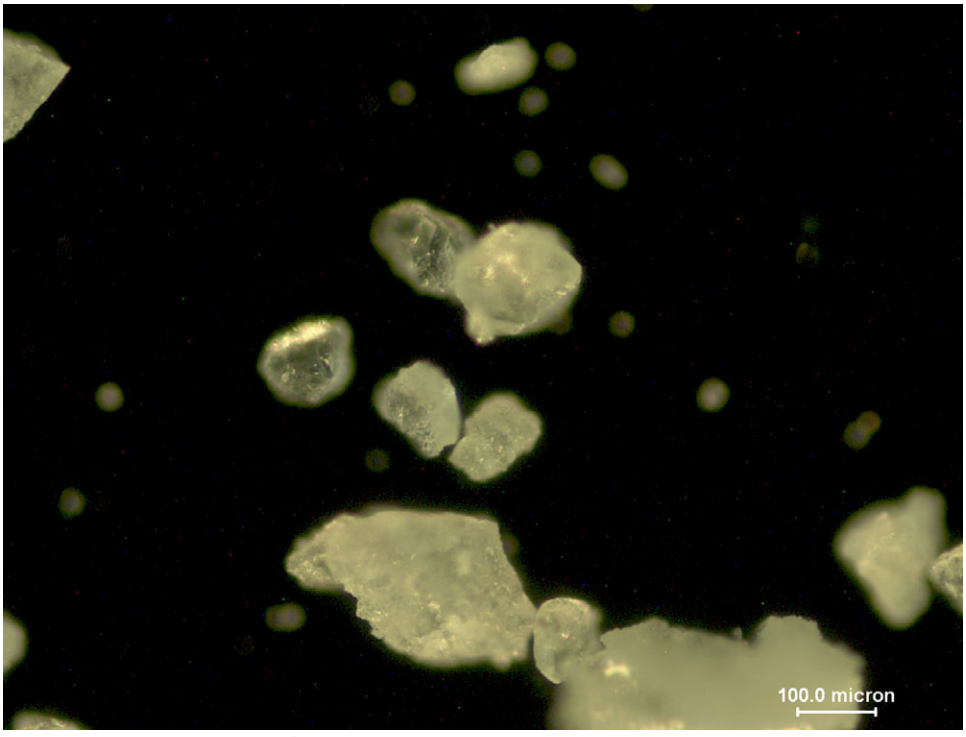
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/29/2005	0.820	0.558	122.2	1.2740	20284	3000	0.0078	0.0276	14669.17	1.94	14671.12	1.21E+09	8.28	0.00008







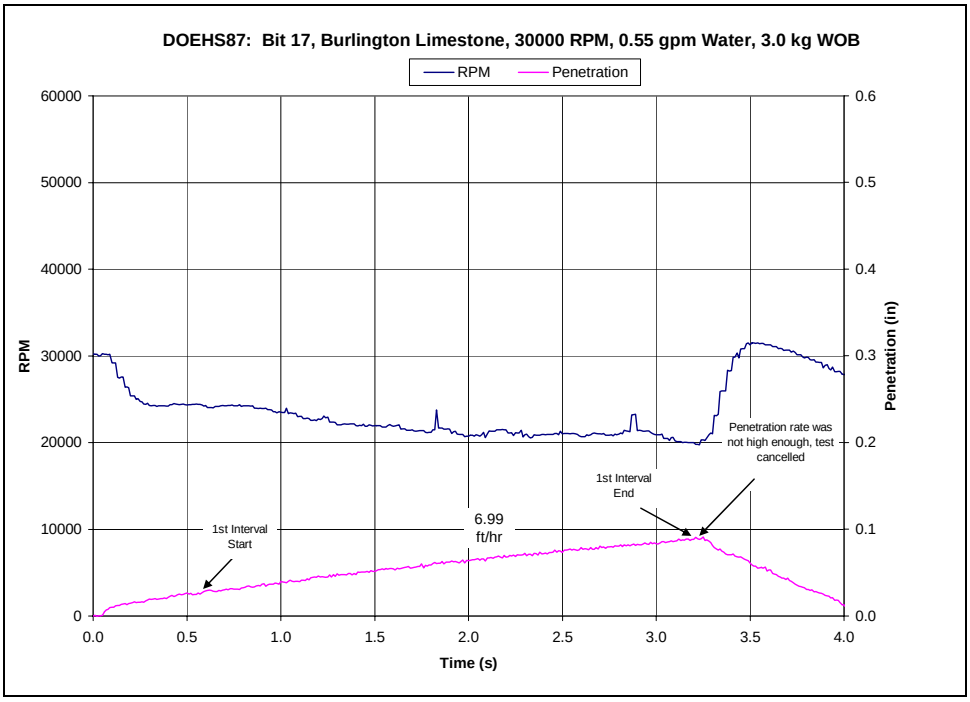
Test DOEH86 Burlington Limestone cuttings 25,000 RPM

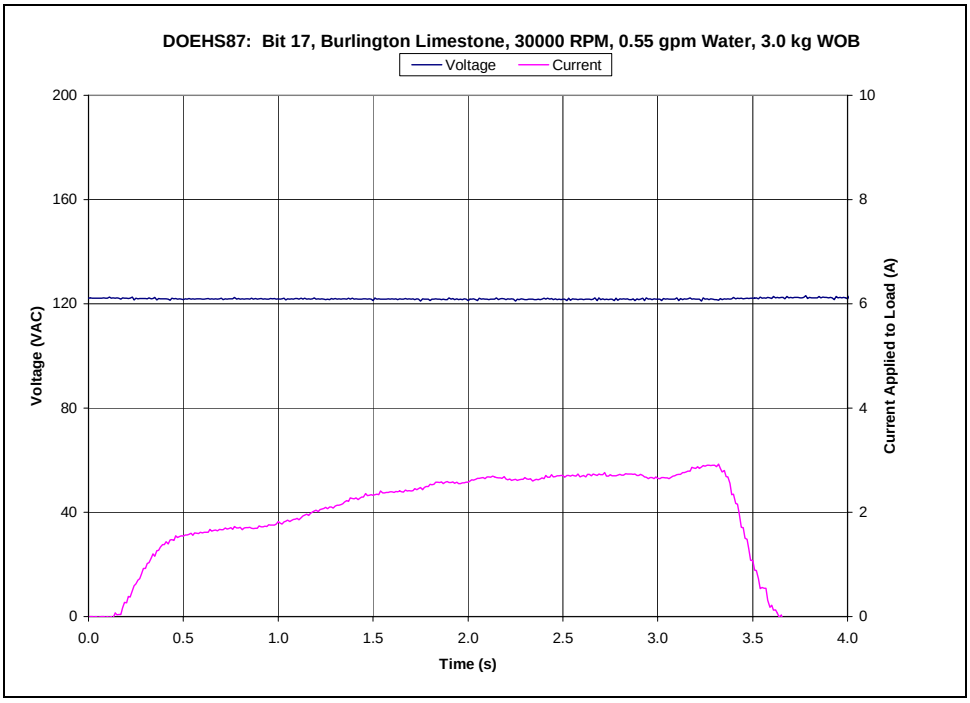


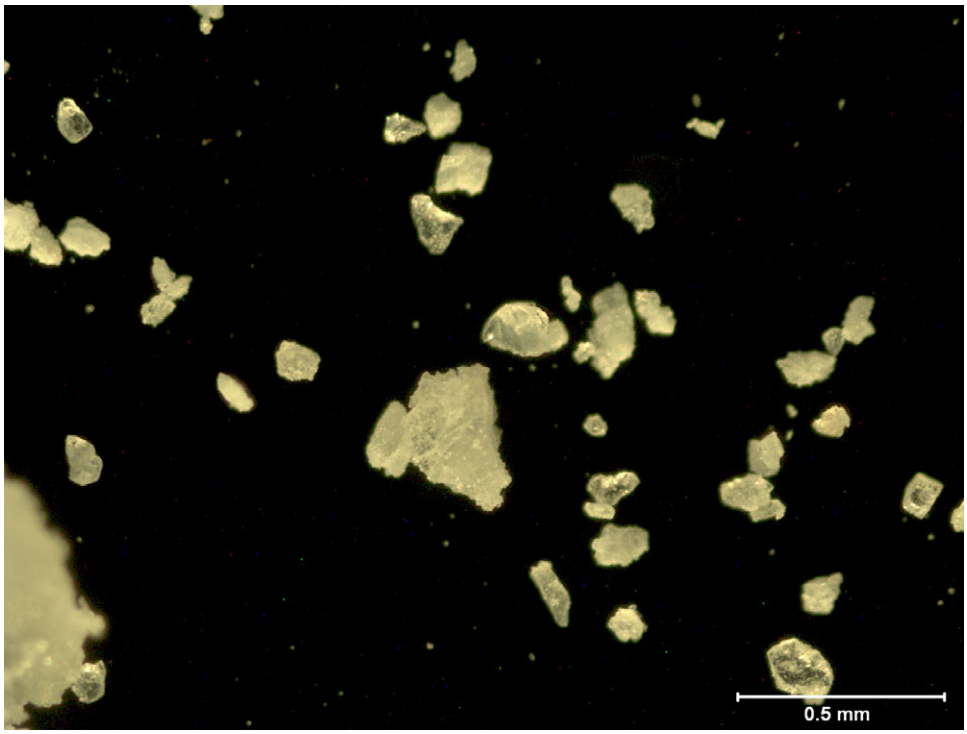
Test DOEH86 Burlington Limestone cuttings 25,000 RPM

DEAHS87: Summary data and plots and cuttings photographs.

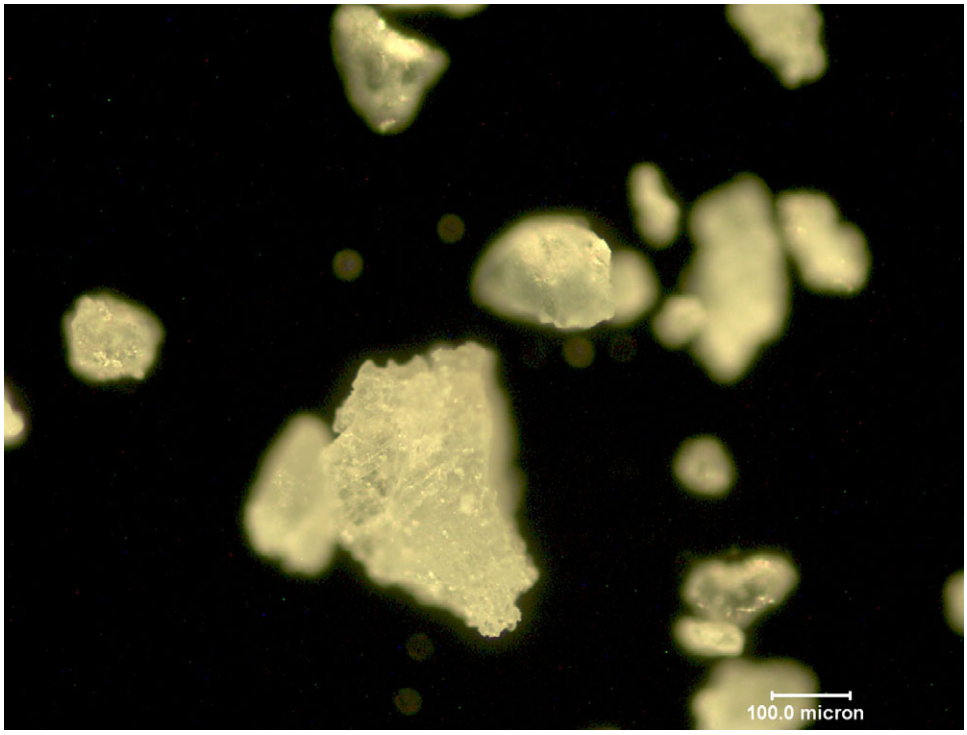
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/29/2005	0.817	0.553	121.8	2.3942	21805	3000	0.0066	0.0233	32501.77	1.94	32503.71	2.69E+09	6.99	0.00006







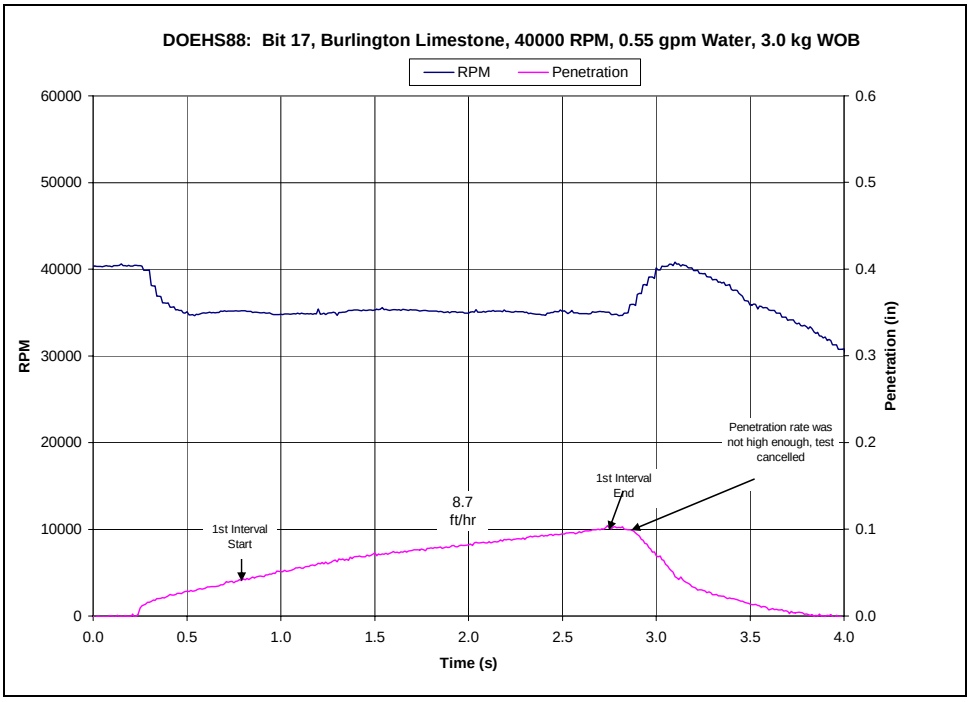
Test DOEH87 Burlington Limestone cuttings 30,000 RPM

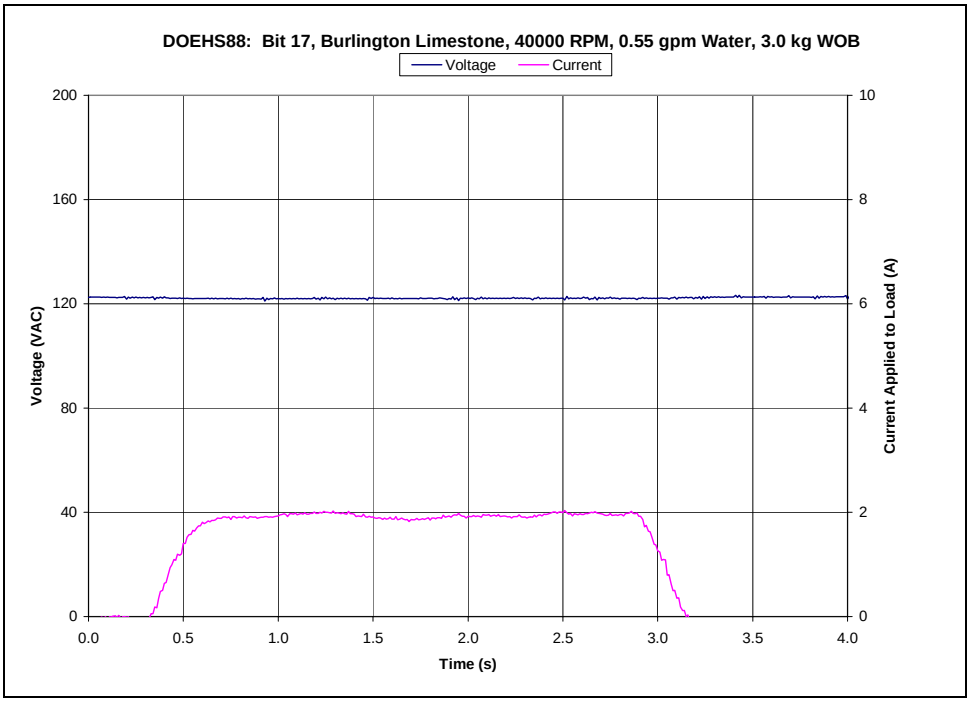


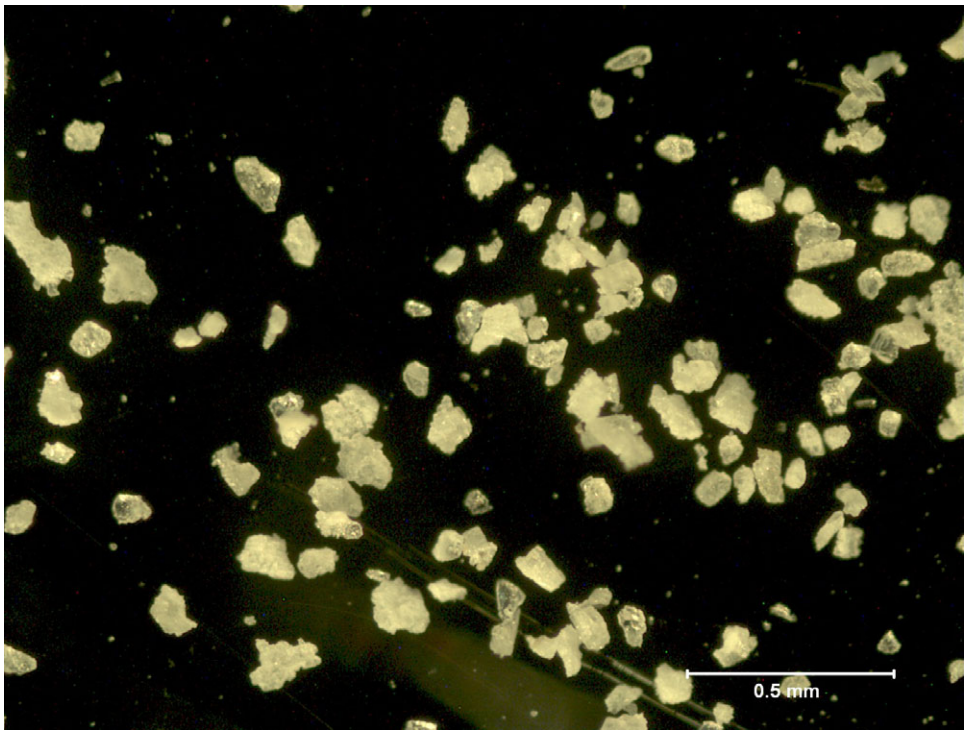
Test DOEH87 Burlington Limestone cuttings 30,000 RPM

DEAHS88: Summary data and plots and cuttings photographs.

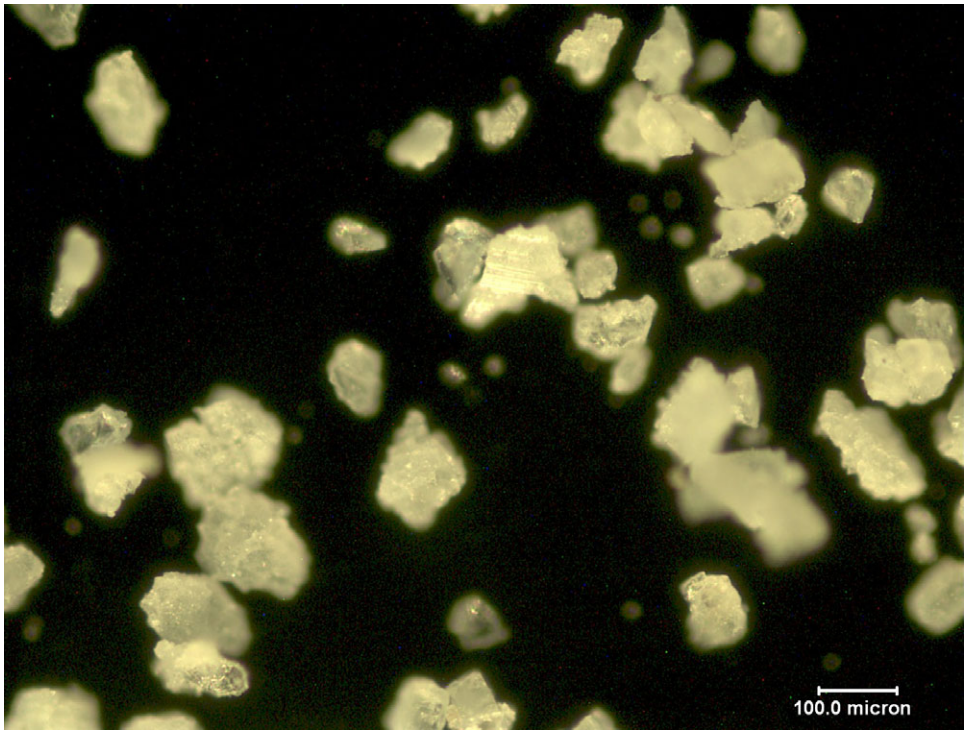
Test Date	Hole OD (in)	Hole ID (In)	Volts (v)	Amps (a)	RPM (rpm)	WOB (gms)	Volume Removal (in3/sec)	ROP (in/sec)	S. E. Rotation (ft-lbs/in3)	S. E. WOB (ft-lbs/in3)	Total S. E. (ft-lbs/in3)	Total S. E. (Joules/m3)	ROP (ft/hr)	(in/rev)
11/29/2005	0.820	0.556	122.1	1.9349	35070	3000	0.0083	0.0290	21054.38	1.93	21056.31	1.74E+09	8.70	0.00005







Test DOEH88 Burlington Limestone cuttings 40,000 RPM



Test DOEH88 Burlington Limestone cuttings 40,000 RPM

APPENDIX C.
Acronyms

ROP – rate of penetration

RPM – rotational speed