DEEPTREK PHASE 1 AND 2 – IMPROVING DEEP DRILLING PERFORMANCE

An Industry/DOE Program to Develop and Benchmark Advanced Diamond Product Drill Bits and HP/HT Drilling Fluids to Significantly Improve Rates of Penetration

Reporting Period Start Date – September 2002

Reporting Period End Date – June 2007

Report Date – January 2008

DOE Award Number – DE-FC26-02NT41657

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ABSTRACT

A deep drilling research program titled "An Industry/DOE Program to Develop and Benchmark Advanced Diamond Product Drill Bits and HP/HT Drilling Fluids to Significantly Improve Rates of Penetration" was conducted at TerraTek's Drilling and Completions Laboratory. Drilling tests were run to simulate deep drilling by using high bore pressures and high confining and overburden stresses. The purpose of this testing was to gain insight into practices that would improve rates of penetration and mechanical specific energy while drilling under high pressure conditions. Thirty-seven test series were run utilizing a variety of drilling parameters which allowed analysis of the performance of drill bits and drilling fluids. Five different drill bit types or styles were tested: four-bladed polycrystalline diamond compact (PDC), 7-bladed PDC in regular and long profile, roller-cone, and impregnated. There were three different rock types used to simulate deep formations: Mancos shale, Carthage marble, and Crab Orchard sandstone. The testing also analyzed various drilling fluids and the extent to which they improved drilling.

The PDC drill bits provided the best performance overall. The impregnated and tungsten carbide insert roller-cone drill bits performed poorly under the conditions chosen. The cesium formate drilling fluid outperformed all other drilling muds when drilling in the Carthage marble and Mancos shale with PDC drill bits. The oil base drilling fluid with manganese tetroxide weighting material provided the best performance when drilling the Crab Orchard sandstone.

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ACKNOWLEDGEMENTS

The support of the U.S. Department of Energy (DOE) under contract DOE DE-FC26-02NT41657 for part of the work is greatly appreciated, as is the support by DOE's project manager Timothy C. Grant. Technical support for this program has been provided by Baker Hughes Drilling Fluids and Hughes Christensen, a Baker Hughes Company. Financial and advisory support has been provided by the following industry participants:

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SUMMARY

An important factor in future gas reserve recovery is the cost to drill a well. This cost is dominated by the rate of rate of penetration (ROP) that becomes increasingly important with increasing depth of drilling. The object of this study is to improve the economics of deep exploration and development using various drill bits and drilling fluids. High confining and overburden pressures and high downhole pressure was used to simulate the conditions of deep, hard rock drilling.

ROP and mechanical specific energy (MSE) were the two factors considered and compared to determine the effectiveness of various drill bits and drilling fluids used in the testing. Three rock types were selected to simulate the deep drilling environment: Carthage marble, Crab Orchard sandstone, and Mancos shale. Generally, the confining pressure and overburden stress were set at 11,000 lb/in^2 and 12,000 lb/in^2, respectively. The borehole pressure was maintained at 10,000 lb/in^2.

It was shown in early testing that rates of penetration observed in deep, high pressure fields were simulated reasonably well in the laboratory.

The results of this study indicate that significant improvements can be made in deep, high pressure drilling by proper selection of drilling fluids and drill bits. The most significant performance was observed when drilling limestone and shale with polycrystalline diamond compact (PDC) drill bits using cesium formate drilling fluid. Improvements were seen when drilling hard sandstone with PDC drill bits using oil-based drilling fluid with manganese tetroxide weighting material and with lighter (11 ppg) water-based drilling fluids.

PDC drill bits provided higher penetration than impregnated or roller cone bits at equivalent weight on bit (WOB) and rotary speed.

Drilling fluids that promote invasion without damaging the formation and drill bit designs that efficiently remove rock and debris from the bottom of the hole promise improved drilling efficiency at high bottomhole pressures.

INTRODUCTION

In September 2002, the U.S. Department of Energy's National Energy Technology Laboratory awarded funding for the test program titled "Optimization of Deep Drilling Performance; Development and Benchmark Testing of Advanced Diamond Product Drill Bits and HP/HT Fluids to Significantly Improve Rates of Penetration" and nicknamed "Deep Trek" to assist in its goal "…to develop technologies that make it economically feasible to produce deep oil and gas reserves…" and "…focus on increasing the overall rate of penetration in deep drilling." This study was conducted in two phases; the first phase established performance baselines with water and water base fluids, and base oil and oil base drilling fluids. The performances of four drill bits were studied during the first phase of testing. Included were a tungsten carbide insert (TCI) drill bit, a diamond impregnated drill bit, a four-bladed polycrystalline diamond compact (PDC) drill bit, and a seven-bladed PDC bit. The bits used in the second phase of testing were somewhat differently than those used in the first phase (except the TCI bit). An additional seven-bladed PDC bit with longer profile was used in Phase 2.

A critical cost in future deep oil and gas recovery is the cost to drill a well. This cost is dominated by the rate of penetration (ROP) that becomes increasingly important with increasing depth. Improving the technology of drilling and increasing the ROP will lower the cost to drill a well. This improves the economics of deep exploration and development, potentially increasing drilling activity, increasing production and supply, lowering the cost to the consumer and improving the economy. The object of this study is to improve the economics of deep exploration and development.

The purpose of this program was to test drill bits and advanced fluids under high pressure conditions which simulated the target formations and drilling conditions. Phase 1 of the proposal was to establish a baseline of performance and provide data upon which to make design improvements. The second phase was to establish improvements in bit and drilling fluid design. A third phase was to take drill bit and drilling fluid improvements to the field to further testing and commercialize the technology, however, funding for a third phase will come totally from industry sources.

There are a number of deep productive horizons in the United States that present deep drilling challenges. The test matrix developed for Deep Trek is based on two of these basins: the Tuscaloosa trend in southern Louisiana and the Arbuckle play in Oklahoma and North Texas. The Tuscaloosa trend is a clastic reservoir with predominately sand/shale sequences up hole. Simulating the drilling in this horizon utilized an oil-based mud system with Crab Orchard sandstone and Mancos Shale. The Arbuckle play is a carbonate reservoir with sequences of carbonate rock, sandstone, and shale above the reservoir. Drilling in this formation was simulated with a water-based mud system and rock of Carthage marble and Crab Orchard sandstone.

This report describes the methods and procedures used, data collected and the findings of the research.

METHODS AND PROCEDURES

Method

Thirty-seven tests were run in a drilling simulator configured to simulate deep drilling conditions. TerraTek's Wellbore Simulator, Figure 1, was used to provide the confining and overburden stresses on large cylinders of rock. The rock was jacketed in a plastic sleeve to prevent pressurized confining fluid from invading the rock. A full-scale laboratory drill rig, Figure 2, supplied the load and rotation to the drill bit. Two mud pumps, Figure 3, were used to supply the drilling fluid at required pressure and flow rates. A description of the equipment and instrumentation used and the test articles follows.

Test Equipment

All DeepTrek Phase 1 and 2 drilling experiments were performed at TerraTek's Drilling and Completions Laboratory under simulated, downhole conditions in the Wellbore Simulator (Figure 1). To simulate the deeper drilling environments desired for the Deep Trek program, it was necessary to circulate at over 10,000 lb/in^2 pressure and generate confining and overburden pressures of 11,000 lb/in^2 and 12,000 lb/in^2. To accomplish this, it was necessary to upgrade equipment and increase the pumping capacity of the Drilling and Completions Laboratory.

Special 15,000 psi delivery pressure pump fluid ends were fitted to TerraTek's 1,600 HP triplex pump (Figure 3). A 15,000 psi pulsation dampener was supplied by Hydril and fitted to a delivery manifold (Figure 3). Drilling fluid was circulated through the drive shaft and bit, up the drilled annulus, and through a cuttings-removal screen (Figure 1). A series of 15,000 psi rated fixed and adjustable chokes were installed in the drilling

Figure 1. The laboratory drill rig used for the Deep Trek drilling program.

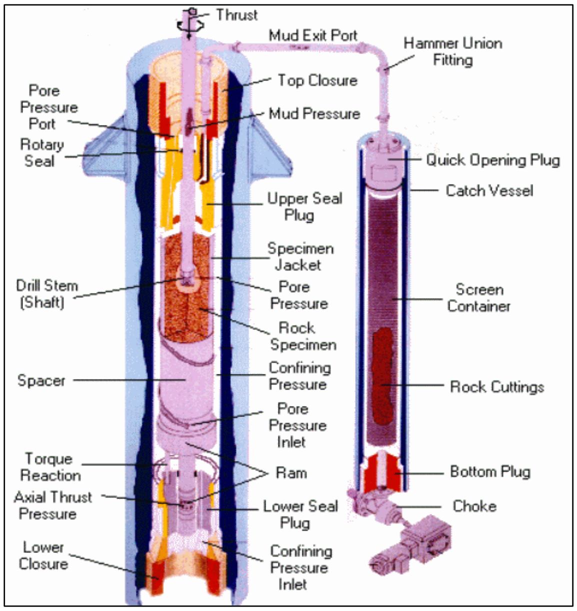

Figure 2. TerraTek's wellbore simulator and cuttings collection system compenents.

fluid return line between the cuttings removal screen and regular adjustable choke to generate the high borehole pressure. As flow rate was increased to the target value of 300 gpm (except for Phase 1 Test 14 with 340 gpm) with the TerraTek 1600 HP Continental Emsco pump (150 gpm supplied) and the Hughes Christensen Sky Brewster 1200 HP pump (150 gpm supplied), the borehole pressure was adjusted to 10,000 psi. The drilling fluid temperature was maintained as constant as possible by passing it through a heat exchanger.

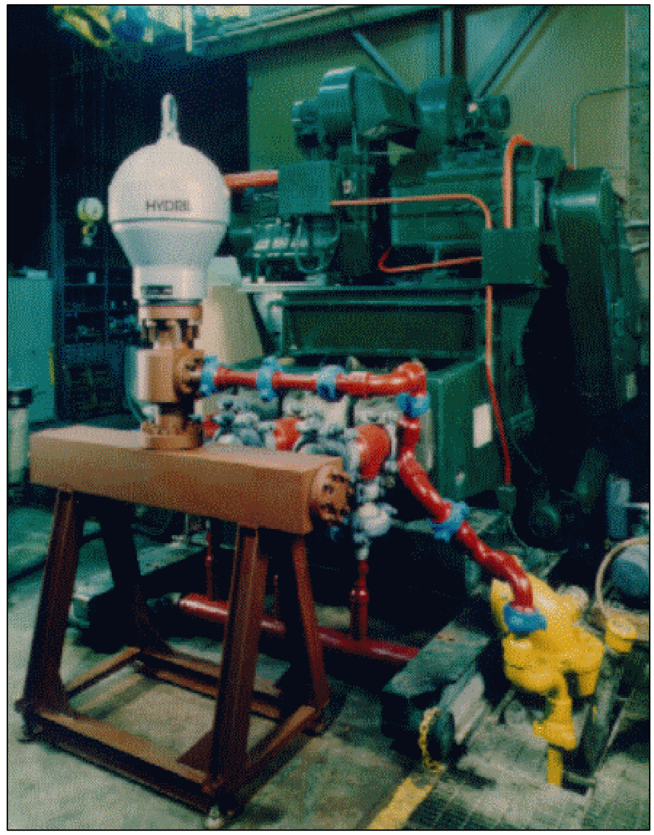

Figure 3. The 1600 hp mud pump fitted with 15,000 psi fluid ends and pulse dampener.

Instrumentation and Data Collection

The Drill Rig and Wellbore Simulator are instrumented with numerous transducers to measure and control the various drilling parameters. The servo-controlled drill rig allows control of WOB during the drilling tests.

The raw data was recorded on a digital computer at low data rates (1 data point per second) and bursts of high rate data (2000 data points per second for 2 seconds). The computer recorded, in standard oilfield units, time (sec), WOB (lb), torque (ft-lb), swivel (stand pipe) pressure (psi), borehole pressure (psi), confining pressure (psi), ram pressure (psi), pump strokes (gpm), rotary speed (rpm), and drilling fluid temperature (degree F). Distance drilled was recorded in inches.

A computer program was used to reduce the low frequency (1 Hz) time-based data from each test into a concise record consisting of one averaged data set for each interval of steady drilling conditions. Typically, each data set contains the following: distance drilled, penetration rate (ft/hr), penetration per revolution (in/rev), torque, WOB, rotary speed, borehole pressure, swivel (stand pipe) pressure, flow rate, drilling fluid temperature, confining pressure, overburden stress, mechanical horsepower, bit pressure drop, bit hydraulic horsepower per square inch of bit area, and summaries of drilling fluid properties. The mechanical and hydraulic parameters are arithmetic averages over the interval. This reduced data table is in Appendix A.

Test Articles

Rock Samples. The rock used in the test program included Crab Orchard sandstone, Mancos shale, and Carthage marble. The properties of the rock selected are provided in Table 1. The strength of the rock when confined is graphed in Figure 4. The rock sample, a cylinder 15 ½-inch diameter by 36" long, is placed on a steel endcap and enclosed inside a urethane rubber jacket. For Phase 1, composite samples, comprising either Crab Orchard sandstone (17”) on the top and

Table 1. Basic properties of the rock drilled during the Deep Trek program.

Rock/Attribute	Property
Carthage Marble	
Bulk density	2.65 g/cm^3
Unconfined compressive strength	16,000 psi
Porosity	1.4%
Permeability	0.002 md
Crab Orchard Sandstone	
Bulk density	2.47 g/cm^3
Unconfined compressive strength	19,000 psi
Porosity	7.0%
Permeability	0.1 md
Mancos Shale	
Bulk density	2.54 g/cm^3
Unconfined compressive strength	9,800 psi
Porosity	7.9%
Permeability	<0.001 md

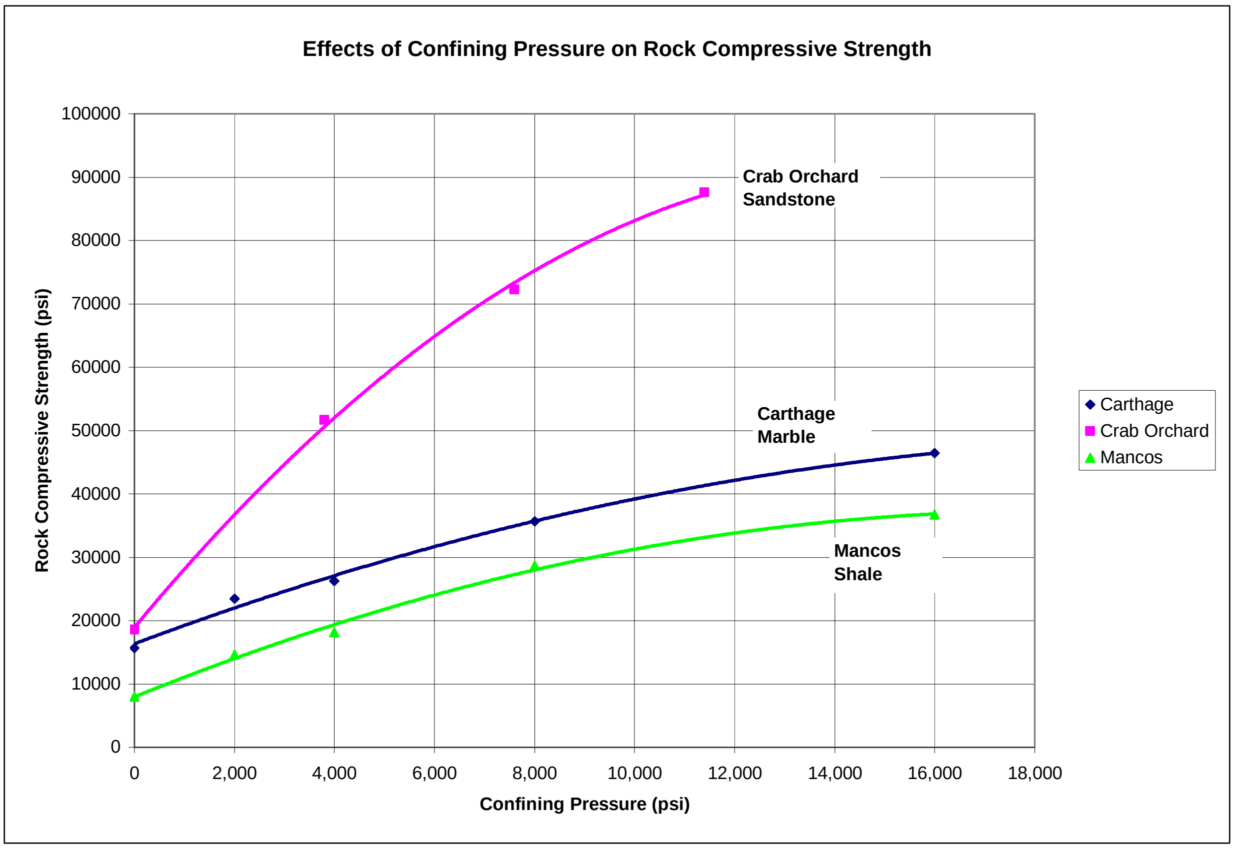

Figure 4. The effects of confining pressure on the rock used in the Deep Trek test program: Crab Orchard sandstone, Carthage marble, and Mancos shale.

Carthage marble (19”) on the bottom or Crab Orchard sandstone (17”) on the top and Mancos shale (19”) on the bottom, were glued together. For Phase 2, five tests were run with full Crab Orchard sandstone samples (36”), two tests were run with Carthage marble (17”)/Crab Orchard sandstone (19”) composite samples, twelve tests were run with Mancos shale (17”)/Carthage marble (19”) composite samples and two tests with composite samples of Mancos shale (13”)/Carthage marble (10”)/Crab Orchard sandstone (13”). The jacketed rock sample is inserted into the Wellbore Simulator as part of the top vessel plug assembly as shown in Figure 5. This contains the rotary drive shaft and drill bit, the high pressure rotary seal, and the vessel seals. The jacketed rock sample is pressurized with confining fluid to simulate the horizontal earth stresses, and an independent piston applies an axial load to the sample to simulate the overburden stress.

Drill Bits. All rock bits tested on the Deep Trek program were 6 inches in diameter, and were supplied by Hughes Christensen. The drill bits used in Phase 1 and Phase 2 are illustrated in Figure 7. Eight of the sixteen Phase 1 tests were run with a 7-blade PDC bit (IADC M333), four with an impregnated bit (M841), two with a four-bladed PDC bit (M121) and two with a carbide

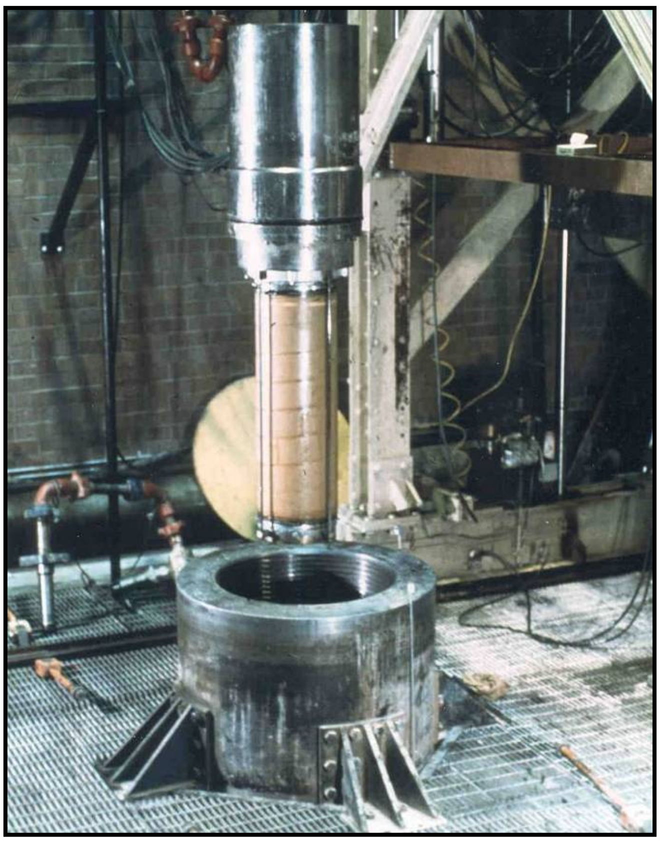

Figure 5. Jacketed rock sample is assembled below the top vessel plug assembly and inserted into the wellbore simulator vessel.

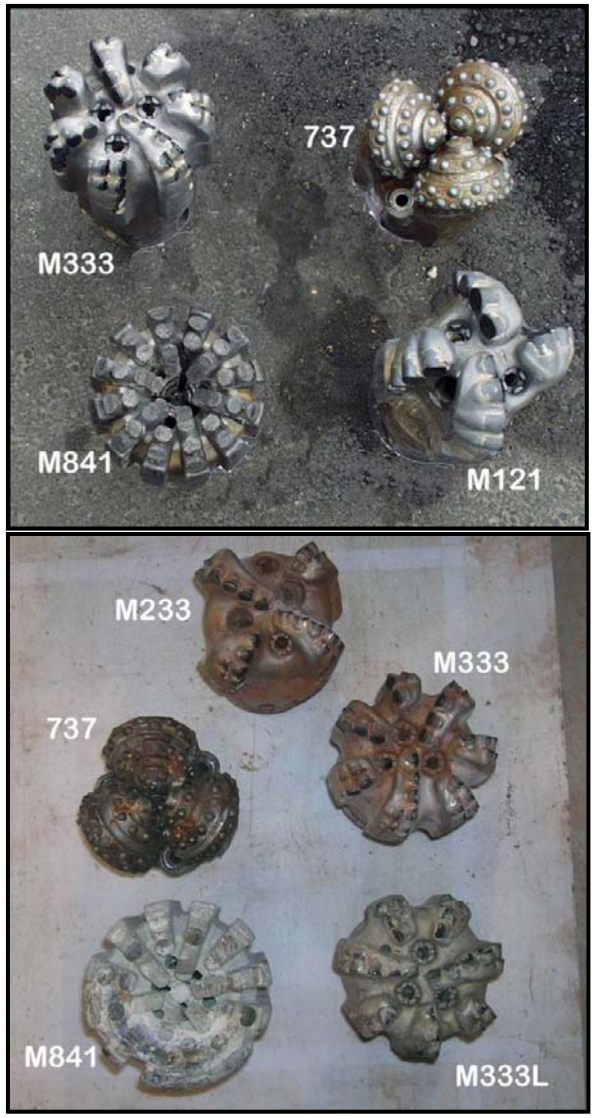

Figure 8. The four drill bits used in Phase 1 Deep Trek testing are shown above and the five drill bits used in Phase 2 are shown below.

insert roller-cone bit (737). Bit nozzles (and port for the M333 bit) were selected to achieve the desired hydraulic horsepower per square inch (HSI). Phase 2 testing included three PDC bits: a 7-blade standard profile (M333) for ten tests, a 7-blade long profile (M333L) for two tests, and a four-bladed (M233) for four tests. A rollercone bit, identical to the one used in Phase 1, was used for two tests and an impregnated bit (M841) with larger grit, softer binder and more aggressive design was used in three tests.

Bit nozzles were selected to achieve the desired HSI.

Drilling Fluids. The drilling fluids used in Phase 1 of the Deep Trek study were based on those typical for drilling the Arbuckle play and Tuscaloosa trend. Phase 2 drilling fluids were selected, based on Phase 1 findings, to improve drilling performance.

The deep Arbuckle is typically drilled with low weight fresh water dispersed drilling fluids. An 11 lb/gal mud weight was selected as representative of much of the deep slow drilling; the formulation is given in Table 2. The Rev Dust was added to simulate drill solids. Clear, solids-free fresh water was also used as a drilling fluid in Test 1 to evaluate the effects of mud-up in the subsequent tests. The properties of the drilling fluid, measured before each test, are given in Table 3 and are consistent with this fluid type.

Table 2. Drilling fluid formulations for Phase 1 testing.

Drilling Fluid	Constituents
11 ppg Water-base	0.86 bbl/bbl water 18 ppb bentonite 2 ppb chrome lignosulfonate 0.5 ppb polymeric thinner 45 ppb RevDust 94.4 ppb barite
12 ppb Oil-base	0.5435 bbl/bbl mineral oil 12 ppb amidoamine emulsifier 2.34 ppb modified FA emulsifier 3.16 ppb lime 4.2 ppb organoclay 0.214 bbl/bbl calcium chloride brine 45 ppb Rev Dust 0.2 ppb XCD (Barazan D) 189.3 ppb barite
16 ppb Oil-base	0.5047 bbl/bbl mineral oil 12 ppb amidoanine emulsifier 4 ppb modified FA emulsifier 3.89 ppb organoclay 0.106 bbl/bbl calcium chloride brine 35 ppb RevDust 425.4 ppb barite

The deep Tuscaloosa trend is almost always drilled with high weight oil-based drilling fluids. A 16 lb/gal mud weight was selected as representative of much of the slow drilling in the deep Tuscaloosa. The Industry Team was also interested in a few tests at 12 lb/gal to evaluate the effect of mud weight. Rev Dust was added to both weighted oil-base fluids to simulate drill solids. Clear, solids-free base-fluid was also used in Test 9 to evaluate the effects of mud-up in

Table 3. Drilling fluid properties at the end of each test of Phase 1.

Water-base Drilling Fluid Properties

	Test Number							
Parameter	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Density, lbm/gal	8.3	11.0	10.9	10.9	10.9	10.9	10.9	10.9
Plastic Viscosity, cps	-	26	19	20	19	19	20	26
Yield Pt[1], lbf/100 ft^2	-	11	10	9	10	10	11	11
Gel Str[2], lbf/100 ft^2	-	4/6	3/14	4/15	3/13	4/14	3/15	4/6
pH	-	9	10	10	10	10	10	9
API FL, cm^3/30 min	-	7.2	5.0	5.2	5.0	5.2	5.0	7.2

Oil-base Drilling Fluid Properties

	Test Number							
Parameter	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Density, lbm/gal	6.7	12.0	12.0	16.0	16.0	16.0	16.0	16.1
Plastic Viscosity, cps	1.6	21	20	27	26	28	26	26
Yield Pt[1], lbf/100 ft^2	-	20	17	18	13	18	16	13
Gel Str[2], lbf/100 ft^2	-	12/23	12/18	10/23	8/19	12/23	11/22	21/26
Electric Stability, volt	-	569	695	800	943	851	884	825

[1] Pt—Point
[2] Str--Strength

later tests. These formulations are listed in Table 2, and Table 3 provides the fluid properties, measured before each test.

The drilling fluids used in Phase 2 were a combination of formulations used in Phase 1 to better compare the performance of new bit designs and/or operating conditions with those used in Phase 1, along with new formulations to explore performance enhancement opportunities either identified in Phase 1 or resulting from field observations. The formulations of all fluids used in Phase 2 are given in Table 4. Table 5 summarizes the properties of the drilling fluids for Phase 2. The logic for the Phase 2 selection of fluids is as follows:

11 lb/gal Fresh Water-Dispersed Mud. This formulation was used in Phase 1 to represent the low mud weight fresh water dispersed drilling fluids commonly used in the deep Arbuckle. The formulation was used in Phase 2 to evaluate the effects of higher WOB than was used in Phase 1 with the carbide insert roller-cone bit.

16 lb/gal Mineral Oil-Based Mud. This formulation was used in Phase 1 to represent the high mud weight non-aqueous/oil-based muds used to drill the deep Tulcaloosa. The formulation was used in Phase 2 to better compare performance of new bit designs with designs from Phase 1 using the same mud formulations.

16 lb/gal Cesium Formate. The results from Phase 1 verified the improved drilling efficiency experienced at the well site using clear fluids. Using cesium formate formulations allowed direct comparison of minimum suspended solids fluids with 16 lb/gal mineral oil-based mud containing a typical concentration of suspended solids for this density. One test was run without the addition of any simulated drill solids and four were run with the addition of 20 lb/bbl simulated drill solids added to the cesium formate.

16 lb/gal Mineral Oil-Based Mud + Lubricant. Unpublished field reports suggest that adding effective lubricants to mineral oil-based muds can increase drilling efficiency and increase ROP.

Table 4. Composition of drilling fluids for Phase 2 testing.

Drilling Fluid	Constituents	Drilling Fluid	Constituents
11-ppg Water-Based	0.86 bbl/bbl water 18 ppb bentonite 2.0 ppb chrome lignosulfonate 0.5 ppb caustic soda 45 ppb RevDust 94.4 ppb barite	**16-ppb Oil-Based with Lubricant Formulation**	0.4547 bbl/bbl mineral oil 12.0 ppb amidoanine emulsifier 4.0 ppb modified FA emulsifier 3.0 ppb lime 3.89 ppb organoclay 0.106 bbl 25% calcium chloride brine 35 ppb RevDust 425.4 ppb barite 5 volume % lubricant
16-ppb Cesium Formate Formulation	0.97 bbl/bbl cesium formate brine 2.0 ppb FLCA 2.0 ppb suspending agent 20.0 ppb calcium carbonate	**16-ppb Oil-Based with Alternate Surfactants Formulation**	0.5609 bbl/bbl mineral oil 8.0 ppb amidoanine emulsifier 1.0 ppb experimental emulsifier 1 1.0 ppb experimental emulsifier 2 3.0 ppb organoclay 0.07 bbl 25% calcium chloride brine 35 ppb RevDust 437.8 ppb barite
16-ppb Cesium Formate Formulation with RevDust	0.95 bbl/bbl cesium formate brine 2.0 ppb FLCA 2.0 ppb suspending agent 20.0 ppb calcium carbonate 20.0 ppb RevDust	**16-ppb Oil-Based with MnO_4 Weight Material**	0.5693 bbl/bbl mineral oil 7.0 ppb amidoanine emulsifier 0.4 ppb wetting agent 1.0 ppb organoclay 0.113 bbl 25% calcium chloride brine 35 ppb RevDust 437.8 ppb manganese tetroxide
16-ppb Oil-Based Formulation	0.5047 bbl/bbl mineral oil 12.0 ppb amidoanine emulsifier 4.0 ppb modified FA emulsifier 3.0 ppb lime 3.89 ppb organoclay 0.106 bbl 25% calcium chloride brine 35 ppb RevDust 425.4 ppb barite		

16 lb/gal Mineral Oil-Based Mud with "Altered" Solids Distribution. An alternate surfactant package was used with the 16 lb/gal oil-based mud in an effort to increase drilling efficiency.

16 lb/gal Manganese Tetroxide Mineral Oil-Based Mud. To counter the detrimental effects of suspended solids on drilling efficiency, it was determined to use manganese tetroxide weighting material, which exhibits higher filtrations rates than conventional weighting material.

Table 5. Drilling fluid properties summary for Phase 2 testing.

Parameter	11-ppg Water-based	16-ppg Cesium Formate	16-ppg Cesium Formate & Solids	16-ppg Oil-based	16-ppg Oil-based with Lubricant	16-ppg Oil-based with Surfractant	16-ppg Oil-based with Manganese Tetroxide
	Drilling Fluid Type						
Density, lbm/gal	10.9	15.7	15.7	16.0	15.9	15.9	15.9
Plastic Viscosity, cps	21	37	37	27	31	32	19
Yield Point, lbf/100 ft^2	13	17	17	16	10	8	13
Gel Strength, lbf/100 ft^2	6/14	4/5	4/5	10/22	12/16	10/17	13/17
pH	10.0	10.5	10.5	-	-	-	-
API Fluid Loss, cm^3/30 min	5.4	1.0	1.0	-	-	-	-
Electrical Stability, v	-	-	-	861	756	1352	600
HPHT Filtrate[1]	-	-	-	2.4	2.4	23	44
Solids Volume, %	14.0	-		33.8	29.6	34.2	30.1
Suspended Phase, volume %	14.0	1.6	3.9	44.4	45.2	41.2	41.4

[1]HPHT Filtrate—High pressure/high temperature filtrate at 150° F

PROCEDURES

The standard laboratory procedures used during Phase 2 testing are provided in Appendix B. This procedure also outlines pre-test and post test procedures. The test matrix and special procedures necessary to accomplish the high pressure drilling are listed below.

Test Matrix

There were 16 tests run during the first phase of Deep Trek. Test 1 used clean water to provide a baseline for idealized conditions. Tests 2 through 8 were run using 11 ppg water base drilling fluids with four different drilling bits. These tests were designed to simulate conditions in the Arbuckle play. Test 9 provided a baseline test, but with the base oil. Tests 10 through 16 were designed to simulate drilling conditions in the Tuscaloosa trend with 12 ppg and 16 ppg oil-base drilling fluids using three drill bit designs. In the second phase of Deep Trek, additional tests were run with the 11 ppg water-base mud with the long profile PDC bit, improved impregnated bit and the roller-cone bit run at much higher WOB. Also, series of tests were run using a 16 ppg clean cesium formate and cesium formate laden with simulated drill solids (Rev Dust), a 16 ppg oil-base fluid, a 16 ppg oil-base fluid with a lubricate additive, a 16 ppg oil-base fluid with an alternate weighting material and a 16 ppg oil-base fluid with manganese tetroxide MnO_4 (Micro Max) weighting material

There were 21 tests run in Phase 2 of the Deep Trek program which utilized specially designed drilling fluids and five drill bits. A water-based mud was used in five tests, cesium formate brine was used in five tests, and oil-base fluids were used for the others. Three PDC bits were tested along with a diamond impregnated bit and a roller-cone bit. The rock tested was the same as during the first phase.

A summary matrix of tests and the target parameters used in the16 Phase 1 tests is provided in Table 6. Table 7 provides the parameters targeted for Phase 2 tests.

Table 6. Test matrix and test parameters for the Deep Trek test program, Phase 1.

Test	Bit[1]	Nozzles[2]	Rock[3]	Mud[4] ppg	HSI[5] Hp/in[2]	WOB[6], klbs	Rotary Speed, rpm
Arbuckle Field Simulation with Water-base Mud							
1	M333	3-12s, port	Composite	8.4	2	5-20	90
2	737	3-15s	Carthage	11	2	10-40	70-110
3	737	3-15s	Crab Orchard	11	2	10-40	70-110
4	M333	2-13s, 14, port	Carthage	11	2	5-20	90-120
5	M333	2-13s, 14, port	Crab Orchard	11	2	5-20	90-120
6	M841	0.97 FA	Carthage	11	0.6	10-40	90-120
7	M841	0.97 FA	Crab Orchard	11	0.6	10-40	90-120
8	M121	2-13s, 12	Composite	11	2	5-20	90
Tuscaloosa Field Simulation with Oil-base Mud							
9	M333	3-12s, port	Composite	6.7	2	5-20	90
10	M333	2-13s, 14, port	Composite	12	2	5-20	90
11	M841	0.97 FA	Composite	12	0.6	20-30	60-250
12	M841	0.97 FA	Composite	16	0.9	20-30	60-250
13	M333	3-15s, port	Composite	16	2	5-20	90
14	M333	2-12s, 13, port	Composite	16	5	5-20	90
15	M121	3-14s, 15	Composite	16	2	5-20	90
16	M333	3-15s, port	Composite	16	2	5-20	90

1 Bits included: 7-blade PDC bit (M333), impregnated bit (M841), four-bladed PDC bit (M121), and a carbide insert roller-cone bit (737).
2 Bit nozzle diameters are in 32s of an inch. There is a fixed port on the M333 bit. The impregnated bit has a flow area (FA) (square inches).
3 Composite rock: Crab Orchard sandstone and Carthage marble in the Arbuckle field simulation and Crab Orchard sandstone and Mancos shale in the Tuscaloosa field simulation.
4 ppg—pounds/gallon. The muds are water (8.4 ppg), 11 ppg water-base mud, mineral oil (6.7 ppg) and 12 ppg and 16 ppg oil base muds.
5 HSI—hydraulic horsepower per square inch.
6 WOB—weight on bit (1000 pounds).

Special Procedures

Several special procedures were followed in the test program to ensure successful test results.

1. For Phase 1, dye was placed in both the water-base (bright pink) and oil-base fluids (bright green) to allow analysis of drilling fluid invasion in drilled cuttings by Baker Hughes Drilling Fluids.

Table 7. Test matrix and parameters for the Deep Trek Phase 2 test program.

Test	Bit[1]	Nozzles[2]	Rock[3]	Mud[4] ppg	HSI[5] Hp/in[2]	WOB[6], klbs	Rotary Speed, rev/min
17	M841	0.6 TFA	Composite A	11	2	20-40	60-220
18	M333	2-13s, 14, port	Composite B	11	2	10-25	90
19	M333L	2-13s, 14, port	Composite B	11	2	10-25	90
20	737	3-15s	Composite C	11	2	40-80	70-110
21	M333	2-13s, 14, port	Composite A	16c	2	10-25	90
22	M841	0.8 FA	Composite A	16c+	2	20-40	60-220
23	M333	3-15s, port	Composite A	16c+	2	10-25	90
24	M333	3-15s, port	Crab Orchard	16c+	2	10-25	90
25	737	2-16, 18	Composite C	16c+	2	40-80	70-110
26	M841	0.8 TFA	Composite A	16	2	20-40	60-220
27	M233	3-15s, port	Crab Orchard	16	2	10-25	90
28	M233	3-15s, port	Composite A	16	2	10-25	90
29	M333	3-15s, port	Crab Orchard	16	2	10-25	90
30	M333	3-15s, port	Composite A	16	5	10-25	90
31	M333L	3-15s, port	Composite A	16+l	2	10-25	90
32	M333	3-15s, port	Crab Orchard	16+s	2	10-25	90
33	M333	3-15s, port	Composite A	16+s	2	10-25	90
34	M333	3-15s, port	Crab Orchard	16mn	2	10-25	90
35	M333	3-15s, port	Composite A	16mn	2	10-25	90
36	M233	3-15s, port	Composite A	16mn	2	10-25	90
37	M333	3-15s, port	Composite A	16+l	2	10-25	90

1 Bits included: 7-blade PDC bit (M333), long profile 7-blade PDC (M333L), impregnated bit (M841), four-bladed PDC bit (M233), and a carbide insert roller-cone bit (737).
2 Bit nozzle diameters are in 32s of an inch. There is a fixed port on the M333 and M333L bits. The impregnated bit has a flow area (FA) (square inches).
3 Composite rock: A – Mancos shale and Carthage marble; B – Carthage Marble and Crab Orchard sandstone; and C – Mancos shale, Carthage marble, and Crab Orchard sandstone.
4 The drilling fluids are 11-ppg water-based mud, 16c – cesium formate, 16c+--cesium formate with drill solids, 16 – oil-based, 16+l oil-based with lubricant, 16+s – oil-based with surfactant, and 16mn – oil-based with manganese tetroxide weighting material.
5 HSI – hydraulic horsepower per square inch.
6 WOB – weight on bit (1,000 lb).

2. Before and after each drilling test, a sample of drilling fluid was taken and provided to Baker Hughes Drilling Fluids for post-test examination and testing.
3. The drilling fluid was analyzed to determine standard American Petroleum Institute (API) drilling fluid properties before and after each test including the following: Fann readings to determine plastic viscosity (PV), yield point (YP), apparent viscosity (AV) and 10-second and 30-min gels; drilling fluid density; API filtration (water-base fluid only); pH (water-base fluid only) and high temperature/high pressure (HTHP) filtration at 500 psi and 200 deg F (oil-base fluid only). The drilling fluid temperature used for the property measurements was typically 120 ^{o}F.
4. The test conditions of 10,000 psi borehole, 11,000 psi confining pressure and 12,000 psi overburden stress were applied to the rock samples, except for Phase 1 Test 16 which was run at 5000 psi borehole, 6000 psi confining and 7000 psi overburden.
5. All drilling tests were run with a flow rate of 300 gpm (150 gpm from the TerraTek pump and 150 gpm from the Hughes Christensen pump) which gave an HSI of about 2 for the PDC and roller-cone bits and an HSI of about 0.6 to 0.9 for the impregnated type bit, except for

Phase 1 Test 14 which was run at 340 gpm flow rate and gave about 5 HSI). The actual HSI's achieved during the testing varied somewhat from the targeted levels.

6. In each drilling test, the bit was spudded into the rock. For the roller-cone bit, impregnated bit and PDC bits, this spud distance was 1", 2" and 3" respectively. The drilling sequences were begun immediately after spudding.

RESULTS

The results of the testing are discussed in terms of ROP and MSE for the various bits, fluids, and rock tested. The data logged during the testing was averaged for each parametric setting or interval of each test. A summary of the averaged input variables and output responses and the calculated values is provided in Appendix A.

Drill cuttings were collected after each test and cuttings size distribution analysis performed. Because only limited analysis was performed, the results provided are limited.

Note that the drill bit designations used on the graphics are those listed by the International Association of Drilling Contractors (IADC) and the numerical extension on the bit is for the testing phase. The mud designations used for the drilling fluids are as follows:

- Water—water as drilling fluid
- Base Oil—base oil without additives
- 11 — 11-ppg water-based mud
- 16c — cesium formate mud
- 16c+ — cesium formate mud with drill solids
- 16 — oil-based mud
- 16+l — oil-based mud with lubricant
- 16+s — oil-based mud with surfactant
- 16mn — oil-based mud with manganese tetroxide weighting material.

General Performance

The overall trends in performance of the various drill bits and fluids in all three rock types tested are summarized in Table 8. This table is for practical comparison purposes and excludes the performance of water and base oil fluids. Positions of performance change in some instances with increased WOB. The performance at 10,000 lb WOB was used for this comparison.

Observations of the ROP generally saw the PDC drill bits outperform the other types of drill bits. The cesium formate drilling fluids performed best in the Carthage marble and the Mancos shale. The 11-ppg water-based mud slightly outperformed the oil-based drilling fluid with manganese tetroxide weighting material in the Crab Orchard sandstone.

Considering the MSE, the PDC drill bits outperformed the other types of drill bits. The cesium formate drilling fluids performed best in the Carthage marble and the Mancos shale. The oil-based drilling fluid with manganese tetroxide weighting material and the 11-ppg water-based mud performed best in the Crab Orchard sandstone.

Deviations from the "normal" operating parameters were made to see if there was significant improvement with increased hydraulic horsepower across the drill bit and to see if there was significant improvement when lowering the external stresses on the rock while reducing the borehole pressure. In Test 14, drilling Crab Orchard sandstone and Mancos shale with 16 ppg

Table 8. General overall performance of drill bits and drilling muds* starting with the best.			
Rock/Parameter	**Carthage Marble**	**Crab Orchard Sandstone**	**Mancos Shale**
Bit Performance—ROP	1. M333 2. M233 and M121 3. 737 4. M841	1. M333 2. M121 and M233 3. M841 4. 737	1. M333 and M233 with cesium formate mud 2. Mixed performance with various PDC drill bits in various oil-based drilling fluids
Bit Performance—MSE	1. M333 2. M233 3. 737 4. M841	1. M333 2. M121 and M233 3. M841 4. 737	1. M333 and M233 with cesium formate mud 2. Mixed performance with various PDC drill bits in various oil-based drilling fluids
Mud Performance—ROP	1. Cesium formate 2. Water-based 3. Oil-based with manganese tetroxide	1. Water-based 2. Oil-based with manganese tetroxide 3. Oil-based 4. Cesium formate	1. Cesium formate 2. Oil-based without additives-generally
Mud Performance—MSE	1. Water-based 2. Cesium formant 3. Oil-based with manganese tetroxide	1. Oil-based with manganese tetroxide 2. Water-based 3. Oil-based 4. Cesium formate	1. Cesium formate 2. Oil-based without additives-generally
Overall Performance—ROP	PDC drill bit with cesium formate drilling fluid	1. PDC bit with water-based 2. PDC drill bit with manganese tetroxide	PDC drill bit with cesium formate drilling fluid
Overall Performance—MSE	1. PDC drill bit with cesium formate drilling fluid 2. PDC drill bits with oil-based drilling fluids with manganese tetroxide	1. PDC drill bit with manganese tetroxide 2. Water-based	PDC drill bit with cesium formate drilling fluid

*Excludes water and base oil as drilling fluids. Ratings at 10,000 lb weight on bit.

oil-based drilling fluid and a 7-bladed PDC drill bit, the HSI was increased without and observed improvement in drilling rate. Significant improvement in ROP and MSE was experienced in Test 16 with reduced stresses on the rock and reduced borehole pressure. The test articles used in this test included the same rock type, drill bit, and drilling fluid used in Test 14.

The trend of ROP as a function of bit weight observed with roller-cone bits at normal bit weights continues to very high WOB (80,000 lb). The same is true of impregnated bits when increasing the WOB to 40,000 lb.

Penetration Rate

A summary of the ROP performance of the various drill bits can be seen in Table 8. The best performance was with the PDC drill bits and the worst with the M841 and 737 drill bits. The cesium formate drilling fluids provided the best ROP in the Carthage marble and Mancos shale, with the water-based mud and 16 ppg oil-based mud with manganese tetroxide having the most positive influence on drilling in the Crab Orchard sandstone. The water and base oil fluids are not considered in this table; the ROP using water and base oil was substantially better than with “muded up” fluids. More specific summaries are provided in Table 9 for 11 ppg water-based drilling fluid and Table 10 for 16 ppg oil-based drilling fluid without special additives. These tables provide a direct comparison of drill bit performance in each of the rock types tested, albeit with only two muds. The Graphical representations of the ROP performance with 11 ppg water-based fluid and 16 ppg oil-based fluid are provided in Figures 7 through 11. Graphs of ROP with all bits, fluids, and rock types are provided in Appendix C for additional comparisons.

Mechanical Specific Energy

MSE is defined as the mechanical work done to excavate a unit volume of rock (Simon, 1963 and Teale, 1965). It has been used to represent and to investigate the mechanical efficiency

Table 9. Bit Performance (from best to least) in 11 ppg water-based drilling fluid.

Rock/Parameter	Carthage Marble	Crab Orchard Sandstone	Mancos Shale
Rate of penetration	1. M333-1 2. M233-2 3. M121-1 4. M333L-2 5. 737-1 6. 737-2 7. M841-2 8. M841-1	1. M333-1 2. M121-1 3. M233-2 4. M333L-2 5. M841-1 6. 737-2 7. 737-1	Only the 737-2 drill bit was run in Mancos shale with water-based mud.
Mechanical Specific Energy	1. 737-1 2. 737-2 3. M333-1 4. M333L-2 5. M233-2 6. M121-1 7. M841-1 8. M841-2	1. M333L-2 2. M333-1 3. M233-2 4. M121-1 5. 737-2 6. M841-1 7. 737-1	Only the 732-2 drill bit was run in Mancos shale with water-based mud.

Ratings at 10,000 lb weight on bit.

Table 10. Bit performance (from best to least) in 16ppg oil-based drilling fluid.			
Rock/Parameter	**Carthage Marble**	**Crab Orchard Sandstone**	**Mancos Shale**
Rate of penetration	1. M233-2 2. M333-2 3. M841-2	1. M121-1 2. M333-1 3. M233-2 4. M333-2 5. M841-1	1. M233-2* 2. M121-1* 3. M333-1 4. M333-2 5. M841-1 6. M841-2
Mechanical Specific Energy	1. M233-2 2. M333-2 3. M841-2	1. M121-1 2. M233-2 3. M333-1 4. M333-2 5. M841-1	1. M233-2** 2. M121-1 3. M333-1 4. M333-2 5. M841-2 6. M841-1

Ratings at 10,000 lb weight on bit.

of the drilling process (Pessier and Fear, 1972), (Waughman et al, 2002), and (Dupriest et al, 2005). Table 8 provides an overall summary of the MSE performance of the various bit and fluids. MSE performance followed closely the ROP performance previously discussed. Tables 9 and 10 provide information on the MSE performance of the various drill bits in each rock type tested using water-based fluid and 16 ppg oil-based mud (without additives). Figures 12 through 16 provide the graphical representations backing up the summaries in the tables. Additional MSE graphs are provided in Appendix C.

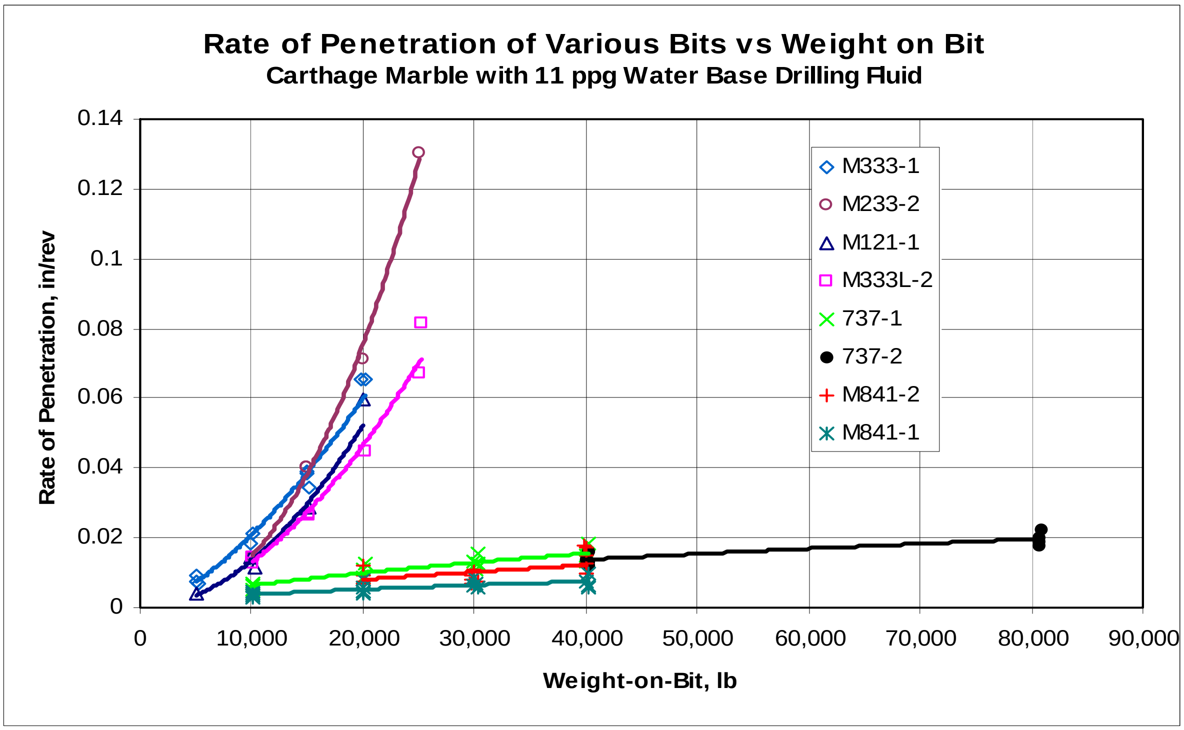

Figure 7. Comparison of bit performance in Carthage marble with a water-based drilling fluid.

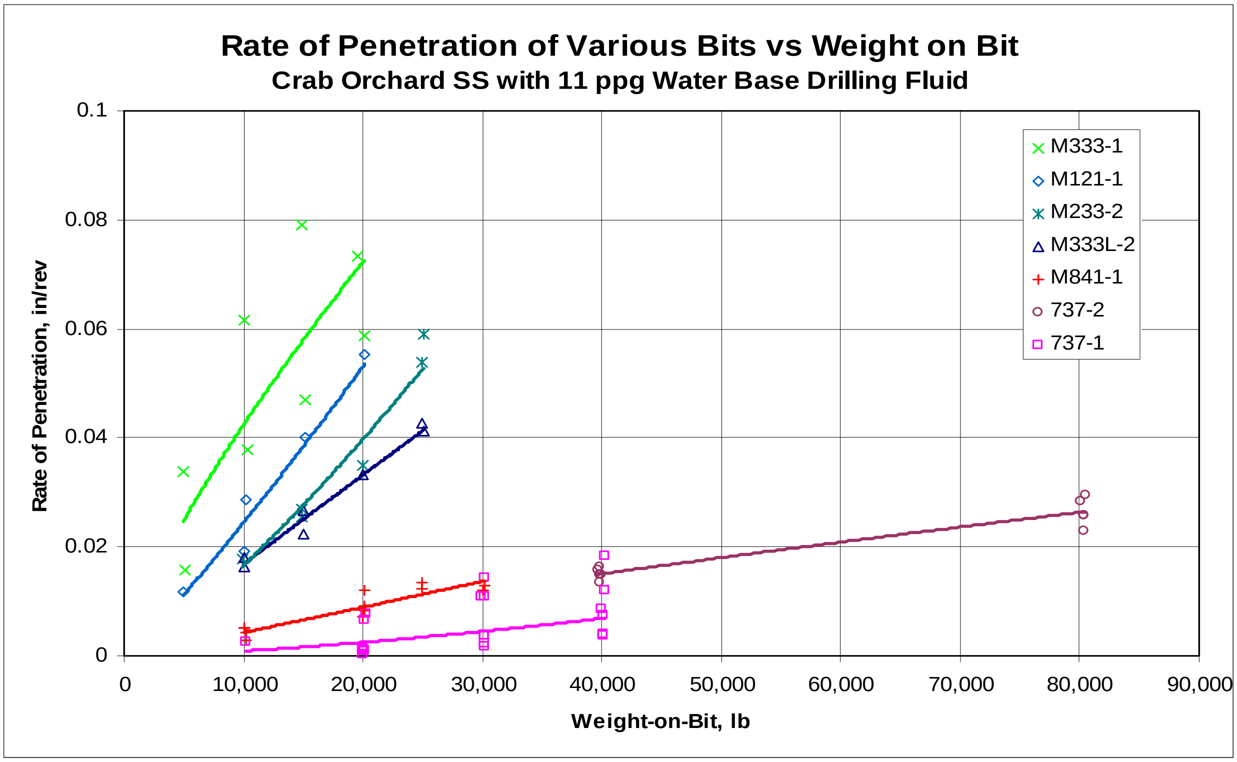

Figure 8. Comparison of bit performance in Crab Orchard sandstone with a water-based drilling fluid.

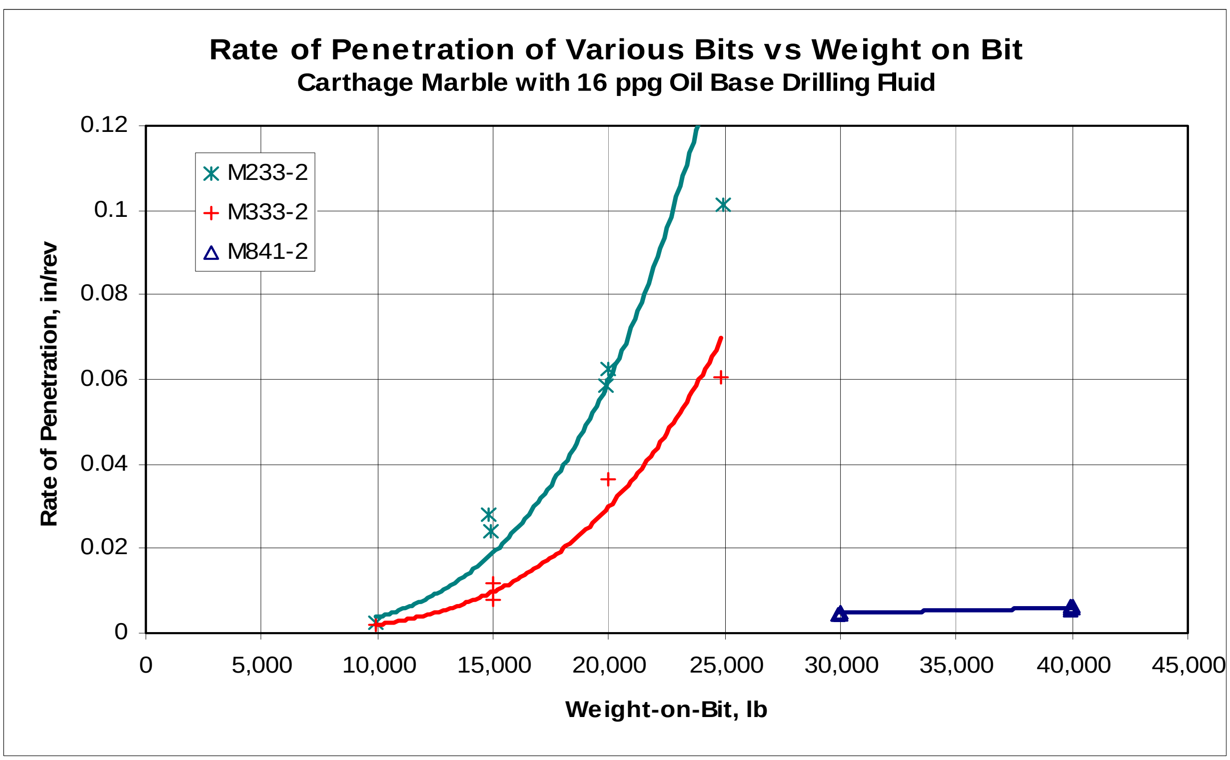

Figure 9. Comparison of bit performance in Carthage marble with a 16 ppg oil-based drilling fluid.

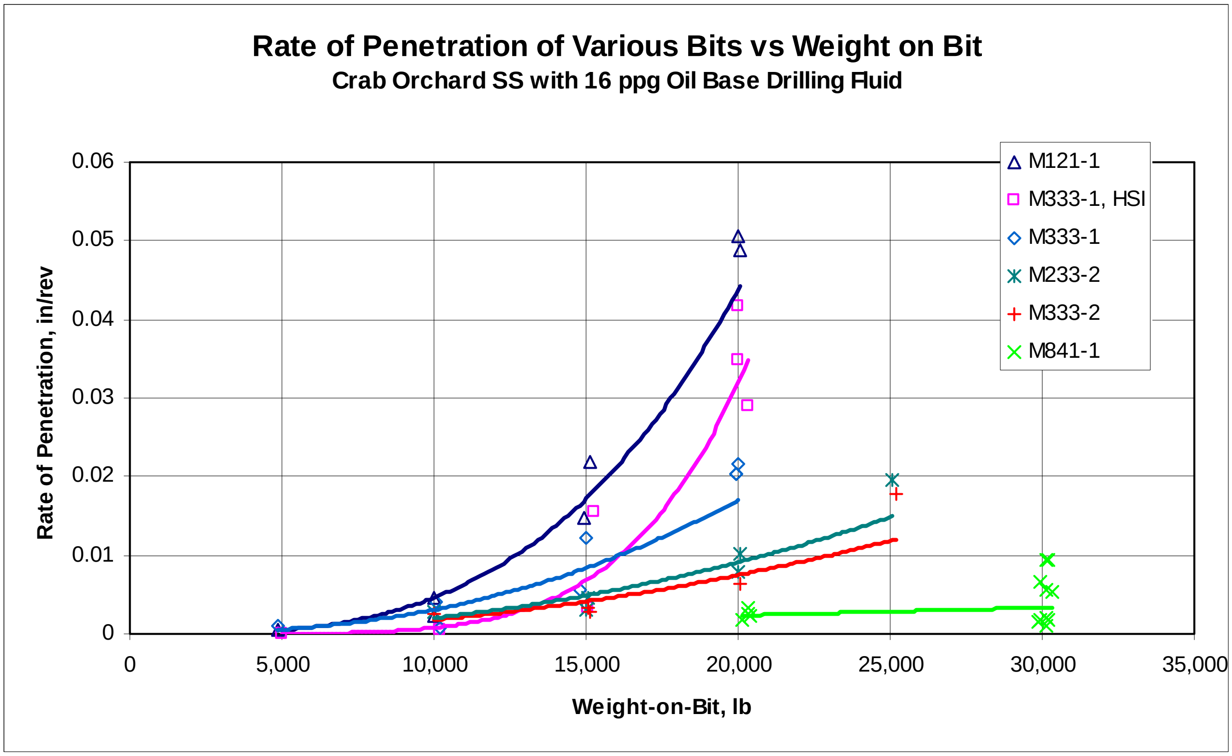

Figure 10. Comparison of bit performance in Crab Orchard sandstone with a 16 ppg oil-based drilling fluid.

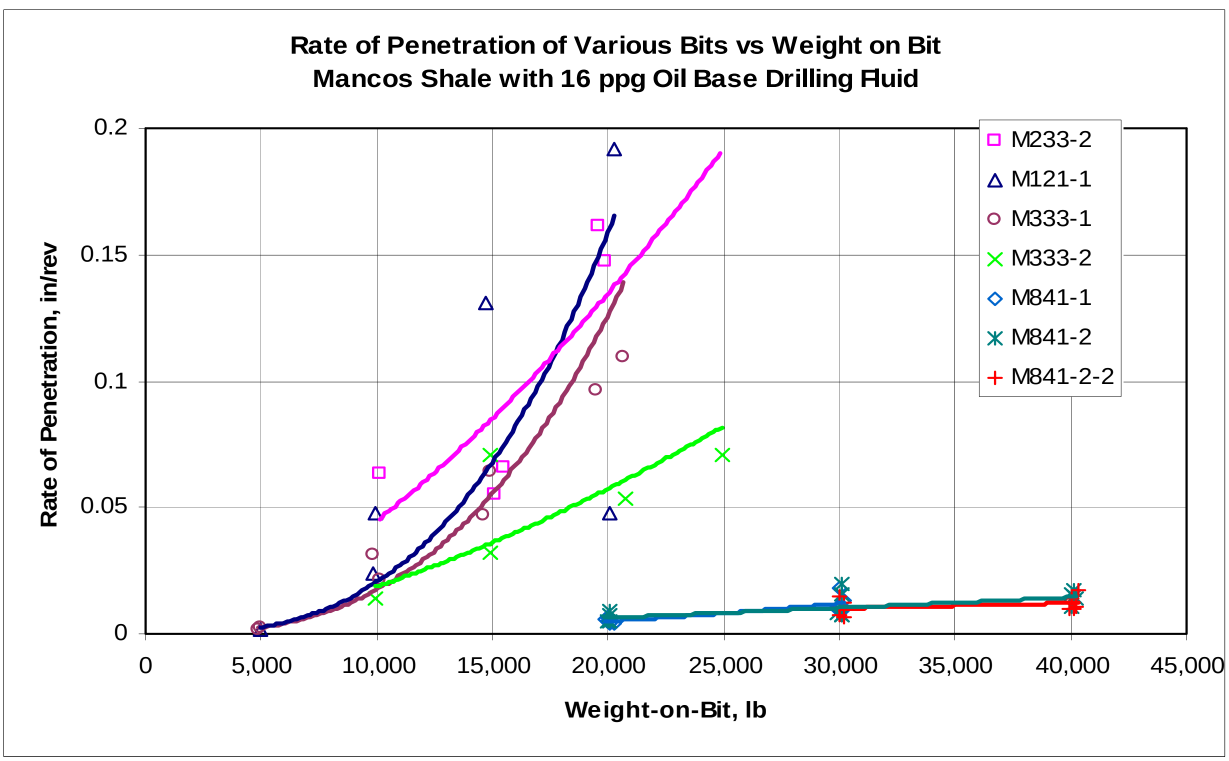

Figure 11. Comparison of bit performance in Mancos shale with a 16 ppg oil-based drilling fluid.

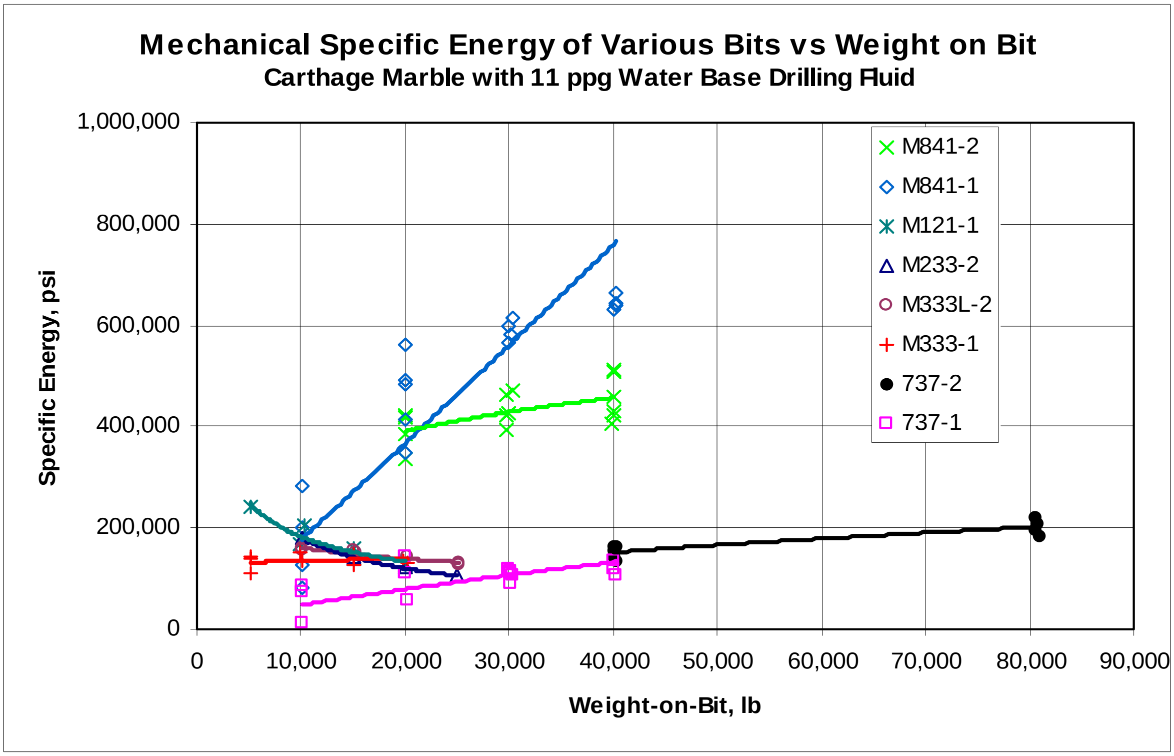

Figure 12. Mechanical specific energy generated by of a number of different drill bits with 11 ppg water-based drilling fluid in Carthage marble.

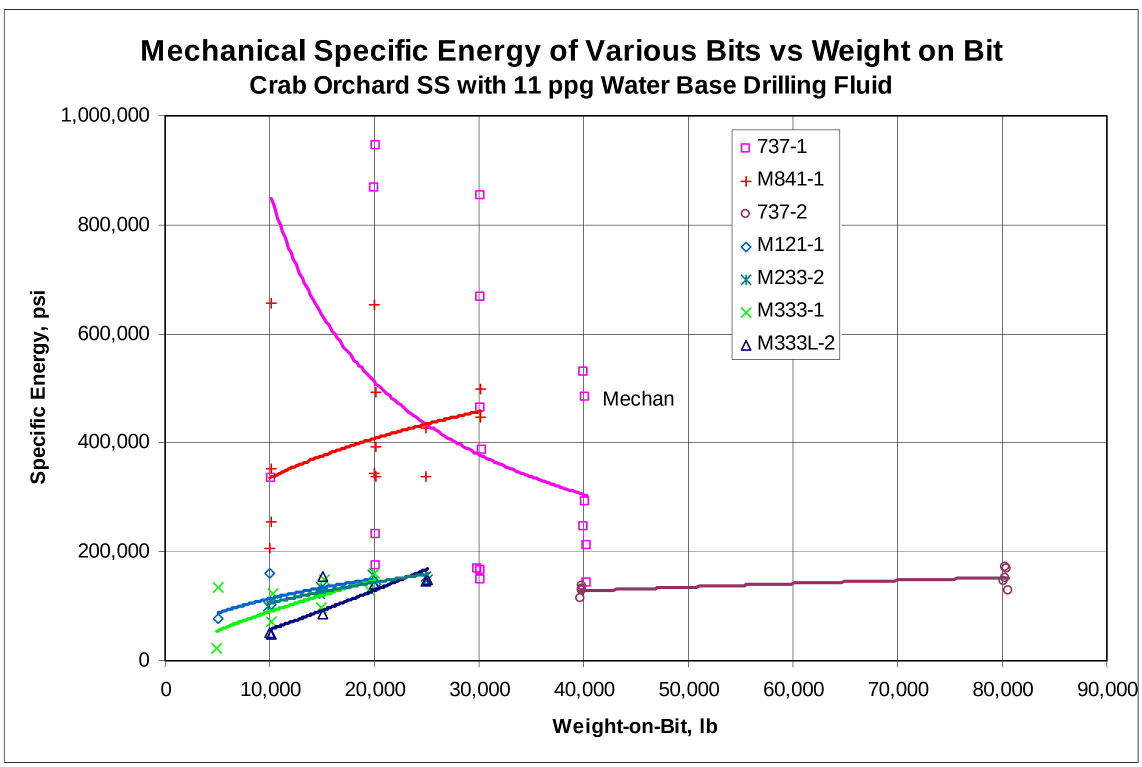

Figure 13. Mechanical specific energy of different drill bits in Crab Orchard sandstone with 11 ppg water-based drilling fluid.

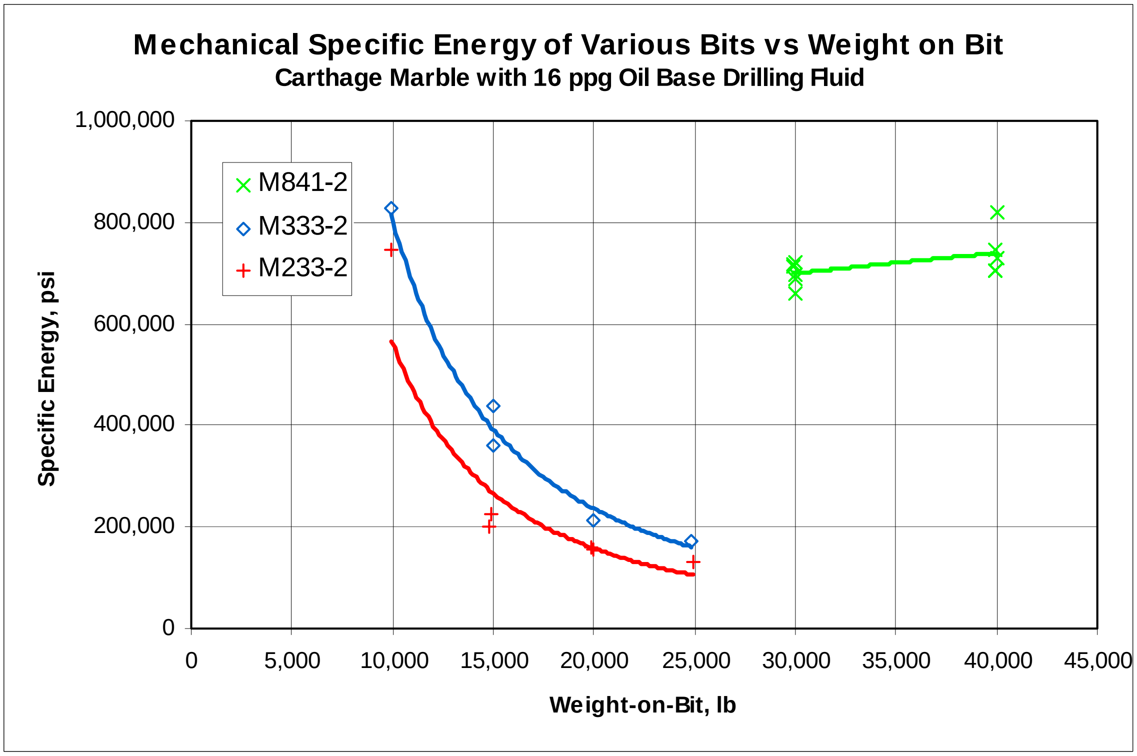

Figure 14. Mechanical specific energy of three drill bits in Carthage marble when using 16 ppg oil-based drilling fluid.

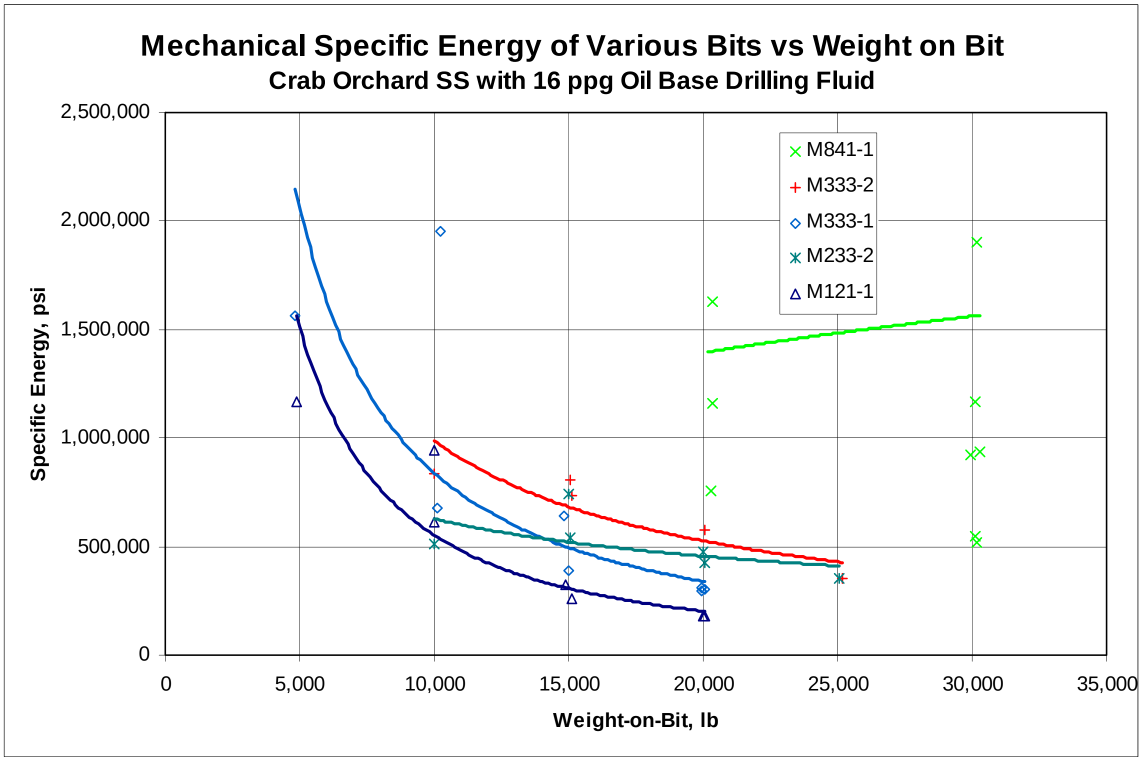

Figure 15. Mechanical specific energy required to drill Crab Orchard sandstone with a variety of drill bits in 16 ppg oil-based drilling fluid.

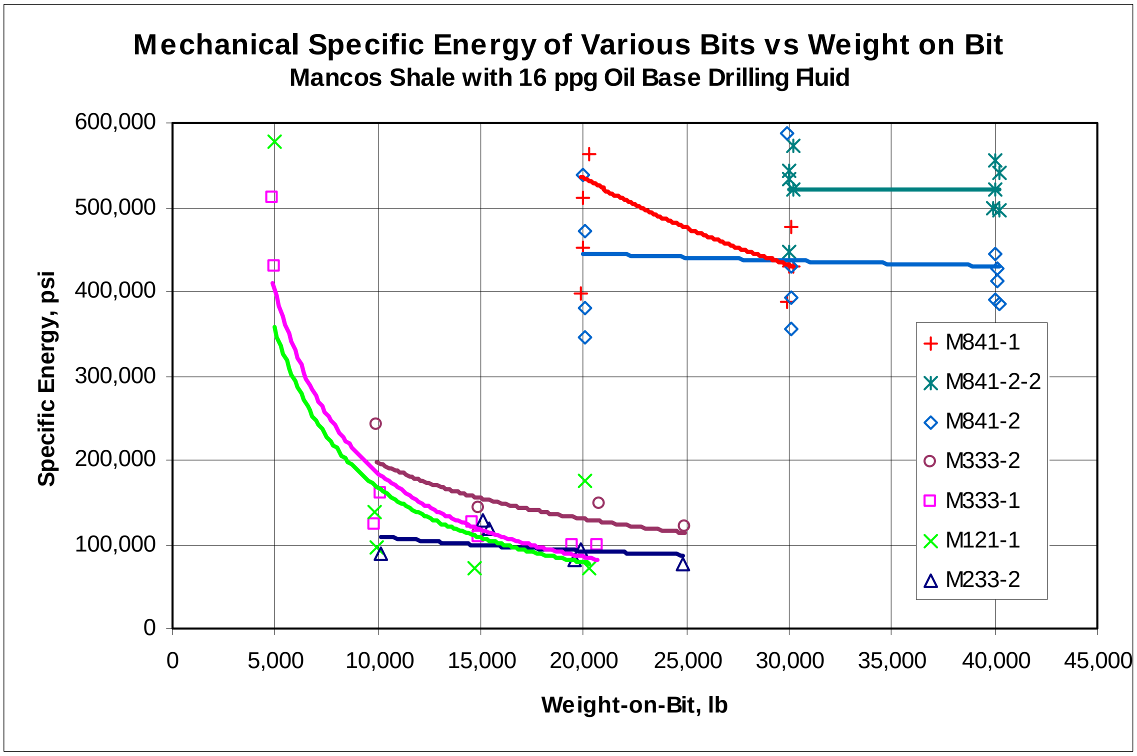

Figure 16. The mechanical specific energy is plotted as a function of WOB with various drill bits in Mancos shale.

Cuttings Analysis

After each test, samples were taken from the cuttings catch basket, which is located just downstream of the drilling simulator pressure vessel and before the drilling fluid passes through the choke that creates and controls the bottomhole pressure. The basket used to collect the cuttings was made of a 20 mesh screen and therefore restricted the size distribution analysis to the higher size fractions. A table listing the cuttings size distribution information is provided in Appendix D.

Examination of the cuttings samples revealed that in most instances they consisted of re-compacted fine rock particles with no apparent primary cementation remaining as is typical of previous drilling simulator testing at high borehole pressures with similar rock. Carthage marble and Crab Orchard sandstone cuttings could be crushed between the thumb and forefinger, confirming their granular nature with minimal cementation.

Cuttings size distributions, provided in Table D-1, were determined for representative grab samples of cuttings from each test using image analysis with the following exceptions:

In Test 9, which was drilled with clean mineral oil and was the first test after the water-based drilling, the Mancos shale cuttings apparently scavenged residual water left in the circulation system and were water-wet. These cuttings could not be dispersed in mineral oil; consequently, no attempt was made to determine the size distribution.

Drill cuttings from Tests 12 through 16 were not evaluated because experienced personnel were not available to perform the examination. Cuttings were not collected for Test s 22a and 22b because of collector basket failure.

Observations of Bit Condition

The condition of the drill bits was noted at the conclusion of each test. No significant wear was observed; however, one cutter on was broken on the M233 four-bladed PDC bit used in Test 36. Bit balling was observed on tests 16. Material sticking to the bit was observed after Test 16 when a bit nozzle was plugged with pump rubber seal material. After Test 33 it was observed that nozzles were plugged. The data recorded indicated that this occurred after Data Point 4 and caused the HSI to increase. Plugged nozzles were also observed after Test 35 Data Point 3 resulting in higher HSI. An impregnated bit balled up when drilling through Mancos shale, even though an oil-based mud was being used and the bit was being operated with reasonable levels of hydraulic horsepower.

DISCUSSION

Caution should be exercised in interpreting the data and results of the testing. The rock selected for the tests represent rock found in the Tuscaloosa Trend and the Arbuckle Play. The results presented here may provide insight and guidance, but knowledge of particular formations being drilled and experience gained must not be overlooked. Consider that the number of parameters affecting ROP and MSE is great and only a few could be significantly explored during the two phases of testing.

The influence of all factors affecting overall performance must be considered in making the proper drill bit and fluid decision. For example, the four-bladed PDC bits performed slightly better that 7-bladed; however, when considering the potential for shorter bit life of the four-bladed bit, they may not provide the best alternative.

The particulars of the design of the drill bits used is not discussed. Some drill bit design information is provided in Table E-1 of Appendix E.

The influence of the drilling fluid properties has not been analyzed completely. A summary of the average properties is provided in Table 5.

Significant discussion of Phase 1 testing results is provided in IADC/SPE Paper 105885 (Judzis, et al, 2007) and IADC/SPE Paper 112731 (Black, et al, 2008) presents the results of both phases of the testing. A through discussion of the impact of bit design and mud penetration rates and the relationship between rock strength, ROP, and MSE is provided in IADC/SPE Paper 105885 (Judzis, et al, 2007). Also included in this paper is a discussion of the effects of chip hold-down on drilling efficiency. Drill bit efficiency and aggressiveness are discussed in the second paper listed, which will be published in March 2008 at the annual IADC/SPE Drilling Conference.

Repeatability of the Data

To establish a statistical measure of the accuracy of the data, replicate data points were obtained during testing. The replicate data points from Phase 2 testing showed that the standard deviation of the mean penetration rate was typically approximately 9% of the mean. For data points in which ROP was less than 10 ft/hr, the scatter tended to be a little higher—about twice that value, but still less than 2 ft/hr. Statistical validity between tests conducted in Phase 1 and Phase 2 is difficult to establish because few tests were repeated between the phases. Plots of data from identical tests in Phases 1 and 2 are used when available.

Comparison of Laboratory Test and Field Penetration Rates

A significant objective of the first phase of the study was to devise test protocols that reproduced in the laboratory the drilling conditions and performance seen when drilling hard rocks at considerable depth. Field applications targeted included the Arbuckle wells drilled in Northern Texas and Western Oklahoma, and the Tuscaloosa trend wells drilled along the Gulf Coast. Typical field penetration rates with TCI and impregnated drill bits were reasonably well reproduced in the laboratory for the applications which they represented. In each instance there is general agreement between the laboratory test and field penetration rates. The similarity of laboratory and field penetration rates was encouraging and supported the conclusion that bit/rock interactions seen in laboratory tests should be indicative of those operating in field operations. A more complete discussion and the field data are presented in IADC/SPE Paper 105885 (Judzis, et al).

Borehole Pressure Effects

The high borehole pressure and confining stress significantly influenced the drilling performance because of the increased strengthening of the rock. Figure 4 illustrates the effects of confining load on rock strength and it is logical that the borehole pressure has a similar influence, especially when the fluid is “mudded up” to reduce filtrate loss into the formation. Test 16 was run with lower confining and borehole pressures; corresponding improvements in drilling were seen, approximately 100 percent for the Mancos shale and 400 percent for the Crab Orchard sandstone (comparing Test 13 and 16 results).

Determining the influence of confining stress and borehole pressure is not attempted other than to note the difference in ROP using base oil (Test 9) as a drilling fluid was more pronounced in the somewhat permeable sandstone than in the shale. It is expected that the base fluid “invaded” the pore space below the bit in the sandstone, reducing the effective stress (the effect of the borehole stress). IADC/SPE Paper 105885 (Judzis, et al) provides a discussion on this suspected occurrence.

“Mudded Up” Versus Clear Fluids

There seems to be a correlation between the ability of the fluid to penetrate into the formation and the rate of penetration. This is born out with the high ROP and low MSE observed when using water and base oil. However, the poor performance of the cesium formate drilling fluid in the Crab Orchard sandstone was counter to that notion. It should be noted that the viscosity of the cesium formate brine was higher than other drilling fluids. A plot of the effects of apparent viscosity on ROP is provided in Figure 17; further analysis is needed to make definitive conclusions.

Performance of Cesium Formate and Oil-based Manganese Tetroxide Fluids

The cesium formate drilling fluid, both with and without solids, performed exceptionally well in both the Carthage marble and Mancos shale when using PDC bits (see Figure 18). There was no significant improvement in ROP when using other drill bit types as shown in Figure 19 (compare with Figure 18). Using an M333 drill bit, the performance in Mancos shale was comparable to the water and base oil fluids as graphed in Figure 20.

The most improvement in ROP when drilling in the Crab Orchard sandstone was with the 16 ppg oil base fluid weighted with manganese tetroxide. The reason has not been determined. Figure 21 provides a graph of the ROP in all rock types using the manganese tetroxide fluid and an M333 drill bit.

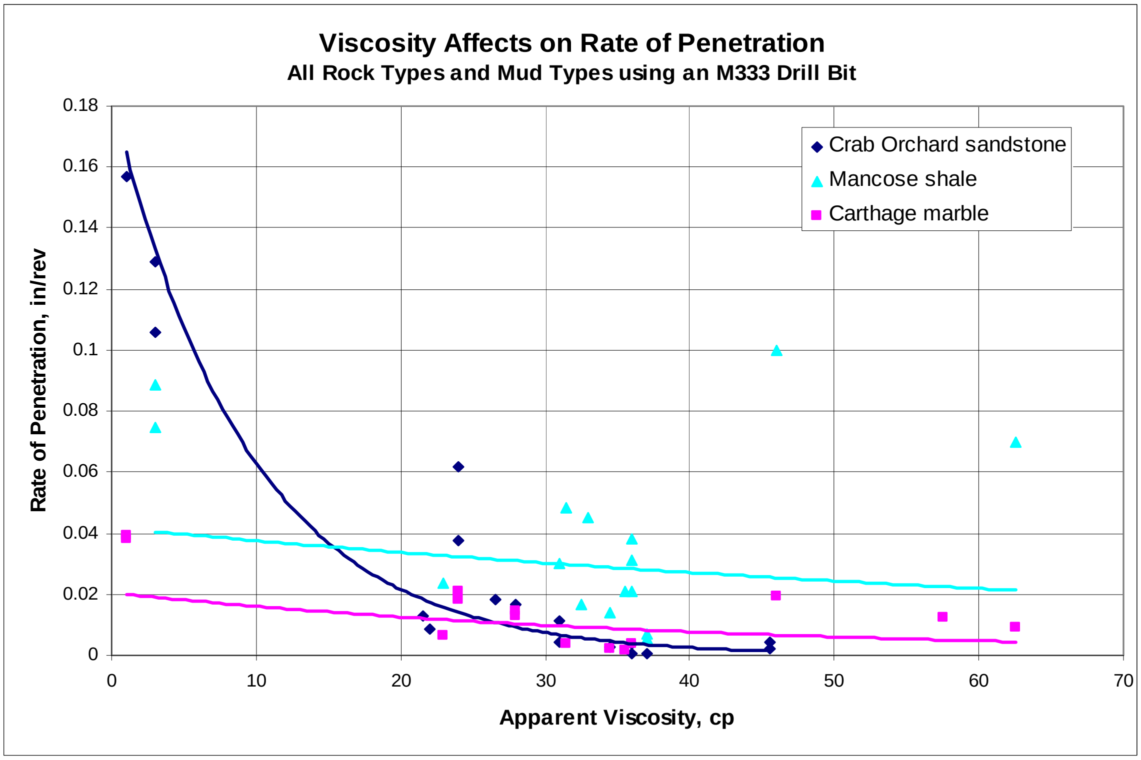

Figure 17. Viscosity effects on rate of penetration in all rock types and with all drilling fluids. The curves are exponentially fit.

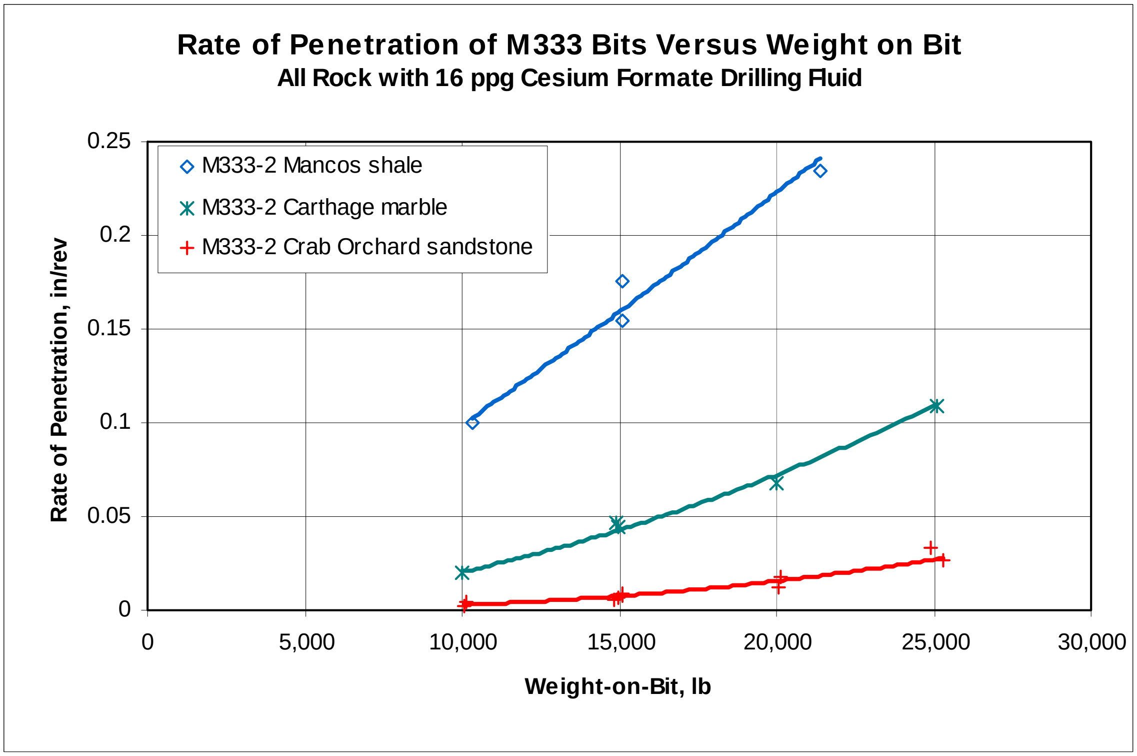

Figure 18. Rate of Penetration in all rock types using cesium formate drilling fluid.

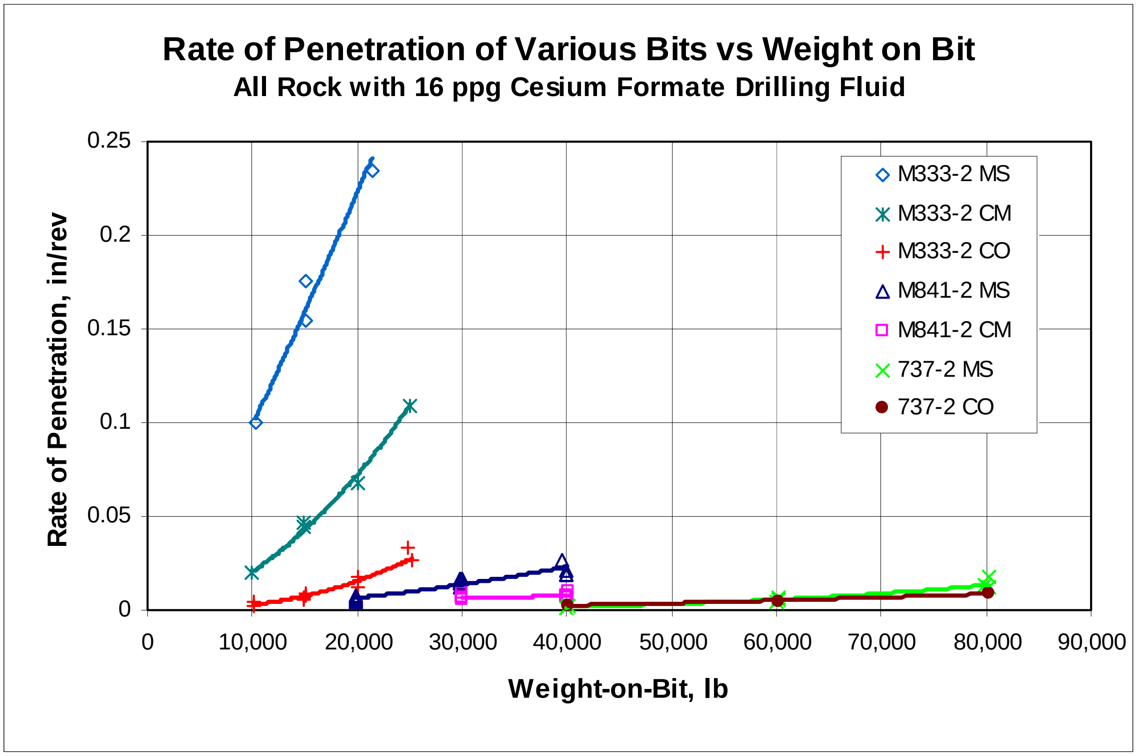

Figure 19. Rate of penetration measured with increased weight on bit using several bits in cesium formate drilling fluid.

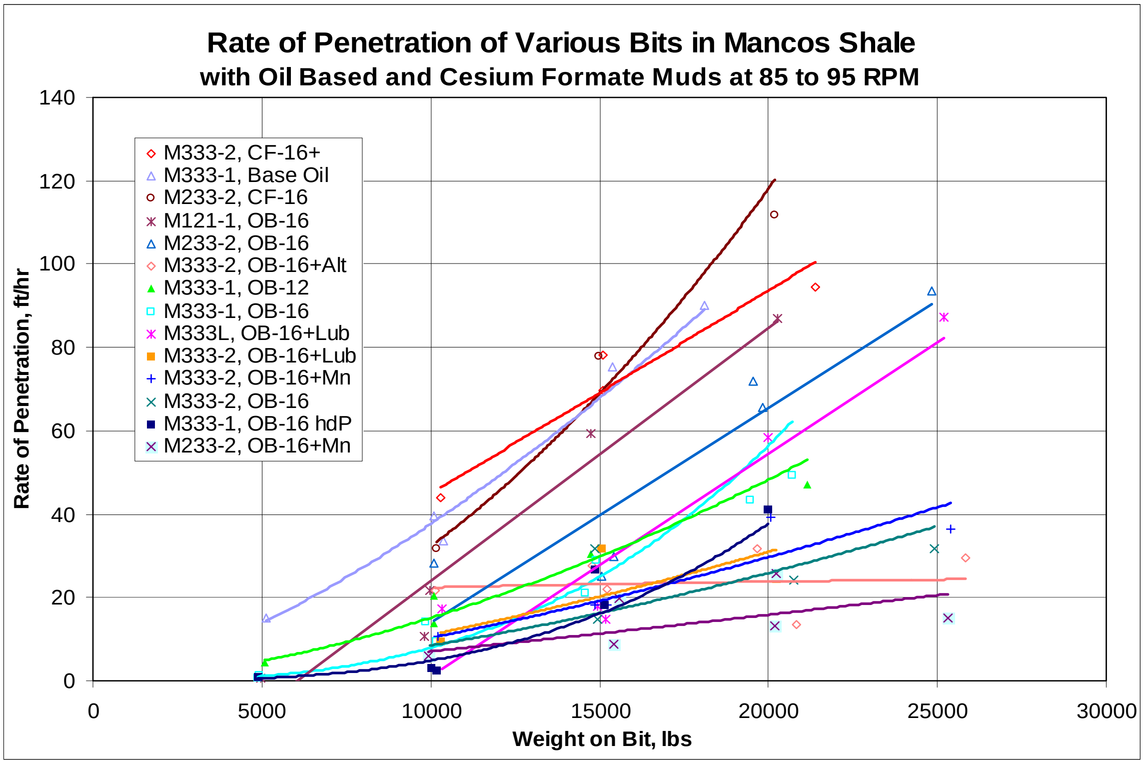

Figure 20. Rate of penetration in Mancos shale with PDC bits and a variety of drilling fluids.

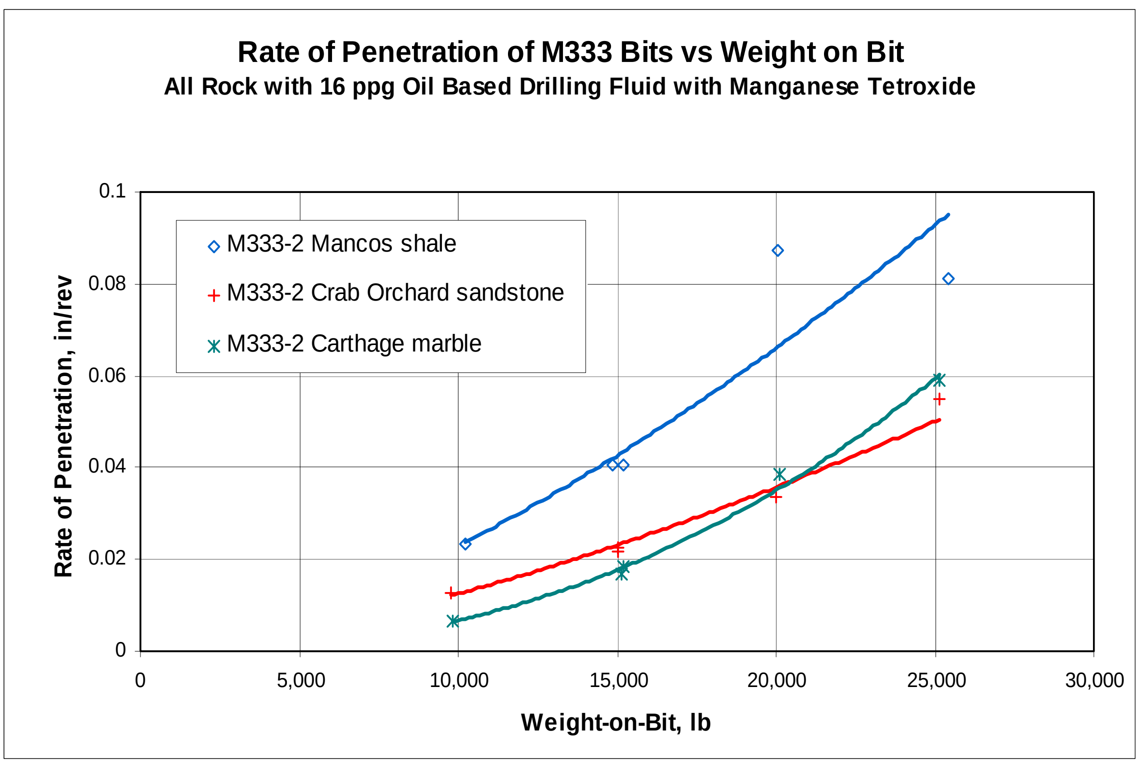

Figure 21. M333 drill bit performance in all rock types using a manganese tetroxide drilling fluid.

CONCLUSIONS

This report describes what is believed to be the first set of full scale laboratory drilling tests yet performed at bottomhole pressures in excess of 10,000 psi. The following conclusions are drawn from the results of this study:

- Penetration rates seen in these laboratory tests correspond reasonably well with those seen in field applications and give a reasonable simulation of field drilling conditions encountered in applications which involve penetrating hard rocks at high bottomhole pressures.
- "Mudding up" at high bottomhole pressure causes penetration ROP reductions.
- Mud type and mud additives can significantly enhance ROPs in high-pressure conditions and may play a larger role than bit design features.
- A 16ppg cesium formate brine increased ROP substantially as compared to 16-ppg oil-based mud in Carthage marble and Mancos shale.
- A 16-ppg oil-based mud weighted with manganese tetroxide increased ROPs in Crab Orchard sandstone substantially as compared to the same density mud with conventional weighting material.
- It appears that the enhanced ROPs realized with cesium formate may occur only in conjunction with PDC type bits.
- 16-ppg oil-based muds formulated with an alternate surfactant and with a drilling lubricant did not achieve a ROP faster than the reference 16-ppg oil-based mud.
- PDC bits have substantially higher penetration rate potential than do impregnated and roller cone bits, even when allowing for the lower operating weights typical of PDC bits. Impregnated and roller cone bits drill much slower than PDC bits at equivalent WOB and RPM.
- Fluid invasion of intact rock and of rock destroyed by the bit's cutting structure seems to play a major role in controlling penetration rates at these high bottomhole pressures.
- Drilling fluid compositions and properties that promote invasion without provoking formation damage, and bit design features that facilitate the removal of rock debris from the hole bottom both hold out promise for improving drilling efficiency in hard rock drilled at high bottomhole pressures.

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R J Waughman, J V Kenner, and R A Moore, “Real-time specific energy monitoring reveals drilling inefficiency and enhances the understanding of when to pull worn PDC bits,” SPE paper no. 74520, presented at 2002 IADC/SPE Drilling Conference, 26-28 February 2002, Dallas, Texas.

APPENDIX A
Data Tables

The input parameters and the output values measured during the testing are provided on Table A-1. The values are averaged over the interval listed on the table for each run of each test. The calculated values of ROP, bit pressure drop, hydraulic horsepower, hydraulic horsepower per square inch of bit face, and the mechanical specific horsepower are given.

Table A-1. Data from all Deep Trek tests, averaged over the interval of “constant” test parameter settings.

Test Number	Data Point . No.	Rock[1]	Drill Bit[2]	Drilling Fluid[3]	Drilled Interval in	ROP[4] ft/hr	ROP in/rev	Temp °F	Torque ft-lb	Hyd. Horse-power[5] HP	Weight on Bit lb	Rotary Speed rpm	Flow Rate gpm	Bore Press. psi	Swivel Mud Press. psi	Bit Press. Drop psi	HSI Horse-power[6] HP/in^2	Conf. Stress psi	Over-burden Stress psi	Mech. Specific Energy psi
Deep 01	1	Crab Orch.	M333-1	Water	3.4- 4.5	34.8	0.076	75.1	645	11.2	4,873	92	305	9,918	10,237	319	2.01	10,972	11,988	22,908
Deep 01	2	Crab Orch.	M333-1	Water	5.4- 6.9	69.3	0.1567	75.4	1282	21.6	9,626	88	304	9,936	10,228	293	1.83	10,967	12,019	22,046
Deep 01	3	Crab Orch.	M333-1	Water	8.6-10.8	80.2	0.1864	75.8	1916	31.4	15,146	86	303	9,918	10,233	315	1.97	10,960	12,060	27,930
Deep 01	4	Carthage	M333-1	Water	18.8-19.1	6.9	0.015	81.6	486	8.5	5,108	92	296	10,041	10,313	272	1.66	10,976	12,036	86,581
Deep 01	5	Carthage	M333-1	Water	19.3-21.6	16.9	0.0381	82.4	1237	20.9	10,075	89	298	9,984	10,269	285	1.76	10,998	12,051	87,215
Deep 01	6	Carthage	M333-1	Water	21.8-24.4	29.1	0.0669	83.3	2119	35.1	14,908	87	300	10,009	10,320	311	1.93	10,996	12,063	84,996
Deep 01	7	Carthage	M333-1	Water	26.7-27.2	34.6	0.0813	84.6	2553	41.4	17,953	85	300	10,007	10,342	335	2.07	10,963	12,066	84,259
Deep 01	8	Carthage	M333-1	Water	28.2-29.4	29.8	0.063	85.3	2123	38.2	14,990	95	300	10,021	10,320	299	1.85	10,968	12,070	90,770
Deep 01	9	Carthage	M333-1	Water	29.8-32.1	17.8	0.0392	86.1	1225	21.2	9,976	91	301	9,994	10,281	287	1.78	10,984	12,070	83,855
Deep 02	1	Carthage	737-1	WB-11	1.0- 2.0	2.4	0.0069	95.4	33	0.4	10,075	71	302	9,999	10,232	232	1.45	10,991	12,016	13,373
Deep 02	2	Carthage	737-1	WB-11	2.2- 4.0	4.5	0.0126	97.9	272	3.6	20,199	70	302	10,009	10,240	231	1.44	10,991	12,014	57,129
Deep 02	3	Carthage	737-1	WB-11	4.3- 6.1	5.4	0.0155	100	509	6.8	30,234	70	301	10,006	10,242	236	1.47	11,002	12,012	89,045
Deep 02	4	Carthage	737-1	WB-11	6.4- 8.0	6.4	0.0183	101.7	713	9.5	40,197	70	300	10,037	10,242	204	1.27	10,995	11,990	105,401
Deep 02	5	Carthage	737-1	WB-11	8.2-11.2	6.7	0.0148	103.7	749	12.9	40,136	91	300	10,040	10,257	217	1.34	10,993	11,985	137,059
Deep 02	6	Carthage	737-1	WB-11	11.4-11.7	5.9	0.0129	105.3	520	9	30,303	91	301	9,913	10,111	199	1.23	10,984	11,975	108,010
Deep 02	7	Carthage	737-1	WB-11	12.2-12.6	6	0.0133	100.3	588	10.2	29,969	91	302	9,879	10,137	258	1.61	11,002	12,042	119,967
Deep 02	8	Carthage	737-1	WB-11	12.8-13.3	4.8	0.0107	100.8	431	7.5	20,095	91	301	9,874	10,139	264	1.64	10,987	11,991	109,658
Deep 02	9	Carthage	737-1	WB-11	13.4-13.8	3	0.0065	101.5	208	3.6	10,137	91	300	9,857	10,113	256	1.59	10,983	11,980	84,483
Deep 02	10	Carthage	737-1	WB-11	13.9-14.2	3	0.0054	102.2	146	3.1	10,072	110	301	9,875	10,104	230	1.42	10,984	11,983	71,734
Deep 02	11	Carthage	737-1	WB-11	14.3-14.8	4.8	0.0086	102.8	465	9.8	20,086	110	300	9,895	10,155	259	1.61	10,987	12,003	142,794
Deep 02	12	Carthage	737-1	WB-11	15.0-15.9	5.9	0.0107	103.5	448	9.4	30,102	110	300	9,869	10,107	238	1.47	10,992	12,020	112,432
Deep 02	13	Carthage	737-1	WB-11	16.0-17.1	7.1	0.013	104.2	568	11.9	40,120	110	300	9,889	10,140	251	1.55	10,985	12,033	118,752
Deep 02	14	Carthage	737-1	WB-11	17.2-18.1	5.8	0.0129	104.9	550	9.5	30,191	91	300	9,866	10,103	237	1.47	10,994	12,024	116,125
Deep 03	1	Crab Orch.	737-1	WB-11	0.8- 1.0	0.9	0.0026	87.6	318	4.3	10,180	71	302	9,988	10,282	294	1.83	10,977	11,969	334,849
Deep 03	2	Crab Orch.	737-1	WB-11	1.1- 1.7	2.8	0.0078	89.1	513	6.9	20,205	71	302	10,006	10,293	286	1.79	10,982	11,989	174,157
Deep 03	3	Crab Orch.	737-1	WB-11	1.8- 2.8	3.9	0.011	90.7	684	9.2	30,198	71	302	9,988	10,287	299	1.86	10,969	12,000	167,099
Deep 03	4	Crab Orch.	737-1	WB-11	3.0- 3.8	2.6	0.0074	92.5	802	10.8	40,181	71	302	9,991	10,274	283	1.77	10,988	12,027	293,431
Deep 03	5	Crab Orch.	737-1	WB-11	3.8- 4.3	1.8	0.0039	94.2	717	12.5	40,174	91	302	10,006	10,288	283	1.76	10,978	12,010	484,732
Deep 03	6	Crab Orch.	737-1	WB-11	4.4- 4.6	0.7	0.0016	96.2	492	8.6	30,143	91	302	9,973	10,256	283	1.77	10,971	11,995	853,866

Table A-1 (continued). Data from all Deep Trek tests, averaged over the interval of “constant” test parameter settings.

Test Number	Data Point . No.	Rock[1]	Drill Bit[2]	Drilling Fluid[3]	Drilled Interval in	ROP[4] ft/hr	ROP in/rev	Temp °F	Torque ft-lb	Hyd. Horse-power[5] HP	Weight on Bit lb	Rotary Speed rpm	Flow Rate gpm	Bore Press. psi	Swivel Mud Press. psi	Bit Press. Drop psi	HSI Horse-power[6] HP/in^2	Conf. Stress psi	Over-burden Stress psi	Mech. Specific Energy psi
Deep 03	7	Crab Orch.	737-1	WB-11	4.6- 4.7	0.1	0.0003	97.7	365	6.4	20,055	92	301	9,980	10,254	274	1.7	10,963	11,987	4,478,043
Deep 03	8	Crab Orch.	737-1	WB-11	4.7- 4.7	0	0	100.2	288	5	10,146	92	302	10,002	10,277	275	1.71	10,987	12,021	
Deep 03	9	Crab Orch.	737-1	WB-11	4.7- 4.7	0	0	101.1	276	5.8	10,067	111	302	9,981	10,250	270	1.68	10,997	12,032	
Deep 03	10	Crab Orch.	737-1	WB-11	4.7- 4.9	0.7	0.0013	102.3	410	8.6	20,025	111	302	9,998	10,267	269	1.68	10,981	12,000	867,565
Deep 03	11	Crab Orch.	737-1	WB-11	5.0- 5.3	2.1	0.0037	103.5	548	11.5	30,242	111	302	10,014	10,279	266	1.66	10,992	12,018	387,279
Deep 03	12	Crab Orch.	737-1	WB-11	5.4- 6.1	4.7	0.0086	104.3	782	16.4	40,034	110	302	10,001	10,257	256	1.59	10,989	12,021	245,444
Deep 03	13	Crab Orch.	737-1	WB-11	6.3- 8.0	4.9	0.0109	105.5	690	11.9	29,889	90	300	9,898	10,152	254	1.57	10,993	11,905	170,037
Deep 03	14	Crab Orch.	737-1	WB-11	8.0- 8.2	2.3	0.0065	107.1	561	7.5	20,148	71	302	9,986	10,233	248	1.54	11,000	11,972	231,617
Deep 03	15	Crab Orch.	737-1	WB-11	8.4- 8.9	5	0.0143	107.7	790	10.6	30,174	70	302	10,003	10,252	249	1.55	10,995	11,990	148,534
Deep 03	16	Crab Orch.	737-1	WB-11	9.1- 9.8	6.4	0.0182	108.2	970	13	40,282	70	302	10,007	10,264	257	1.6	10,992	12,010	142,883
Deep 03	17	Crab Orch.	737-1	WB-11	9.9-10.4	5.4	0.0119	108.7	934	16.2	40,257	91	302	10,009	10,254	245	1.53	10,984	12,004	211,286
Deep 03	18	Crab Orch.	737-1	WB-11	10.5-10.7	1.7	0.0036	109.2	649	11.3	30,174	91	302	9,989	10,245	255	1.59	10,993	11,991	464,275
Deep 03	19	Crab Orch.	737-1	WB-11	10.7-10.7	0.6	0.0012	109.8	467	8.1	20,124	91	302	10,005	10,252	247	1.54	10,986	11,973	945,090
Deep 03	20	Crab Orch.	737-1	WB-11	10.7-10.9	0.6	0.001	110.5	439	9.3	20,117	111	302	10,002	10,247	246	1.53	10,964	11,961	1,083,578
Deep 03	21	Crab Orch.	737-1	WB-11	10.9-11.0	1.3	0.0023	111.1	585	12.4	30,175	111	302	10,003	10,244	240	1.5	11,000	11,987	667,067
Deep 03	22	Crab Orch.	737-1	WB-11	11.1-11.4	2	0.0036	111.6	715	15.1	40,066	111	302	9,993	10,227	235	1.46	10,962	11,980	530,517
Deep 04	1	Carthage	M333-1	WB-11	2.9- 3.8	4.3	0.0094	93.7	386	6.7	5,098	91	302	9,989	10,272	284	1.77	11,002	11,944	109,098
Deep 04	2	Carthage	M333-1	WB-11	4.0- 6.0	9.5	0.0211	95	1070	18.4	10,148	90	302	9,998	10,261	263	1.64	11,013	11,939	135,517
Deep 04	3	Carthage	M333-1	WB-11	6.3- 8.4	17.5	0.0389	96	2086	35.7	15,030	90	302	9,993	10,264	272	1.69	11,001	11,934	143,572
Deep 04	4	Carthage	M333-1	WB-11	8.9-12.2	29.4	0.0653	96.7	3193	54.7	20,147	90	302	9,998	10,271	272	1.7	11,016	11,950	131,039
Deep 04	5	Carthage	M333-1	WB-11	13.5-18.1	39.7	0.0656	97.7	3276	75.5	19,891	121	302	10,007	10,272	265	1.65	11,028	11,959	133,834
Deep 04	6	Carthage	M333-1	WB-11	18.5-20.7	20.9	0.0346	98.4	1921	44.3	15,076	121	302	9,994	10,259	265	1.65	11,033	11,956	148,821
Deep 04	7	Carthage	M333-1	WB-11	21.0-22.7	11.2	0.0184	99.2	1046	24.1	10,002	121	302	9,978	10,243	265	1.65	11,013	11,950	151,028
Deep 04	8	Carthage	M333-1	WB-11	22.9-23.3	4.2	0.0069	100.1	357	8.2	5,173	121	301	9,958	10,217	259	1.61	10,993	11,952	137,316
Deep 04	9	Carthage	M333-1	WB-11	23.6-26.0	17.3	0.0382	100.8	1816	31.4	14,987	91	301	10,018	10,279	261	1.62	11,005	11,960	127,895
Deep 04	10	Carthage	M333-1	WB-11	26.2-26.5	3.4	0.0074	101.5	402	7	5,138	91	302	10,017	10,272	255	1.59	11,012	11,959	143,641
Deep 05	1	Crab Orch.	M333-1	WB-11	3.7- 4.1	7.2	0.0158	96.2	796	13.8	5,041	91	302	9,966	10,249	283	1.77	11,036	11,923	134,319
Deep 05	2	Crab Orch.	M333-1	WB-11	4.5- 5.8	17.1	0.0378	96.7	1731	29.7	10,301	90	302	9,976	10,257	281	1.75	10,960	11,980	121,838
Deep 05	3	Crab Orch.	M333-1	WB-11	6.2- 8.6	21.3	0.0471	97.3	2659	45.7	15,217	90	302	9,983	10,283	300	1.87	11,029	12,046	150,341
Deep 05	4	Crab Orch.	M333-1	WB-11	9.2-12.2	26.5	0.0588	98.1	3516	60.3	20,064	90	302	9,993	10,293	300	1.87	11,015	12,034	159,925
Deep 05	5	Crab Orch.	M333-1	WB-11	3.1-17.0	44.3	0.0733	98.9	3539	81.5	19,621	121	302	9,969	10,261	291	1.82	11,012	12,038	129,579

Table A-1 (continued). Data from all Deep Trek tests, averaged over the interval of "constant" test parameter settings.

Test Number	Data Point . No.	Rock[1]	Drill Bit[2]	Drilling Fluid[3]	Drilled Interval in	ROP[4] ft/hr	ROP in/rev	Temp °F	Torque ft-lb	Hyd. Horse-power[5] HP	Weight on Bit lb	Rotary Speed rpm	Flow Rate gpm	Bore Press. psi	Swivel Mud Press. psi	Bit Press. Drop psi	HSI Horse-power[6] HP/in²	Conf. Stress psi	Over-burden Stress psi	Mech. Specific Energy psi
Deep 05	6	Crab Orch.	M333-1	WB-11	17.9-22.5	48	0.0792	99.6	2875	66.4	14,925	121	303	9,993	10,280	288	1.8	11,038	12,090	97,160
Deep 05	7	Crab Orch.	M333-1	WB-11	23.2-25.9	37.5	0.0616	100.2	1629	37.8	10,076	122	302	9,945	10,224	279	1.74	10,995	12,008	71,019
Deep 05	8	Crab Orch.	M333-1	WB-11	26.4-28.1	20.7	0.0339	100.8	288	6.7	4,964	122	302	9,998	10,288	290	1.81	11,050	12,019	22,807
Deep 06	1	Carthage	M841-1	WB-11	2.0- 2.8	1.4	0.0046	96.3	145	1.6	10,055	59	302	10,000	10,058	58	0.36	11,002	12,029	81,832
Deep 06	2	Carthage	M841-1	WB-11	2.9- 4.0	2.4	0.004	99.5	190	4.4	10,092	121	301	10,010	10,092	82	0.51	11,014	12,051	128,079
Deep 06	3	Carthage	M841-1	WB-11	4.1- 5.0	3	0.0033	101.8	249	8.5	10,147	180	301	10,028	10,105	77	0.48	10,998	12,058	199,559
Deep 06	4	Carthage	M841-1	WB-11	5.1- 6.5	3.5	0.0028	103.7	295	14.1	10,192	251	301	10,023	10,103	80	0.5	11,021	12,062	282,437
Deep 06	5	Carthage	M841-1	WB-11	6.6- 8.0	5.1	0.0041	105.4	856	40.7	20,090	250	301	10,032	10,102	70	0.44	11,024	12,068	560,188
Deep 06	6	Carthage	M841-1	WB-11	8.1- 9.5	4.4	0.0048	106.8	898	30.8	20,034	180	301	10,023	10,103	80	0.5	11,002	12,073	490,527
Deep 06	7	Carthage	M841-1	WB-11	9.6-11.0	3.5	0.0058	108.4	902	20.6	19,997	120	301	10,020	10,093	72	0.45	11,011	12,093	413,050
Deep 06	8	Carthage	M841-1	WB-11	11.1-12.0	2.4	0.0081	110	1047	11.9	20,083	60	302	10,013	10,049	35	0.22	11,007	12,083	349,710
Deep 06	9	Carthage	M841-1	WB-11	12.1-13.0	2.6	0.0087	111.6	1946	22.3	30,015	60	301	10,027	10,060	33	0.2	11,012	12,062	599,831
Deep 06	10	Carthage	M841-1	WB-11	13.1-14.0	4.2	0.0068	112.8	1491	35	30,040	123	318	10,025	10,033	8	0.05	11,001	12,071	583,262
Deep 06	11	Carthage	M841-1	WB-11	14.2-15.2	5.8	0.0064	113.8	1361	46.7	30,010	180	301	10,027	10,075	48	0.3	10,995	12,077	564,234
Deep 06	12	Carthage	M841-1	WB-11	15.6-16.8	7.2	0.0058	114.7	1325	63.1	30,293	250	301	10,030	10,102	72	0.44	11,006	12,071	614,497
Deep 06	13	Carthage	M841-1	WB-11	17.1-18.8	8.1	0.0065	115.5	1605	76.5	40,290	250	301	10,039	10,113	74	0.46	11,005	12,037	661,919
Deep 06	14	Carthage	M841-1	WB-11	18.9-20.0	5	0.0056	116.2	1330	45.6	40,236	180	301	10,027	10,109	82	0.51	11,000	12,015	639,823
Deep 06	15	Carthage	M841-1	WB-11	20.1-21.1	4.4	0.0073	116.9	1749	39.6	40,097	119	310	9,999	10,033	34	0.21	10,997	11,992	632,118
Deep 06	16	Carthage	M841-1	WB-11	21.2-21.4	2.9	0.0097	117.3	2326	26.8	40,271	60	292	10,050	10,095	45	0.27	10,996	11,980	643,079
Deep 06	17	Carthage	M841-1	WB-11	21.4-21.8	2.9	0.0047	117.8	866	20	19,974	121	296	10,036	10,082	46	0.28	10,994	11,945	482,481
Deep 07	1	Crab Orch.	M841-1	WB-11	2.1- 2.5	0.9	0.0028	101.8	737	8.4	10,143	60	303	9,992	10,025	34	0.21	11,001	12,014	655,470
Deep 07	2	Crab Orch.	M841-1	WB-11	2.6- 3.6	2.7	0.0044	103.8	592	13.5	10,173	120	303	10,005	10,072	68	0.42	11,002	12,028	351,175
Deep 07	3	Crab Orch.	M841-1	WB-11	3.7- 5.1	4.7	0.0053	105.3	501	17.2	10,127	180	303	10,027	10,089	62	0.39	10,995	12,015	256,188
Deep 07	4	Crab Orch.	M841-1	WB-11	5.3- 7.0	6.7	0.0053	106.5	415	19.8	10,028	251	303	10,008	10,058	50	0.31	10,997	12,047	207,648
Deep 07	5	Crab Orch.	M841-1	WB-11	7.4- 9.1	11.5	0.0092	107.3	1164	55.5	20,149	250	303	9,956	10,007	51	0.32	11,004	12,072	338,104
Deep 07	6	Crab Orch.	M841-1	WB-11	9.3-11.1	7.6	0.0084	108	1242	42.6	20,158	180	303	10,012	10,060	48	0.3	11,006	12,022	392,923
Deep 07	7	Crab Orch.	M841-1	WB-11	11.2-12.1	5.1	0.0086	108.7	1566	35.9	20,172	120	306	10,004	10,031	27	0.17	11,008	12,017	492,008
Deep 07	8	Crab Orch.	M841-1	WB-11	12.1-13.1	2.2	0.0072	109.6	1765	20.5	19,969	61	303	10,001	10,042	40	0.25	11,000	12,039	653,221
Deep 07	9	Crab Orch.	M841-1	WB-11	14.3-16.1	7.3	0.0121	111.8	2272	52.1	30,091	120	303	10,010	10,030	20	0.12	11,006	12,037	499,037
Deep 07	10	Crab Orch.	M841-1	WB-11	16.5-18.0	11.6	0.0128	112.5	2139	73.7	30,136	181	305	10,024	10,047	23	0.15	11,004	12,069	446,076
Deep 07	11	Crab Orch.	M841-1	WB-11	22.5-24.2	15.4	0.0123	114.7	1553	74.1	24,985	250	302	9,990	10,005	14	0.09	11,008	12,078	337,031

Table A-1 (continued). Data from all Deep Trek tests, averaged over the interval of "constant" test parameter settings.

Test Number	Data Point . No.	Rock[1]	Drill Bit[2]	Drilling Fluid[3]	Drilled Interval in	ROP[4] ft/hr	ROP in/rev	Temp °F	Torque ft-lb	Hyd. Horse-power[5] HP	Weight on Bit lb	Rotary Speed rpm	Flow Rate gpm	Bore Press. psi	Swivel Mud Press. psi	Bit Press. Drop psi	HSI Horse-power[6] HP/in²	Conf. Stress psi	Over-burden Stress psi	Mech. Specific Energy psi
Deep 07	12	Crab Orch.	M841-1	WB-11	27.2-28.2	8	0.0134	115.5	2137	48.9	24,948	120	304	9,979	9,964	-14	-0.09	11,013	12,073	428,282
Deep 07	13	Crab Orch.	M841-1	WB-11	28.6-30.1	7.3	0.0121	116.2	1566	35.9	20,067	120	303	9,980	9,977	-2	-0.02	11,029	12,043	343,943
Deep 08	1	Crab Orch.	M121-1	WB-11	3.2- 4.2	5.4	0.0118	94.8	350	6	5,000	90	301	10,012	10,410	398	2.47	11,015	12,031	77,955
Deep 08	2	Crab Orch.	M121-1	WB-11	4.5- 6.3	12.9	0.0286	95.8	1112	19.1	10,199	90	301	10,023	10,409	386	2.4	11,016	12,034	103,803
Deep 08	3	Crab Orch.	M121-1	WB-11	6.6- 8.7	17.9	0.04	96.5	1912	32.6	15,213	90	302	10,007	10,405	398	2.48	11,017	12,033	128,717
Deep 08	4	Crab Orch.	M121-1	WB-11	9.2-12.0	24.9	0.0554	97.1	2877	49.3	20,182	90	302	10,024	10,393	369	2.3	11,011	12,037	139,364
Deep 08	5	Crab Orch.	M121-1	WB-11	12.2-14.2	8.7	0.0193	98.2	1153	19.9	10,065	91	301	10,007	10,389	383	2.38	11,014	12,029	161,158
Deep 08	6	Carthage	M121-1	WB-11	18.5-19.2	1.8	0.004	101.7	360	6.2	5,113	91	301	10,013	10,391	377	2.34	11,025	12,044	242,848
Deep 08	7	Carthage	M121-1	WB-11	19.3-20.7	5.1	0.0113	103.1	865	14.9	10,257	90	301	10,021	10,399	378	2.35	11,019	12,040	203,892
Deep 08	8	Carthage	M121-1	WB-11	21.0-23.2	13	0.0289	104.1	1725	29.5	15,152	90	301	10,029	10,399	370	2.3	11,035	12,027	159,767
Deep 08	9	Carthage	M121-1	WB-11	23.7-28.2	26.6	0.0594	104.9	2775	47.4	20,031	90	301	10,009	10,373	364	2.26	11,020	12,026	125,896
Deep 08	10	Carthage	M121-1	WB-11	28.5-29.5	6.5	0.0143	105.7	896	15.5	9,920	91	301	10,009	10,372	363	2.26	11,019	12,037	167,604
Deep 09	1	Crab Orch.	M333-1	Base Oil	3.7- 3.9	27.5	0.0613	92.5	481	8.2	4,982	90	300	10,018	10,390	372	2.3	11,005	12,003	21,165
Deep 09	2	Crab Orch.	M333-1	Base Oil	4.7- 5.8	47.4	0.1058	92.9	952	16.2	10,307	90	300	10,011	10,349	338	2.09	11,002	12,009	24,466
Deep 09	3	Crab Orch.	M333-1	Base Oil	6.7- 8.9	61.3	0.137	93.3	1424	24.3	15,075	90	300	9,998	10,358	360	2.23	11,011	12,022	28,409
Deep 09	4	Crab Orch.	M333-1	Base Oil	10.4-11.4	89.1	0.2001	93.8	2482	42.1	18,666	89	300	9,956	10,339	382	2.37	11,019	12,004	33,716
Deep 09	5	Crab Orch.	M333-1	Base Oil	14.5-15.8	57.8	0.129	94.3	1229	21	10,765	90	302	10,032	10,421	388	2.42	11,020	12,030	25,896
Deep 09	6	Mancos	M333-1	Base Oil	18.5-19.8	15	0.0333	95.4	944	16.1	5,137	90	301	9,994	10,344	350	2.18	11,027	12,015	75,702
Deep 09	7	Mancos	M333-1	Base Oil	20.5-21.8	39.7	0.0888	96.1	1982	33.8	10,081	89	302	10,028	10,346	318	1.98	11,029	12,023	59,600
Deep 09	8	Mancos	M333-1	Base Oil	23.2-26.2	75.3	0.1683	96.6	3373	57.5	15,389	90	300	9,993	10,308	315	1.95	11,029	12,027	54,297
Deep 09	9	Mancos	M333-1	Base Oil	27.6-28.7	90.1	0.2013	96.9	4055	69.1	18,097	90	301	10,037	10,381	344	2.14	11,029	12,037	54,647
Deep 09	10	Mancos	M333-1	Base Oil	29.3-31.4	33.7	0.0747	97.5	2097	36	10,385	90	301	9,974	10,318	345	2.14	11,028	12,031	75,038
Deep 10	1	Crab Orch.	M333-1	OB-12	3.0- 3.3	1.6	0.0034	109.3	595	10.3	5,059	91	301	10,078	10,418	340	2.11	11,006	12,023	451,387
Deep 10	2	Crab Orch.	M333-1	OB-12	3.4- 4.4	5.2	0.0114	110.8	1167	20.1	10,198	90	300	10,053	10,397	344	2.13	10,998	12,012	269,668
Deep 10	3	Crab Orch.	M333-1	OB-12	4.6- 6.9	9	0.02	113.1	1975	33.9	15,214	90	300	10,074	10,399	325	2.01	11,000	12,005	263,871
Deep 10	4	Crab Orch.	M333-1	OB-12	7.1-13.9	13.9	0.031	117	2741	47	20,141	90	299	10,058	10,357	300	1.85	11,005	12,011	237,345
Deep 10	5	Crab Orch.	M333-1	OB-12	14.0-14.6	2	0.0043	120.8	1090	18.8	10,185	91	300	10,051	10,356	305	1.89	11,021	12,017	661,627
Deep 10	6	Crab Orch.	M333-1	OB-12	15.0-16.2	15.8	0.0352	122.3	3002	51.3	20,118	90	300	10,050	10,339	289	1.79	11,021	12,016	228,712
Deep 10	7	Mancos	M333-1	OB-12	19.3-19.8	4.4	0.0098	127.2	1064	18.4	5,098	91	301	10,048	10,327	279	1.74	11,027	12,011	293,586
Deep 10	8	Mancos	M333-1	OB-12	20.2-21.3	13.7	0.0302	128.2	1852	31.9	10,098	90	301	10,053	10,330	277	1.72	11,030	12,016	162,576
Deep 10	9	Mancos	M333-1	OB-12	21.6-24.8	30.4	0.0675	129.2	2820	48.3	14,749	90	301	10,141	10,416	275	1.71	11,031	12,025	111,837

Table A-1 (continued). Data from all Deep Trek tests, averaged over the interval of “constant” test parameter settings.

Test Number	Data Point . No.	Rock[1]	Drill Bit[2]	Drilling Fluid[3]	Drilled Interval in	ROP[4] ft/hr	ROP in/rev	Temp °F	Torque ft-lb	Hyd. Horse-power[5] HP	Weight on Bit lb	Rotary Speed rpm	Flow Rate gpm	Bore Press. psi	Swivel Mud Press. psi	Bit Press. Drop psi	HSI Horse-power[6] HP/in^2	Conf. Stress psi	Over-burden Stress psi	Mech. Specific Energy psi
Deep 10	10	Mancos	M333-1	OB-12	26.1-27.9	47	0.1045	130	4294	73.6	21,148	90	300	10,094	10,357	263	1.63	11,031	12,026	110,382
Deep 10	11	Mancos	M333-1	OB-12	30.3-31.8	20.5	0.0454	130.6	2157	37.2	10,094	91	302	10,128	10,397	269	1.68	11,031	12,005	128,023
Deep 11	1	Crab Orch.	M841-1	OB-12	2.2- 2.5	0.9	0.003	98.2	2252	25.8	20,076	60	302	10,014	10,171	157	0.98	11,069	12,083	2,002,488
Deep 11	2	Crab Orch.	M841-1	OB-12	2.5- 3.7	4.1	0.0069	100.2	1902	43.4	20,339	120	302	10,013	10,191	178	1.11	11,073	12,075	742,963
Deep 11	3	Crab Orch.	M841-1	OB-12	4.2- 5.3	6.6	0.0073	102.8	1131	38.7	20,116	180	302	10,018	10,195	177	1.1	11,071	12,067	411,984
Deep 11	4	Crab Orch.	M841-1	OB-12	5.6- 7.3	10.1	0.008	104.4	982	47	20,227	251	301	10,008	10,162	154	0.96	11,072	12,071	326,104
Deep 11	5	Crab Orch.	M841-1	OB-12	7.6-10.2	15.6	0.0125	106.6	2268	108	30,184	250	302	9,995	10,166	171	1.06	11,080	12,088	485,683
Deep 11	6	Crab Orch.	M841-1	OB-12	10.7-12.2	10.2	0.0114	108.5	2677	91.6	30,242	180	302	9,986	10,147	160	1	11,071	12,092	630,952
Deep 11	7	Crab Orch.	M841-1	OB-12	12.5-13.3	6.9	0.0116	109.9	2964	67.6	30,035	120	303	10,005	10,166	160	1	11,069	12,101	688,367
Deep 11	8	Mancos	M841-1	OB-12	19.5-20.0	2	0.0066	121	2026	23.3	20,014	60	301	10,028	10,141	113	0.7	11,110	12,149	811,108
Deep 11	9	Mancos	M841-1	OB-12	20.1-21.3	7.6	0.0127	122.9	2277	52.2	19,919	120	301	10,012	10,133	121	0.75	11,113	12,132	480,073
Deep 11	10	Mancos	M841-1	OB-12	21.6-22.2	8	0.0089	124.8	1491	50.9	19,992	179	301	9,998	10,103	106	0.65	11,121	12,105	445,522
Deep 11	11	Mancos	M841-1	OB-12	22.6-23.5	11	0.0088	126.3	1379	65.8	20,050	251	301	10,010	10,129	119	0.74	11,124	12,111	420,259
Deep 11	12	Mancos	M841-1	OB-12	23.9-25.4	17.4	0.014	127.2	2090	99.4	29,973	250	301	10,017	10,128	112	0.69	11,130	12,135	401,443
Deep 11	13	Mancos	M841-1	OB-12	25.7-27.4	15.4	0.0169	128.4	2745	95	30,437	182	301	10,016	10,122	106	0.66	11,137	12,150	433,622
Deep 11	14	Mancos	M841-1	OB-12	28.1-28.7	8.5	0.014	129.6	2736	63.2	25,219	121	301	10,023	10,132	109	0.68	11,145	12,162	520,195
Deep 11	15	Mancos	M841-1	OB-12	28.8-29.1	5.2	0.017	130.5	2788	32.1	24,619	60	301	10,000	10,094	94	0.58	11,150	12,166	429,794
Deep 11	16	Mancos	M841-1	OB-12	29.5-30.1	5.6	0.0093	132.1	2264	51.7	19,842	120	302	10,012	10,111	99	0.62	11,159	12,177	647,559
Deep 11	17	Mancos	M841-1	OB-12	30.4-30.8	7.6	0.0084	133.3	1602	54.9	19,803	180	302	10,012	10,109	97	0.61	11,165	12,183	506,595
Deep 13	1	Crab Orch.	M333-1	OB-16	3.2- 3.3	0.4	0.0009	99.2	521	8.9	4,852	90	303	10,041	10,237	197	1.23	11,018	12,000	1,563,172
Deep 13	2	Crab Orch.	M333-1	OB-16	3.4- 4.0	1.8	0.004	101.9	1012	17.4	10,098	90	302	9,960	10,147	188	1.17	11,007	12,000	675,024
Deep 13	3	Crab Orch.	M333-1	OB-16	4.2- 5.1	5.5	0.0122	104	1766	30.2	15,027	90	303	9,937	10,125	189	1.18	11,012	12,012	385,841
Deep 13	4	Crab Orch.	M333-1	OB-16	5.3- 6.5	9.7	0.0217	105.2	2426	41.4	20,030	90	304	10,003	10,185	182	1.15	11,006	12,024	300,832
Deep 13	5	Crab Orch.	M333-1	OB-16	6.9-13.5	12.3	0.0203	107.8	2359	54.2	19,957	121	305	10,029	10,213	184	1.16	11,021	12,033	310,125
Deep 13	6	Crab Orch.	M333-1	OB-16	13.6-13.9	3.4	0.0057	110	1356	31.3	14,826	121	305	10,005	10,210	205	1.29	11,018	12,016	643,960
Deep 13	7	Crab Orch.	M333-1	OB-16	13.9-13.9	0.5	0.0008	110.5	599	13.9	10,212	122	306	10,029	10,217	187	1.18	11,018	12,017	1,949,108
Deep 13	8	Crab Orch.	M333-1	OB-16	14.2-16.9	12.2	0.0203	111.6	2252	51.8	19,918	121	305	10,027	10,227	201	1.26	11,019	12,036	298,510
Deep 13	9	Mancos	M333-1	OB-16	19.2-19.3	0.7	0.0015	113.7	295	5.1	4,905	91	305	9,995	10,155	160	1.01	11,020	12,008	511,507
Deep 13	10	Mancos	M333-1	OB-16	19.7-20.3	9.4	0.021	114.6	1247	21.3	10,159	90	305	10,035	10,212	177	1.11	11,026	12,027	159,551
Deep 13	11	Mancos	M333-1	OB-16	20.5-21.3	20.9	0.0466	114.9	2178	37.2	14,577	90	305	9,986	10,158	172	1.08	11,027	12,030	125,568
Deep 13	12	Mancos	M333-1	OB-16	24.0-25.2	49.2	0.1093	115.3	4002	68.7	20,698	90	301	10,137	10,305	169	1.05	11,028	12,045	98,342

Table A-1 (continued). Data from all Deep Trek tests, averaged over the interval of “constant” test parameter settings.

Test Number	Data Point. No.	Rock[1]	Drill Bit[2]	Drilling Fluid[3]	Drilled Interval in	ROP[4] ft/hr	ROP in/rev	Temp °F	Torque ft-lb	Hyd. Horse-power[5] HP	Weight on Bit lb	Rotary Speed rpm	Flow Rate gpm	Bore Press. psi	Swivel Mud Press. psi	Bit Press. Drop psi	HSI Horse-power[6] HP/in^2	Conf. Stress psi	Over-burden Stress psi	Mech. Specific Energy psi
Deep 13	13	Mancos	M333-1	OB-16	26.3-28.2	28.9	0.0639	115.7	2621	45.1	14,907	90	300	10,158	10,291	132	0.82	11,029	12,036	109,358
Deep 13	14	Mancos	M333-1	OB-16	28.4-29.1	14.2	0.0311	116	1451	25.2	9,869	91	301	10,068	10,202	134	0.83	11,028	12,022	124,331
Deep 13	15	Mancos	M333-1	OB-16	29.2-29.3	1.1	0.0024	116.4	385	6.7	4,924	92	301	10,140	10,277	137	0.85	11,030	12,023	429,507
Deep 13	16	Mancos	M333-1	OB-16	30.0-31.7	43.4	0.0962	116.7	3554	61	19,466	90	300	10,124	10,272	148	0.92	11,033	12,054	98,956
Deep 14	1	Crab Orch.	M333-1	OB-16	2.9- 2.9	0.01	0	108.5	383	6.7	4,992	91	335	9,924	10,562	638	4.41	11,018	12,015	46,470,843
Deep 14	2	Crab Orch.	M333-1	OB-16	2.9- 2.9	0.3	0.0006	109.7	607	10.5	10,220	91	335	9,932	10,569	637	4.4	11,011	12,020	2,455,339
Deep 14	3	Crab Orch.	M333-1	OB-16	3.2- 4.2	7	0.0154	111.1	1778	30.6	15,255	90	335	9,942	10,576	634	4.38	11,014	12,033	305,340
Deep 14	4	Crab Orch.	M333-1	OB-16	4.5- 6.6	18.8	0.0417	112.2	2909	49.9	19,998	90	335	9,919	10,558	638	4.41	11,009	12,041	186,388
Deep 14	5	Crab Orch.	M333-1	OB-16	7.2-12.4	17.6	0.0291	114	2590	59.8	20,320	121	335	9,915	10,535	620	4.29	11,009	12,023	238,135
Deep 14	6	Crab Orch.	M333-1	OB-16	13.0-13.1	2.1	0.0034	115.7	1257	29.1	15,070	122	335	9,925	10,546	621	4.29	11,009	12,020	974,209
Deep 14	7	Crab Orch.	M333-1	OB-16	13.5-15.9	21	0.0349	116.5	2653	60.9	19,983	121	335	9,925	10,542	617	4.27	11,009	12,032	204,525
Deep 14	8	Mancos	M333-1	OB-16	20.2-20.3	0.9	0.0019	119.5	350	6.1	4,905	91	335	9,943	10,547	604	4.18	11,019	12,005	472,025
Deep 14	9	Mancos	M333-1	OB-16	20.5-20.6	3.2	0.0071	120.1	734	12.7	10,028	91	335	9,954	10,552	598	4.14	11,024	12,022	278,663
Deep 14	10	Mancos	M333-1	OB-16	20.9-24.2	26.8	0.0594	121	2228	38.2	14,875	90	335	9,955	10,566	611	4.23	11,028	12,034	100,287
Deep 14	11	Mancos	M333-1	OB-16	25.2-28.7	41	0.091	121.9	3359	57.6	19,979	90	335	9,950	10,574	623	4.31	11,030	12,043	99,019
Deep 14	12	Mancos	M333-1	OB-16	29.6-30.7	18.3	0.0405	122.5	2069	35.7	15,136	91	335	9,947	10,556	609	4.21	11,033	12,041	137,715
Deep 14	13	Mancos	M333-1	OB-16	31.0-31.1	2.5	0.0054	123.2	772	13.4	10,158	91	335	9,920	10,512	592	4.09	11,038	12,039	375,037
Deep 15	1	Crab Orch.	M121-1	OB-16	3.3- 3.3	0.3	0.0006	99.2	292	5	4,886	90	302	10,008	10,307	298	1.86	11,001	11,990	1,168,173
Deep 15	2	Crab Orch.	M121-1	OB-16	3.4- 3.7	2.1	0.0047	100.7	1069	18.4	10,020	90	302	10,011	10,307	297	1.85	11,011	12,067	611,212
Deep 15	3	Crab Orch.	M121-1	OB-16	4.0- 5.3	9.9	0.0219	102.1	2140	36.7	15,114	90	302	10,031	10,314	282	1.76	11,017	12,062	259,928
Deep 15	4	Crab Orch.	M121-1	OB-16	5.7- 7.4	22.9	0.0507	103.1	3421	58.8	20,018	90	302	10,049	10,330	280	1.75	11,005	12,054	179,974
Deep 15	5	Crab Orch.	M121-1	OB-16	7.9-10.7	29.7	0.0489	103.9	3298	76.3	20,038	121	301	10,009	10,298	289	1.8	11,007	12,051	179,859
Deep 15	6	Crab Orch.	M121-1	OB-16	10.9-11.3	9	0.0148	104.6	1790	41.3	14,907	121	301	9,950	10,257	307	1.91	11,009	12,047	321,401
Deep 15	7	Crab Orch.	M121-1	OB-16	11.4-11.5	1.5	0.0024	105.3	876	20.3	9,973	121	301	9,962	10,234	271	1.69	11,010	12,042	942,539
Deep 15	8	Mancos	M121-1	OB-16	12.0-16.3	28.5	0.0474	106.3	3102	71.1	20,091	120	302	10,055	10,335	279	1.74	11,023	12,062	174,858
Deep 15	9	Mancos	M121-1	OB-16	18.9-19.0	0.6	0.0013	108.4	286	5	4,968	91	301	10,002	10,271	269	1.67	11,017	12,047	578,531
Deep 15	10	Mancos	M121-1	OB-16	19.3-20.8	21.7	0.0479	109.1	1695	29.2	9,981	91	301	10,034	10,315	281	1.75	11,024	12,050	95,127
Deep 15	11	Mancos	M121-1	OB-16	22.1-24.5	59.3	0.1312	109.6	3524	60.7	14,729	90	301	10,082	10,330	248	1.54	11,015	12,040	71,833
Deep 15	12	Mancos	M121-1	OB-16	26.6-30.0	86.8	0.1921	110	5075	87.3	20,263	90	300	10,074	10,352	278	1.72	11,009	12,033	70,878
Deep 15	13	Mancos	M121-1	OB-16	30.4-31.2	10.6	0.0236	110.6	1227	21.1	9,805	90	301	10,021	10,299	278	1.73	11,003	12,016	139,252
Deep 12	1	Crab Orch.	M841-1	OB-16	1.7- 1.8	0.5	0.0017	105.8	1600	18.6	20,164	61	300	10,074	10,164	90	0.55	11,019	12,055	2,603,380

Table A-1 (continued). Data from all Deep Trek tests, averaged over the interval of “constant” test parameter settings.

Test Number	Data Point . No.	Rock[1]	Drill Bit[2]	Drilling Fluid[3]	Drilled Interval in	ROP[4] ft/hr	ROP in/rev	Temp °F	Torque ft-lb	Hyd. Horse-power[5] HP	Weight on Bit lb	Rotary Speed rpm	Flow Rate gpm	Bore Press. psi	Swivel Mud Press. psi	Bit Press. Drop psi	HSI Horse-power[6] HP/in^2	Conf. Stress psi	Over-burden Stress psi	Mech. Specific Energy psi
Deep 12	2	Crab Orch.	M841-1	OB-16	1.8- 2.0	1.4	0.0023	107.3	1421	32.5	20,371	120	300	10,014	10,128	114	0.71	11,009	12,054	1,624,720
Deep 12	3	Crab Orch.	M841-1	OB-16	2.1- 2.4	2.2	0.0025	108.5	1057	36.4	20,322	181	299	10,013	10,123	110	0.68	11,001	12,054	1,160,216
Deep 12	4	Crab Orch.	M841-1	OB-16	2.5- 3.2	4.1	0.0033	109.8	926	44.4	20,310	252	299	10,004	10,126	122	0.75	10,994	12,012	759,587
Deep 12	5	Crab Orch.	M841-1	OB-16	3.3- 3.7	6.7	0.0053	110.9	1874	89.2	30,303	250	299	10,033	10,178	146	0.9	10,990	12,019	933,410
Deep 12	6	Crab Orch.	M841-1	OB-16	4.0- 4.9	2.5	0.002	112.5	1417	68	30,162	252	299	10,004	10,126	123	0.76	11,019	12,042	1,905,515
Deep 12	7	Crab Orch.	M841-1	OB-16	4.9- 5.1	1.5	0.0017	114	1626	56	29,951	181	299	10,038	10,138	99	0.61	11,024	12,051	2,617,113
Deep 12	8	Crab Orch.	M841-1	OB-16	5.1- 5.3	0.9	0.0015	115	1718	39.2	29,894	120	299	10,048	10,125	77	0.47	11,029	12,031	3,055,280
Deep 12	9	Crab Orch.	M841-1	OB-16	5.2- 5.3	0.3	0.0011	115.8	1899	21.7	30,133	60	299	10,033	10,113	80	0.5	11,032	12,047	5,065,066
Deep 12	10	Crab Orch.	M841-1	OB-16	5.4-13.2	11.8	0.0095	118.7	1927	91.7	30,119	250	299	10,035	10,150	116	0.71	11,067	12,121	545,416
Deep 12	11	Crab Orch.	M841-1	OB-16	13.3-14.0	5.8	0.0065	120.6	2222	76.2	29,921	180	299	10,034	10,151	117	0.72	11,078	12,055	920,507
Deep 12	12	Crab Orch.	M841-1	OB-16	14.1-14.4	3.3	0.0055	120.8	2379	54.8	30,108	121	299	10,047	10,146	99	0.61	11,086	12,064	1,164,132
Deep 12	13	Crab Orch.	M841-1	OB-16	14.4-14.4	0.5	0.0018	121.2	2547	29.1	30,166	60	299	10,045	10,147	101	0.63	11,092	12,069	4,076,267
Deep 12	14	Crab Orch.	M841-1	OB-16	14.7-15.8	11.6	0.0093	122.2	1811	86.2	30,171	250	299	10,062	10,183	121	0.75	11,101	12,082	521,469
Deep 12	15	Mancos	M841-1	OB-16	18.8-18.9	1.2	0.0041	123.3	1288	14.7	20,099	60	299	10,007	10,137	130	0.8	11,018	12,021	859,378
Deep 12	16	Mancos	M841-1	OB-16	19.0-19.4	2.5	0.0041	123.9	870	20.1	20,280	121	299	10,013	10,157	144	0.89	11,029	12,033	562,157
Deep 12	17	Mancos	M841-1	OB-16	19.5-20.3	5.6	0.0062	124.7	1047	36.1	19,922	181	299	10,027	10,160	133	0.82	11,042	12,052	451,912
Deep 12	18	Mancos	M841-1	OB-16	20.5-21.3	7.6	0.006	125.3	899	43	19,869	251	298	10,030	10,156	126	0.77	11,054	12,070	396,578
Deep 12	19	Mancos	M841-1	OB-16	21.6-22.8	12.2	0.0097	126.4	1407	67.5	29,948	252	298	10,048	10,173	125	0.77	11,066	12,058	388,561
Deep 12	20	Mancos	M841-1	OB-16	23.5-24.0	8.4	0.0093	126.1	1652	56.9	30,077	181	298	9,986	10,086	99	0.61	11,077	12,020	475,686
Deep 12	21	Mancos	M841-1	OB-16	24.1-24.9	8	0.0133	126.4	2141	48.9	30,205	120	298	10,007	10,098	91	0.56	11,086	12,039	429,268
Deep 12	22	Mancos	M841-1	OB-16	25.1-25.8	5.6	0.0183	126.8	2946	34.2	30,044	61	298	10,031	10,116	85	0.52	11,031	12,034	428,934
Deep 12	23	Mancos	M841-1	OB-16	25.8-26.2	3.1	0.0051	127.3	982	22.6	20,006	121	298	10,005	10,077	72	0.44	11,035	12,027	511,770
Deep 16	1	Crab Orch.	M333-1	OB-16	2.9- 3.0	0.3	0.0006	91	225	3.9	5,114	91	301	4,989	5,265	275	1.71	5,999	7,003	910,181
Deep 16	2	Crab Orch.	M333-1	OB-16	3.0- 3.4	2.1	0.0048	92.5	713	12.2	10,123	90	301	4,994	5,267	273	1.7	5,991	7,002	407,787
Deep 16	3	Crab Orch.	M333-1	OB-16	3.9- 7.7	30.3	0.0674	94.1	2186	37.4	15,243	90	302	5,021	5,295	274	1.71	6,008	7,014	87,113
Deep 16	4	Crab Orch.	M333-1	OB-16	8.3-15.2	39.1	0.0867	95.5	3164	54.3	20,148	90	301	4,999	5,275	275	1.71	5,996	6,999	97,817
Deep 16	5	Crab Orch.	M333-1	OB-16	15.3-15.6	2.1	0.0047	97.2	765	13.2	10,119	91	302	5,002	5,267	265	1.65	5,985	6,982	442,358
Deep 16	6	Crab Orch.	M333-1	OB-16	15.7-16.4	12.2	0.027	98.2	1689	29	15,118	90	302	5,007	5,273	265	1.65	6,000	6,996	166,666
Deep 16	7	Mancos	M333-1	OB-16	19.3-19.5	2.8	0.0062	100.8	552	9.5	5,100	91	302	5,001	5,256	254	1.58	6,012	7,027	239,380
Deep 16	8	Mancos	M333-1	OB-16	20.1-21.2	7.5	0.0167	101.7	1117	19.2	10,390	90	302	5,004	5,261	257	1.6	6,011	7,025	179,087
Deep 16	9	Mancos	M333-1	OB-16	21.8-24.0	65.3	0.1457	102.3	3039	51.8	14,536	90	301	5,020	5,272	252	1.57	6,010	7,021	56,361

Table A-1 (continued). Data from all Deep Trek tests, averaged over the interval of "constant" test parameter settings.

Test Number	Data Point . No.	Rock[1]	Drill Bit[2]	Drilling Fluid[3]	Drilled Interval in	ROP[4] ft/hr	ROP in/rev	Temp °F	Torque ft-lb	Hyd. Horse-power[5] HP	Weight on Bit lb	Rotary Speed rpm	Flow Rate gpm	Bore Press. psi	Swivel Mud Press. psi	Bit Press. Drop psi	HSI Horse-power[6] HP/in^2	Conf. Stress psi	Over-burden Stress psi	Mech. Specific Energy psi
Deep 16	10	Mancos	M333-1	OB-16	27.4-29.1	93.1	0.2061	102.9	4215	72.5	19,591	90	301	5,014	5,289	275	1.71	6,004	6,998	55,022
Deep 16	11	Mancos	M333-1	OB-16	29.8-31.1	27.9	0.0614	103.2	2373	41.1	20,719	91	301	4,992	5,471	480	2.98	6,002	6,983	103,931
Deep 17	1	Mancos	M841-2	OB-16	2.0- 2.3	6	0.02	96.7	2659	30.2	30,126	60	296	10,005	10,182	178	1.09	10,998	12,074	355,599
Deep 17	2	Mancos	M841-2	OB-16	2.6- 3.5	9.4	0.0157	97.9	2294	52.4	30,136	120	295	9,965	10,189	224	1.36	11,009	12,080	391,534
Deep 17	3	Mancos	M841-2	OB-16	3.8- 4.2	6.4	0.0071	99.1	1761	60.5	30,059	181	295	9,952	10,163	211	1.28	10,994	12,077	665,107
Deep 17	4	Mancos	M841-2	OB-16	4.5- 5.1	7.7	0.007	100.3	1123	47.2	30,117	221	295	10,015	10,204	190	1.15	11,001	12,086	430,819
Deep 17	5	Mancos	M841-2	OB-16	5.4- 6.2	11.9	0.0108	100.9	1785	75	40,065	221	295	9,999	10,189	191	1.16	11,022	12,110	443,417
Deep 17	6	Mancos	M841-2	OB-16	6.6- 7.4	13.5	0.015	101.9	2379	81.8	40,175	181	295	9,982	10,198	216	1.32	11,012	12,107	426,704
Deep 17	7	Mancos	M841-2	OB-16	7.8- 8.3	8.2	0.0137	102.5	1970	45	40,259	120	295	9,981	10,279	298	1.81	11,004	12,104	385,814
Deep 17	8	Mancos	M841-2	OB-16	8.4- 8.9	5.3	0.0174	103.3	2681	30.9	40,148	61	297	10,007	10,188	181	1.11	10,995	12,104	412,844
Deep 17	9	Mancos	M841-2	OB-16	8.9- 9.1	2.8	0.0093	104	1206	13.8	20,068	60	295	9,997	10,234	237	1.44	11,014	12,093	345,281
Deep 17	10	Mancos	M841-2	OB-16	9.2- 9.6	4.6	0.0076	104.7	1079	24.8	20,021	121	295	10,023	10,237	214	1.3	11,008	12,095	379,140
Deep 17	11	Mancos	M841-2	OB-16	9.8-10.2	4.5	0.005	105.8	1009	34.6	19,999	180	294	9,989	10,191	202	1.23	11,001	12,095	538,841
Deep 17	12	Mancos	M841-2	OB-16	10.3-10.8	5.1	0.0046	106.8	809	34.3	20,069	223	294	10,012	10,250	238	1.44	11,000	12,075	472,362
Deep 17	13	Mancos	M841-2	OB-16	11.1-12.2	7.7	0.0086	107.8	1882	64.5	29,943	180	294	10,020	10,258	238	1.44	11,012	12,052	587,656
Deep 17	14	Mancos	M841-2	OB-16	12.9-14.7	13.9	0.0155	108.9	2250	77	40,049	180	294	9,964	10,261	297	1.8	11,005	12,060	389,906
Deep 17B	1	Carthage	M841-2	WB-11	18.9-19.1	2.9	0.0094	99.3	1500	17.5	29,772	61	301	9,981	10,196	215	1.34	10,995	12,018	421,743
Deep 17B	2	Carthage	M841-2	WB-11	19.6-19.8	4.1	0.0069	100.8	1013	23	29,648	119	302	9,988	10,220	232	1.45	10,994	12,024	393,071
Deep 17B	3	Carthage	M841-2	WB-11	20.2-20.7	6.9	0.0078	101.8	1341	45.3	29,756	178	302	10,017	10,250	234	1.45	10,991	12,032	462,305
Deep 17B	4	Carthage	M841-2	WB-11	21.0-21.6	8.4	0.0076	103	1354	56.6	30,409	219	302	9,973	10,198	225	1.4	10,999	12,042	471,752
Deep 17B	5	Carthage	M841-2	WB-11	22.8-23.4	10.8	0.0098	104.5	1865	78.3	39,986	220	302	10,003	10,184	181	1.15	10,983	12,064	507,957
Deep 17B	6	Carthage	M841-2	WB-11	23.6-24.2	9	0.01	105.2	1901	65.6	40,069	181	301	9,998	10,200	202	1.28	10,996	12,076	511,167
Deep 17B	7	Carthage	M841-2	WB-11	24.5-25.0	7.6	0.0126	106.2	2168	49.5	40,015	120	302	9,922	10,118	196	1.26	10,992	12,077	457,836
Deep 17B	8	Carthage	M841-2	WB-11	25.1-25.4	5.1	0.0171	106.4	2720	30.8	40,036	59	300	9,901	10,115	215	1.33	10,985	12,077	420,972
Deep 17B	9	Carthage	M841-2	WB-11	25.6-25.8	3.6	0.0119	107.4	1502	17.2	19,964	60	301	9,970	10,188	218	1.36	10,991	12,055	334,484
Deep 17B	10	Carthage	M841-2	WB-11	25.9-26.2	5.7	0.0094	108.2	1360	31.3	19,997	121	301	9,974	10,133	159	1.01	10,997	12,063	385,643
Deep 17B	11	Carthage	M841-2	WB-11	26.4-26.9	6.9	0.0076	108.9	1202	41.5	20,026	181	301	9,983	10,199	216	1.34	10,993	12,065	421,118
Deep 17B	12	Carthage	M841-2	WB-11	27.1-27.9	7.8	0.0071	109.8	1112	46.5	19,993	220	301	9,989	10,204	215	1.34	11,004	12,078	418,895
Deep 17B	13	Carthage	M841-2	WB-11	28.2-28.5	6.7	0.0111	110.6	1788	40.7	30,021	120	301	9,963	10,128	166	1.05	11,003	12,104	428,047
Deep 17B	14	Carthage	M841-2	WB-11	28.8-29.4	9	0.0151	111.1	2416	55	40,051	120	301	9,987	10,230	243	1.51	10,999	12,128	430,928
Deep 17B	15	Carthage	M841-2	WB-11	29.6-29.8	5.4	0.0176	111.6	2696	31.3	39,931	61	301	9,975	10,199	224	1.39	10,995	12,133	407,476

Table A-1 (continued). Data from all Deep Trek tests, averaged over the interval of "constant" test parameter settings.

Test Number	Data Point . No.	Rock[1]	Drill Bit[2]	Drilling Fluid[3]	Drilled Interval in	ROP[4] ft/hr	ROP in/rev	Temp °F	Torque ft-lb	Hyd. Horse-power[5] HP	Weight on Bit lb	Rotary Speed rpm	Flow Rate gpm	Bore Press. psi	Swivel Mud Press. psi	Bit Press. Drop psi	HSI Horse-power[6] HP/in^2	Conf. Stress psi	Over-burden Stress psi	Mech. Specific Energy psi
Deep 18	1	Carthage	M233-2	WB-11	3.0- 3.1	6.5	0.0144	87.9	978	16.7	10,029	90	300	10,033	10,286	253	1.57	10,962	12,011	180,909
Deep 18	2	Carthage	M233-2	WB-11	3.7- 4.3	17.8	0.0402	88.7	2086	35.2	15,020	89	300	10,027	10,313	286	1.77	10,993	12,028	139,598
Deep 18	3	Carthage	M233-2	WB-11	4.9- 6.6	31.7	0.0709	89.5	3276	55.8	20,016	89	300	10,021	10,270	249	1.54	10,977	12,022	123,343
Deep 18	4	Carthage	M233-2	WB-11	7.5-10.0	57.4	0.13	90.2	5078	85.4	25,058	88	300	10,018	10,253	235	1.49	10,963	12,019	104,687
Deep 18	5	Carthage	M233-2	WB-11	10.6-11.4	18.2	0.0401	91.3	2115	36.5	15,022	91	300	10,010	10,271	261	1.61	10,960	12,001	141,531
Deep 18	6	Crab Orch.	M233-2	WB-11	20.4-21.1	8.2	0.0178	96.5	665	11.6	9,905	92	300	10,004	10,279	276	1.71	10,982	12,024	99,830
Deep 18	7	Crab Orch.	M233-2	WB-11	21.3-22.0	11.5	0.0254	97.9	1288	22.1	14,930	90	300	10,006	10,275	269	1.67	10,973	12,028	134,928
Deep 18	8	Crab Orch.	M233-2	WB-11	22.3-23.0	15.6	0.0349	98.8	2061	35.1	19,922	89	300	10,009	10,280	271	1.68	10,973	12,035	157,482
Deep 18	9	Crab Orch.	M233-2	WB-11	23.5-24.4	26.3	0.0589	98.8	3306	56.3	25,036	89	301	10,019	10,275	257	1.6	10,982	12,048	150,054
Deep 18	10	Crab Orch.	M233-2	WB-11	24.5-25.2	12.2	0.027	99.6	1244	21.4	14,843	91	300	9,994	10,273	279	1.73	10,972	12,033	124,245
Deep 18	11	Crab Orch.	M233-2	WB-11	25.5-26.5	23.7	0.0539	100.2	3089	51.7	24,952	88	300	10,006	10,301	295	1.83	10,997	12,058	153,812
Deep 19	1	Carthage	M333L-2	WB-11	2.9- 3.1	6.4	0.0143	87.8	855	14.7	10,117	90	302	10,020	10,311	291	1.81	11,019	12,065	160,670
Deep 19	2	Carthage	M333L-2	WB-11	3.4- 4.3	11.8	0.0264	88.7	1528	26.1	15,106	90	302	10,031	10,309	278	1.73	10,998	12,045	155,924
Deep 19	3	Carthage	M333L-2	WB-11	4.7- 5.8	19.7	0.0445	88.9	2374	40	20,205	88	302	10,036	10,347	311	1.94	11,024	12,048	142,110
Deep 19	4	Carthage	M333L-2	WB-11	6.6- 9.1	36	0.0814	90.9	3788	63.9	25,183	89	302	10,070	10,311	241	1.53	10,997	12,027	125,754
Deep 19	5	Carthage	M333L-2	WB-11	9.5-10.3	12.2	0.027	92.1	1525	26.2	15,177	90	302	10,040	10,318	279	1.74	10,993	12,012	150,537
Deep 19	6	Carthage	M333L-2	WB-11	12.1-13.7	29.8	0.0671	93.4	3303	55.9	25,100	89	302	10,048	10,262	214	1.36	11,006	12,013	132,417
Deep 19	7	Carthage	M333L-2	WB-11	14.8-15.0	5.9	0.0128	95.1	750	13	10,026	91	302	10,034	10,276	242	1.51	11,005	12,001	154,592
Deep 19	8	Crab Orch.	M333L-2	WB-11	20.5-21.1	7.6	0.0164	100.4	325	5.7	10,039	92	302	10,021	10,308	287	1.78	11,028	12,055	52,811
Deep 19	9	Crab Orch.	M333L-2	WB-11	21.4-22.1	10.1	0.0224	101.4	1308	22.5	15,011	90	302	10,021	10,311	290	1.81	11,004	12,063	155,937
Deep 19	10	Crab Orch.	M333L-2	WB-11	22.4-22.9	14.9	0.0331	102.3	1749	29.9	20,038	90	302	10,031	10,306	275	1.71	11,002	12,069	141,568
Deep 19	11	Crab Orch.	M333L-2	WB-11	23.6-24.5	19.1	0.0427	102.3	2355	40.1	24,945	89	302	10,018	10,329	311	1.94	11,016	12,080	147,196
Deep 19	12	Crab Orch.	M333L-2	WB-11	25.8-26.5	12	0.0266	104.3	850	14.5	15,021	90	302	10,011	10,306	296	1.84	11,018	12,080	85,531
Deep 19	13	Crab Orch.	M333L-2	WB-11	26.8-28.0	18.2	0.0412	104.3	2292	38.5	25,118	88	302	10,020	10,309	289	1.8	11,013	12,081	148,651
Deep 19	14	Crab Orch.	M333L-2	WB-11	28.1-28.7	8.1	0.0181	105.2	329	5.6	10,132	89	302	10,012	10,306	295	1.84	11,001	12,069	48,558
Deep 20	1	Mancos	737-2	WB-11	1.0- 1.3	3.9	0.0114	99.4	794	10.5	40,446	69	302	9,999	10,369	369	2.3	10,954	12,049	188,733
Deep 20	2	Mancos	737-2	WB-11	1.7- 2.1	8.1	0.0233	100.4	1688	22.3	81,039	69	302	10,009	10,378	369	2.3	11,005	12,119	194,590
Deep 20	3	Mancos	737-2	WB-11	2.2- 3.0	9.6	0.0214	101.2	1686	28.9	81,120	90	302	9,991	10,379	388	2.42	11,008	12,119	213,619
Deep 20	4	Mancos	737-2	WB-11	3.0- 3.3	3.6	0.0081	102.6	764	13.1	40,560	90	302	9,964	10,332	368	2.3	11,017	12,101	256,101
Deep 20	5	Mancos	737-2	WB-11	3.4- 3.8	4	0.0073	103.6	819	17.2	40,442	110	303	10,009	10,388	380	2.38	11,016	12,098	301,730
Deep 20	6	Mancos	737-2	WB-11	4.3- 5.5	9.4	0.0171	105.5	1751	36.6	80,997	110	303	10,024	10,405	382	2.38	11,073	12,177	276,070

Table A-1 (continued). Data from all Deep Trek tests, averaged over the interval of "constant" test parameter settings.

Test Number	Data Point . No.	Rock[1]	Drill Bit[2]	Drilling Fluid[3]	Drilled Interval in	ROP[4] ft/hr	ROP in/rev	Temp °F	Torque ft-lb	Hyd. Horse-power[5] HP	Weight on Bit lb	Rotary Speed rpm	Flow Rate gpm	Bore Press. psi	Swivel Mud Press. psi	Bit Press. Drop psi	HSI Horse-power[6] HP/in^2	Conf. Stress psi	Over-burden Stress psi	Mech. Specific Energy psi
Deep 20	7	Mancos	737-2	WB-11	5.7- 6.8	8.3	0.0185	106.6	1546	26.5	80,578	90	303	9,976	10,362	386	2.41	10,993	12,139	226,368
Deep 20	8	Mancos	737-2	WB-11	7.0- 7.4	3.8	0.0085	108.5	772	13.3	40,108	91	303	9,926	10,312	386	2.41	11,018	12,127	247,917
Deep 20	9	Mancos	737-2	WB-11	7.7- 9.1	8.6	0.0192	109.8	1657	28.4	80,710	90	303	9,928	10,304	377	2.36	10,989	12,158	234,064
Deep 20	10	Carthage	737-2	WB-11	14.0-14.4	6	0.0134	116.7	807	13.8	40,204	90	301	9,969	10,365	397	2.52	10,993	12,161	162,822
Deep 20	11	Carthage	737-2	WB-11	14.5-14.9	5.7	0.0162	117.1	809	10.8	40,231	70	301	9,979	10,371	393	2.49	10,997	12,163	133,891
Deep 20	12	Carthage	737-2	WB-11	15.2-15.9	7.7	0.0221	117.8	1532	20.2	80,853	69	301	10,030	10,439	409	2.61	10,975	12,218	185,904
Deep 20	13	Carthage	737-2	WB-11	16.1-17.2	8.6	0.0191	119.2	1488	25.4	80,728	90	301	10,019	10,434	415	2.64	10,993	12,056	210,483
Deep 20	14	Carthage	737-2	WB-11	17.3-18.0	6.1	0.0137	119.9	781	13.3	40,140	90	301	9,998	10,412	414	2.64	10,993	12,056	155,059
Deep 20	15	Carthage	737-2	WB-11	18.1-18.7	6.5	0.0118	120.8	736	15.3	40,145	109	301	9,985	10,385	400	2.55	10,991	12,055	165,982
Deep 20	16	Carthage	737-2	WB-11	19.1-20.1	9.6	0.0176	121.4	1432	29.8	80,585	109	301	9,962	10,381	419	2.67	10,994	12,115	219,639
Deep 20	17	Carthage	737-2	WB-11	20.3-21.0	6.2	0.014	122.2	744	12.7	40,077	89	301	9,979	10,404	426	2.72	10,984	12,073	143,817
Deep 20	18	Carthage	737-2	WB-11	21.3-22.6	9	0.0202	123.2	1459	24.8	80,577	89	301	9,998	10,412	415	2.65	10,990	12,141	195,222
Deep 20	19	Crab Orch.	737-2	WB-11	24.1-24.5	6.7	0.0149	124.6	716	12.2	39,916	89	301	9,982	10,392	411	2.62	10,984	12,103	128,226
Deep 20	20	Crab Orch.	737-2	WB-11	24.7-25.0	5.4	0.0157	125.2	665	8.8	39,719	69	301	9,977	10,391	414	2.64	10,986	12,105	114,701
Deep 20	21	Crab Orch.	737-2	WB-11	25.3-26.0	10.2	0.0296	125.4	1400	18.4	80,538	69	301	9,985	10,385	400	2.56	10,987	12,173	129,123
Deep 20	22	Crab Orch.	737-2	WB-11	26.1-26.8	11.6	0.0258	125.8	1448	24.8	80,349	90	301	9,980	10,414	434	2.77	10,991	12,184	152,635
Deep 20	23	Crab Orch.	737-2	WB-11	26.8-27.6	6.7	0.0148	126.2	723	12.5	39,783	91	301	9,960	10,373	412	2.63	10,984	12,133	132,338
Deep 20	24	Crab Orch.	737-2	WB-11	27.7-28.4	7.4	0.0135	126.9	690	14.4	39,884	109	302	9,993	10,407	414	2.65	11,002	12,145	136,924
Deep 20	25	Crab Orch.	737-2	WB-11	28.6-30.0	12.5	0.023	127.4	1430	29.8	80,403	109	302	9,991	10,405	414	2.65	10,995	12,216	169,105
Deep 20	26	Crab Orch.	737-2	WB-11	30.2-30.8	9.9	0.0284	127.7	1534	20.3	80,149	69	302	9,978	10,407	429	2.74	10,987	12,220	145,388
Deep 20	27	Crab Orch.	737-2	WB-11	31.3-32.3	11.6	0.0259	128.7	1636	28	80,352	90	302	9,965	10,381	417	2.66	10,984	12,233	172,083
Deep 20	28	Crab Orch.	737-2	WB-11	32.4-32.6	7.4	0.0162	128.9	914	15.8	39,818	91	302	9,938	10,361	423	2.71	10,995	12,169	151,271
Deep 21	1	Mancos	M333-2	CF-16	3.8- 5.0	31.6	0.0697	97.4	2593	44.7	10,180	91	303	10,018	10,300	282	1.76	11,015	12,042	99,922
Deep 21	2	Mancos	M333-2	CF-16	6.0- 7.3	78	0.1748	97.9	4780	81.3	14,975	89	303	10,015	10,287	272	1.72	11,095	12,078	73,251
Deep 21	3	Mancos	M333-2	CF-16	9.4-12.1	111.9	0.2536	98.5	6030	101.3	20,186	88	303	10,031	10,280	250	1.56	11,020	12,031	63,942
Deep 21	4	Carthage	M333-2	CF-16	19.8-19.9	4.2	0.0093	103.9	1095	19	10,057	91	303	10,015	10,278	263	1.65	11,016	12,054	316,689
Deep 21	5	Carthage	M333-2	CF-16	20.1-20.6	16.3	0.0364	104.3	2199	37.6	14,919	90	303	10,039	10,293	254	1.59	11,010	12,061	162,417
Deep 21	6	Carthage	M333-2	CF-16	20.8-21.6	27.5	0.0614	104.7	3291	56.2	19,995	90	303	10,048	10,318	270	1.69	11,005	12,068	144,314
Deep 21	7	Carthage	M333-2	CF-16	22.1-23.7	43.4	0.0968	105.2	4515	77	24,930	90	303	10,027	10,221	194	1.23	11,026	12,088	125,720
Deep 21	8	Carthage	M333-2	CF-16	24.1-24.6	17.4	0.0375	105.7	2257	39.8	15,116	93	302	10,017	10,278	262	1.63	11,018	12,066	161,378
Deep 21	9	Carthage	M333-2	CF-16	25.0-25.8	29	0.0643	106.2	3250	55.8	19,977	90	302	9,969	10,210	241	1.5	11,011	12,069	135,189

Table A-1 (continued). Data from all Deep Trek tests, averaged over the interval of "constant" test parameter settings.

Test Number	Data Point . No.	Rock[1]	Drill Bit[2]	Drilling Fluid[3]	Drilled Interval in	ROP[4] ft/hr	ROP in/rev	Temp °F	Torque ft-lb	Hyd. Horse-power[5] HP	Weight on Bit lb	Rotary Speed rpm	Flow Rate gpm	Bore Press. psi	Swivel Mud Press. psi	Bit Press. Drop psi	HSI Horse-power[6] HP/in^2	Conf. Stress psi	Over-burden Stress psi	Mech. Specific Energy psi
Deep 21	10	Carthage	M333-2	CF-16	25.9-26.1	5.5	0.0121	106.7	1232	21.3	9,999	91	302	9,956	10,200	245	1.52	11,045	12,067	272,140
Deep 22A	1	Mancos	M841-2	CF-16+	2.1- 2.3	4.1	0.014	103.5	2049	23.1	29,875	59	303	9,966	10,215	250	1.56	10,985	12,010	394,198
Deep 22A	2	Mancos	M841-2	CF-16+	2.4- 2.9	9.5	0.0157	104.4	1838	42.4	29,789	121	303	9,957	10,218	261	1.63	10,984	12,009	313,191
Deep 22A	3	Mancos	M841-2	CF-16+	3.3- 3.7	14.9	0.0166	105.2	1848	63.4	29,927	180	303	9,950	10,204	255	1.59	10,996	12,017	298,723
Deep 22A	4	Mancos	M841-2	CF-16+	4.1- 4.6	18.3	0.0165	105.9	1766	74.4	29,737	221	303	9,981	10,214	233	1.46	10,986	12,011	285,413
Deep 22A	5	Mancos	M841-2	CF-16+	5.1- 5.9	29.2	0.0264	106.4	2704	113.8	39,584	221	303	9,992	10,205	214	1.34	10,977	12,017	274,269
Deep 22A	6	Mancos	M841-2	CF-16+	6.2- 6.8	17.4	0.0194	106.7	2402	82.1	40,011	179	303	10,035	10,372	337	2.11	10,968	12,013	330,885
Deep 22A	7	Mancos	M841-2	CF-16+	7.4- 7.8	12.5	0.0209	107.3	2807	64.1	39,913	120	303	9,998	10,330	332	2.08	10,992	12,023	360,708
Deep 22A	8	Mancos	M841-2	CF-16+	8.0- 8.2	5.6	0.0185	107.8	2905	33.3	39,929	60	303	9,949	10,201	252	1.6	10,987	12,019	416,412
Deep 22A	9	Mancos	M841-2	CF-16+	8.2- 8.3	2.3	0.0074	108.4	1122	13.2	19,902	62	303	9,962	10,243	281	1.76	10,975	12,007	403,973
Deep 22A	10	Mancos	M841-2	CF-16+	8.4- 8.6	4	0.0066	109.1	938	21.7	19,882	121	303	9,953	10,232	279	1.75	10,972	12,002	379,030
Deep 22A	11	Mancos	M841-2	CF-16+	8.8- 9.0	5.3	0.0059	109.9	747	25.7	19,838	181	303	10,051	10,375	324	2.04	10,996	12,011	340,845
Deep 22A	12	Mancos	M841-2	CF-16+	9.1- 9.4	5.5	0.005	110.6	567	23.8	19,907	220	303	9,936	10,266	330	2.06	10,978	11,998	303,104
Deep 22A	13	Mancos	M841-2	CF-16+	9.8-10.5	13.4	0.0148	111.3	1711	58.8	29,891	180	303	10,031	10,400	369	2.31	10,996	12,010	307,505
Deep 22A	14	Mancos	M841-2	CF-16+	10.8-11.4	7.7	0.0127	112	1744	40	29,899	121	302	9,989	10,378	389	2.43	10,973	11,997	366,467
Deep 22B	1	Carthage	M841-2	CF-16+	2.2- 2.7	2.6	0.0085	105.2	2096	24.1	30,029	60	302	9,972	10,253	281	1.75	10,991	12,004	645,985
Deep 22B	2	Carthage	M841-2	CF-16+	2.8- 3.7	4	0.0066	107.7	1745	40.3	29,968	121	302	9,969	10,252	283	1.76	10,991	12,064	704,877
Deep 22B	3	Carthage	M841-2	CF-16+	3.9- 4.7	5.9	0.0065	109.8	1568	54.4	29,905	182	302	9,969	10,244	275	1.72	10,995	12,063	645,975
Deep 22B	4	Carthage	M841-2	CF-16+	4.9- 6.0	6.4	0.0058	111.8	1475	62.5	30,012	222	303	9,988	10,271	283	1.77	10,997	12,060	683,249
Deep 22B	5	Carthage	M841-2	CF-16+	6.2- 7.8	7.5	0.0067	113.7	1737	73.4	40,074	222	303	9,973	10,265	292	1.83	10,987	12,059	686,953
Deep 22B	6	Carthage	M841-2	CF-16+	8.0- 9.0	5.9	0.0065	115.4	1771	61.4	40,025	182	303	9,975	10,259	285	1.78	11,002	12,068	729,827
Deep 22B	7	Carthage	M841-2	CF-16+	9.2-10.2	4.5	0.0073	117.2	2067	47.8	40,023	122	303	9,969	10,278	309	1.93	10,989	12,064	748,598
Deep 22B	8	Carthage	M841-2	CF-16+	10.3-11.0	2.9	0.0097	119.1	2480	28.5	40,082	60	303	9,970	10,260	290	1.81	10,987	12,069	685,556
Deep 22B	9	Carthage	M841-2	CF-16+	11.2-11.9	3.8	0.0063	121	1647	38	30,013	121	303	9,966	10,282	317	1.98	11,000	12,077	700,314
Deep 23	1	Mancos	M333-2	CF-16+	3.1- 4.0	44	0.0999	89.2	2915	48.9	10,302	88	299	10,036	10,172	136	0.84	11,023	12,045	78,098
Deep 23	2	Mancos	M333-2	CF-16+	5.3- 5.9	78.1	0.1758	89.7	4586	77.6	15,091	89	303	10,038	10,200	162	1.01	11,028	12,049	70,214
Deep 23	3	Mancos	M333-2	CF-16+	8.0- 9.1	94.5	0.2344	90.3	6500	99.8	21,369	81	300	10,097	10,264	167	1.04	11,015	12,039	75,041
Deep 23	4	Mancos	M333-2	CF-16+	11.4-15.8	69.7	0.1541	91.2	4449	76.7	15,096	91	303	10,062	10,149	87	0.54	10,999	12,031	77,982
Deep 23	5	Carthage	M333-2	CF-16+	20.2-20.6	8.7	0.0195	95.3	1573	26.9	10,025	90	300	9,993	10,079	86	0.53	11,018	12,049	217,320
Deep 23	6	Carthage	M333-2	CF-16+	20.9-21.9	20.5	0.0462	96.1	2696	45.5	14,888	89	299	9,998	10,075	77	0.47	11,007	12,051	156,588
Deep 23	7	Carthage	M333-2	CF-16+	22.4-24.1	31.3	0.0675	96.8	3503	61.9	20,021	93	301	9,999	10,062	63	0.39	11,001	12,057	139,485

Table A-1 (continued). Data from all Deep Trek tests, averaged over the interval of "constant" test parameter settings.

Test Number	Data Point . No.	Rock[1]	Drill Bit[2]	Drilling Fluid[3]	Drilled Interval in	ROP[4] ft/hr	ROP in/rev	Temp °F	Torque ft-lb	Hyd. Horse-power[5] HP	Weight on Bit lb	Rotary Speed rpm	Flow Rate gpm	Bore Press. psi	Swivel Mud Press. psi	Bit Press. Drop psi	HSI Horse-power[6] HP/in²	Conf. Stress psi	Over-burden Stress psi	Mech. Specific Energy psi
Deep 23	8	Carthage	M333-2	CF-16+	24.9-27.8	48.6	0.1093	97.7	4713	79.9	25,124	89	302	9,988	10,027	39	0.24	10,997	12,066	115,966
Deep 23	9	Carthage	M333-2	CF-16+	28.9-30.1	20	0.0442	98.8	2632	45.3	14,943	90	300	10,055	10,110	56	0.34	10,991	12,049	158,449
Deep 24	1	Crab Orch.	M333-2	CF-16+	3.3- 3.4	1.9	0.0041	108	622	11	10,151	93	303	9,966	10,368	402	2.52	11,027	12,095	406,296
Deep 24	2	Crab Orch.	M333-2	CF-16+	5.5- 5.8	4.3	0.0094	112.4	1072	18.9	15,125	92	302	9,984	10,397	413	2.58	11,038	12,085	306,346
Deep 24	3	Crab Orch.	M333-2	CF-16+	9.3- 9.8	8.4	0.0182	115.9	1764	31.1	20,116	93	303	9,977	10,396	418	2.62	11,014	12,105	261,111
Deep 24	4	Crab Orch.	M333-2	CF-16+	11.9-12.8	15.5	0.0336	117.4	2589	45.5	24,899	92	303	9,971	10,396	425	2.66	11,007	12,035	205,774
Deep 24	5	Crab Orch.	M333-2	CF-16+	14.7-14.8	2.9	0.0062	121.3	857	15.1	14,979	92	304	9,676	10,111	435	2.72	11,024	12,056	363,031
Deep 24	6	Crab Orch.	M333-2	CF-16+	15.4-15.5	1.5	0.0024	123.4	401	9.4	10,086	123	303	9,984	10,418	434	2.72	11,033	12,095	438,783
Deep 24	7	Crab Orch.	M333-2	CF-16+	16.7-17.0	4.5	0.0073	125.1	846	20	15,070	124	303	9,979	10,415	436	2.73	11,041	12,126	311,360
Deep 24	8	Crab Orch.	M333-2	CF-16+	18.6-19.4	7.7	0.0124	126.4	1287	30.3	20,090	124	303	9,979	10,422	443	2.78	11,050	12,108	277,053
Deep 24	9	Crab Orch.	M333-2	CF-16+	22.1-23.2	16.5	0.027	127.6	2148	50	25,279	122	304	9,966	10,389	423	2.65	11,062	12,136	212,656
Deep 24	10	Crab Orch.	M333-2	CF-16+	24.8-25.0	3.7	0.006	129.2	695	16.3	14,840	123	304	9,996	10,426	430	2.7	11,085	12,098	308,579
Deep 25	1	Mancos	737-2	CF-16+	0.7- .8	0.8	0.0022	99.3	261	3.5	40,154	70	303	9,971	10,360	389	2.43	11,050	12,099	305,920
Deep 25	2	Mancos	737-2	CF-16+	1.0- 1.1	2.2	0.0062	101.2	825	10.9	60,120	70	303	9,957	10,342	385	2.41	11,043	12,117	352,126
Deep 25	3	Mancos	737-2	CF-16+	1.4- 1.8	6.2	0.0178	102.5	1420	18.7	80,363	69	303	9,952	10,337	385	2.41	11,062	12,149	213,552
Deep 25	4	Mancos	737-2	CF-16+	2.2- 2.7	5.7	0.0126	104.4	1195	20.4	80,320	90	303	9,945	10,340	395	2.47	11,051	12,149	254,420
Deep 25	5	Mancos	737-2	CF-16+	2.9- 3.1	2	0.0043	106.3	562	9.6	60,070	90	303	9,993	10,401	409	2.56	11,038	12,129	339,325
Deep 25	6	Mancos	737-2	CF-16+	3.2- 3.3	0.8	0.0017	108.7	243	4.1	40,072	89	303	9,963	10,362	399	2.5	11,046	12,115	361,867
Deep 25	7	Mancos	737-2	CF-16+	3.3- 3.4	0.8	0.0014	110.6	250	5.2	40,015	109	303	9,969	10,374	405	2.54	11,044	12,115	455,582
Deep 25	8	Mancos	737-2	CF-16+	4.1- 4.3	2.8	0.0051	112.9	586	12.2	60,272	109	303	9,967	10,345	378	2.37	11,033	12,138	306,294
Deep 25	9	Mancos	737-2	CF-16+	5.0- 5.6	7	0.0129	114.7	1170	24.3	79,930	109	303	9,987	10,411	424	2.66	11,043	12,178	245,741
Deep 25	10	Carthage	737-2	CF-16+	13.9-14.0	0.9	0.0026	125.5	159	2.1	40,082	69	304	9,967	10,383	416	2.61	11,060	12,111	163,951
Deep 25	11	Carthage	737-2	CF-16+	14.1-14.2	1.7	0.0049	126.4	485	6.4	60,208	69	304	9,976	10,411	435	2.72	11,057	12,144	264,600
Deep 25	12	Carthage	737-2	CF-16+	14.4-14.7	3.1	0.0091	127.2	892	11.7	80,259	69	304	9,979	10,415	436	2.73	11,056	12,184	267,561
Deep 26	1	Mancos	M841-2	OB-16	2.2- 2.4	5	0.0162	108.3	2066	24.1	29,629	61	299	9,993	10,241	248	1.53	10,972	12,041	337,117
Deep 26	2	Mancos	M841-2	OB-16	2.7- 3.2	7.7	0.0127	109.4	1876	43.3	30,070	121	299	9,973	10,285	312	1.92	10,964	12,038	394,130
Deep 26	3	Mancos	M841-2	OB-16	3.7- 4.3	10.9	0.0121	110.7	1940	66.8	30,099	181	299	9,970	10,246	275	1.7	10,980	12,048	430,594
Deep 26A	1	Mancos	M841-2	OB-16	6.0- 6.2	4.6	0.0151	94.1	3009	34.8	30,023	61	296	9,831	10,091	260	1.59	10,971	12,087	533,088
Deep 26A	2	Mancos	M841-2	OB-16	6.4- 6.7	7.3	0.0121	95.3	2333	54	30,184	122	295	9,810	10,153	344	2.09	10,956	12,075	520,932
Deep 26A	3	Mancos	M841-2	OB-16	6.8- 7.3	9.6	0.0106	96.4	1772	61.1	30,005	181	295	9,817	10,137	320	1.95	10,942	12,063	446,522
Deep 26A	4	Mancos	M841-2	OB-16	7.5- 7.8	7.6	0.0069	97.5	1489	62.2	30,231	219	295	9,791	10,145	354	2.15	10,927	12,048	573,159

Table A-1 (continued). Data from all Deep Trek tests, averaged over the interval of “constant” test parameter settings.

Test Number	Data Point . No.	Rock[1]	Drill Bit[2]	Drilling Fluid[3]	Drilled Interval in	ROP[4] ft/hr	ROP in/rev	Temp °F	Torque ft-lb	Hyd. Horse-power[5] HP	Weight on Bit lb	Rotary Speed rpm	Flow Rate gpm	Bore Press. psi	Swivel Mud Press. psi	Bit Press. Drop psi	HSI Horse-power[6] HP/in^2	Conf. Stress psi	Over-burden Stress psi	Mech. Specific Energy psi
Deep 26A	5	Mancos	M841-2	OB-16	8.0- 8.4	11.1	0.0101	98.5	1889	78.9	39,945	219	295	9,814	10,157	343	2.09	11,027	12,106	498,339
Deep 26A	6	Mancos	M841-2	OB-16	8.7- 9.2	9.3	0.0102	99.6	2131	73.4	40,084	181	295	9,790	10,182	392	2.39	10,984	12,080	554,408
Deep 26A	7	Mancos	M841-2	OB-16	9.5-10.0	8.6	0.0142	100.9	2766	63.5	40,064	121	296	9,857	10,244	386	2.36	10,967	12,067	520,310
Deep 26A	8	Mancos	M841-2	OB-16	10.1-10.3	5.1	0.0169	101.9	3388	39.3	40,284	61	299	9,809	10,325	516	3.18	10,953	12,054	541,733
Deep 26A	9	Mancos	M841-2	OB-16	10.6-11.2	9.8	0.0109	103.2	2010	69.2	40,258	181	296	9,817	10,374	558	3.41	10,940	12,046	496,403
Deep 26A	10	Mancos	M841-2	OB-16	11.5-11.9	7	0.0077	104.7	1576	54.3	30,033	181	296	9,809	10,378	569	3.48	10,989	12,053	544,407
Deep 26A	11	Carthage	M841-2	OB-16	18.7-18.8	1.5	0.005	121.6	1308	15	29,975	60	298	9,797	10,323	526	3.23	10,984	12,098	698,660
Deep 26A	12	Carthage	M841-2	OB-16	18.8-19.0	3	0.005	122.3	1228	28.2	29,955	121	299	9,849	10,441	591	3.64	10,983	12,105	661,451
Deep 26A	13	Carthage	M841-2	OB-16	19.1-19.3	4.2	0.0046	123	1249	43	29,940	181	299	9,848	10,351	503	3.1	10,981	12,110	718,738
Deep 26A	14	Carthage	M841-2	OB-16	19.5-19.8	5.1	0.0046	124	1193	50.1	30,033	220	299	9,859	10,361	503	3.1	10,980	12,116	687,232
Deep 26A	15	Carthage	M841-2	OB-16	19.9-20.2	6.4	0.0058	124.5	1588	66.6	40,035	220	299	9,863	10,315	452	2.79	10,980	12,139	729,249
Deep 26A	16	Carthage	M841-2	OB-16	20.4-20.8	5.6	0.0061	125.1	1629	56.1	39,934	181	299	9,854	10,357	502	3.1	10,980	12,083	703,434
Deep 26A	17	Carthage	M841-2	OB-16	20.9-21.1	3.9	0.0065	125.6	1701	39.1	39,963	121	299	9,860	10,281	421	2.59	10,980	12,053	705,075
Deep 26A	18	Carthage	M841-2	OB-16	21.1-21.3	1.8	0.0062	126.2	1844	21.1	40,039	60	299	9,835	10,247	412	2.54	10,980	12,059	820,972
Deep 26A	19	Carthage	M841-2	OB-16	21.5-21.7	4.8	0.0053	127.2	1477	50.8	39,932	181	299	9,861	10,252	391	2.41	10,981	12,068	744,015
Deep 26A	20	Carthage	M841-2	OB-16	21.8-22.1	4.2	0.0046	127.7	1243	42.7	29,912	180	299	9,847	10,250	403	2.48	10,983	12,055	711,344
Deep 26A	21	Carthage	M841-2	OB-16	22.2-22.3	2.7	0.0045	128	1203	27.7	29,951	121	299	9,841	10,231	390	2.41	10,985	12,059	719,889
Deep 27	1	Crab Orch.	M233-2	OB-16	3.1- 3.2	1.2	0.0028	122.9	509	8.7	10,016	90	300	10,013	10,352	339	2.1	11,003	12,081	509,354
Deep 27	2	Crab Orch.	M233-2	OB-16	3.5- 3.6	2.1	0.0046	124	943	16.2	15,072	90	300	10,007	10,317	310	1.92	10,997	12,091	539,390
Deep 27	3	Crab Orch.	M233-2	OB-16	4.2- 4.4	4.5	0.0101	125.3	1582	27.1	20,082	90	300	10,005	10,324	319	1.97	10,993	12,100	422,577
Deep 27	4	Crab Orch.	M233-2	OB-16	5.6- 5.9	8.9	0.0197	126.4	2635	45.3	25,069	90	300	9,995	10,333	338	2.09	10,991	12,110	356,168
Deep 27	5	Crab Orch.	M233-2	OB-16	6.0- 6.1	1.4	0.003	127.1	862	14.8	14,984	90	300	9,994	10,303	310	1.92	10,989	12,105	739,387
Deep 27	6	Crab Orch.	M233-2	OB-16	6.6- 6.7	3.6	0.0079	128.2	1414	24.2	19,976	90	301	10,056	10,365	309	1.92	10,989	12,122	472,040
Deep 28	1	Mancos	M233-2	OB-16	3.4- 4.0	28.4	0.0631	98.4	2079	35.6	10,088	90	295	9,941	10,329	388	2.36	10,993	12,048	88,202
Deep 28	2	Mancos	M233-2	OB-16	5.0- 5.4	29.7	0.0657	99	2908	50.1	15,439	91	294	9,899	10,287	388	2.35	10,982	12,040	119,346
Deep 28	3	Mancos	M233-2	OB-16	7.0- 7.8	65.5	0.1476	100	5138	86.8	19,844	89	302	9,988	10,332	344	2.14	10,995	12,045	93,787
Deep 28	4	Mancos	M233-2	OB-16	10.4-12.2	93.6	0.2119	100.7	6112	102.9	24,850	88	295	9,926	10,297	370	2.26	10,980	12,018	77,497
Deep 28	5	Mancos	M233-2	OB-16	13.2-13.8	25.2	0.055	101.4	2625	45.8	15,054	92	295	9,873	10,287	414	2.52	10,995	12,002	128,310
Deep 28	6	Mancos	M233-2	OB-16	15.3-16.9	71.8	0.161	102.2	4885	83	19,554	89	302	9,969	10,289	320	2	10,996	12,031	81,428
Deep 28	7	Carthage	M233-2	OB-16	20.1-20.2	1.2	0.0025	106.8	730	12.8	9,952	92	296	9,875	10,271	395	2.41	11,000	12,024	746,574
Deep 28	8	Carthage	M233-2	OB-16	20.4-20.7	10.7	0.024	107.7	2033	34.6	14,922	89	296	9,912	10,301	389	2.38	11,005	12,042	225,994

Table A-1 (continued). Data from all Deep Trek tests, averaged over the interval of "constant" test parameter settings.

Test Number	Data Point . No.	Rock[1]	Drill Bit[2]	Drilling Fluid[3]	Drilled Interval in	ROP[4] ft/hr	ROP in/rev	Temp °F	Torque ft-lb	Hyd. Horse-power[5] HP	Weight on Bit lb	Rotary Speed rpm	Flow Rate gpm	Bore Press. psi	Swivel Mud Press. psi	Bit Press. Drop psi	HSI Horse-power[6] HP/in²	Conf. Stress psi	Over-burden Stress psi	Mech. Specific Energy psi
Deep 28	9	Carthage	M233-2	OB-16	21.0-22.3	26.6	0.0583	108.5	3511	61.1	19,897	91	297	9,951	10,293	342	2.09	10,996	12,048	160,855
Deep 28	10	Carthage	M233-2	OB-16	22.8-25.1	44.8	0.1015	109.2	4966	83.5	24,890	88	304	9,913	10,244	330	2.07	10,984	12,049	130,942
Deep 28	11	Carthage	M233-2	OB-16	26.1-26.6	12.7	0.0278	110.2	2096	36.3	14,790	91	296	9,873	10,248	374	2.28	10,993	12,030	200,771
Deep 28	12	Carthage	M233-2	OB-16	27.3-28.5	28.7	0.0626	111.2	3654	63.8	19,927	92	297	9,892	10,214	322	1.97	10,987	12,038	156,880
Deep 29	1	Crab Orch.	M333-2	OB-16	3.3- 3.4	1.2	0.0026	113.4	838	14.4	10,010	90	297	10,037	10,322	285	1.74	11,005	12,078	838,354
Deep 29	2	Crab Orch.	M333-2	OB-16	3.8- 3.9	1.5	0.0033	116.6	1007	17.3	15,065	90	297	10,011	10,280	269	1.65	11,029	12,109	806,133
Deep 29	3	Crab Orch.	M333-2	OB-16	4.6- 4.9	2.9	0.0064	119.5	1378	23.8	20,054	91	297	10,000	10,276	276	1.69	11,022	12,127	577,252
Deep 29	4	Crab Orch.	M333-2	OB-16	7.0- 7.8	8	0.0178	122.7	2361	40.3	25,196	90	297	9,983	10,266	283	1.73	11,025	12,159	355,041
Deep 29	5	Crab Orch.	M333-2	OB-16	8.3- 8.5	1.3	0.0029	125.3	795	13.7	15,127	90	299	10,046	10,336	290	1.79	11,045	12,077	734,381
Deep 30	1	Mancos	M333-2	OB-16	3.0- 3.3	6.2	0.0138	98.1	1243	21.3	9,969	90	295	9,956	10,275	319	1.94	11,012	12,015	240,933
Deep 30	2	Mancos	M333-2	OB-16	3.8- 5.4	31.6	0.0709	99.8	3001	50.9	14,866	89	296	9,972	10,291	320	1.95	10,985	11,999	113,222
Deep 30	3	Mancos	M333-2	OB-16	7.2- 8.2	24.3	0.0531	101	2896	50.5	20,741	92	296	9,962	10,491	528	3.23	10,966	11,980	146,924
Deep 30	4	Mancos	M333-2	OB-16	9.3-11.5	31.7	0.0706	102.4	3177	54.3	24,923	90	295	9,959	10,481	522	3.18	10,986	12,015	121,146
Deep 30	5	Mancos	M333-2	OB-16	13.0-13.8	14.6	0.0325	104.9	1727	29.5	14,932	90	296	9,972	10,453	481	2.94	10,978	12,011	142,473
Deep 30	6	Carthage	M333-2	OB-16	20.0-20.1	0.9	0.0019	115.2	613	10.6	9,909	91	297	9,963	10,287	324	1.99	10,975	12,040	826,765
Deep 30	7	Carthage	M333-2	OB-16	20.3-20.8	5.2	0.0117	116.7	1566	26.8	15,019	90	297	9,948	10,290	342	2.1	11,004	12,064	361,916
Deep 30	8	Carthage	M333-2	OB-16	21.3-22.5	16.6	0.0366	118	2881	49.7	19,945	91	297	9,956	10,296	340	2.09	10,988	12,070	211,285
Deep 30	9	Carthage	M333-2	OB-16	24.4-26.6	28.5	0.0605	119.5	3910	70.1	24,878	94	298	9,961	10,240	279	1.71	10,974	12,076	172,828
Deep 30	10	Carthage	M333-2	OB-16	28.0-28.3	3.6	0.008	122	1312	22.5	15,001	90	299	9,977	10,279	302	1.86	11,001	12,081	437,864
Deep 31	1	Mancos	M333L-2	OB-16+Lub	3.1- 3.7	17.3	0.0383	98.9	1661	28.5	10,349	90	301	9,995	10,265	270	1.68	11,028	12,044	115,580
Deep 31	2	Mancos	M333L-2	OB-16+Lub	4.7- 5.2	14.7	0.0327	100.4	2074	35.4	15,182	90	301	9,953	10,275	322	2	10,991	12,045	169,843
Deep 31	3	Mancos	M333L-2	OB-16+Lub	6.6- 8.9	58.5	0.1317	101.6	4748	80.3	20,005	89	307	10,037	10,299	261	1.66	11,036	12,065	97,020
Deep 31	4	Mancos	M333L-2	OB-16+Lub	10.0-12.0	87.2	0.2437	102.1	6416	87.4	25,199	72	302	10,056	10,394	338	2.1	10,992	12,031	71,526
Deep 31	5	Mancos	M333L-2	OB-16+Lub	13.0-14.1	17.8	0.0398	103.4	2164	36.9	14,952	90	302	9,995	10,322	327	2.04	10,964	11,976	146,416
Deep 31	6	Carthage	M333L-2	OB-16+Lub	20.1-20.3	1.7	0.0037	114.3	598	10.2	9,966	90	303	9,950	10,249	300	1.88	11,011	12,060	422,470
Deep 31	7	Carthage	M333L-2	OB-16+Lub	20.6-21.2	6.4	0.0143	116.1	1465	25	15,002	90	304	9,960	10,277	317	1.99	11,003	12,068	275,218
Deep 31	8	Carthage	M333L-2	OB-16+Lub	21.9-23.3	16.1	0.036	117.7	2716	46.3	20,098	90	304	9,955	10,265	310	1.94	11,018	12,091	203,146

Table A-1 (continued). Data from all Deep Trek tests, averaged over the interval of "constant" test parameter settings.

Test Number	Data Point . No.	Rock[1]	Drill Bit[2]	Drilling Fluid[3]	Drilled Interval in	ROP[4] ft/hr	ROP in/rev	Temp °F	Torque ft-lb	Hyd. Horse-power[5] HP	Weight on Bit lb	Rotary Speed rpm	Flow Rate gpm	Bore Press. psi	Swivel Mud Press. psi	Bit Press. Drop psi	HSI Horse-power[6] HP/in^2	Conf. Stress psi	Over-burden Stress psi	Mech. Specific Energy psi
Deep 31	9	Carthage	M333L-2	OB-16+Lub	25.1-27.4	27.5	0.0594	119.3	3908	68.7	25,108	92	309	9,959	10,223	264	1.68	11,000	12,098	175,208
Deep 31	10	Carthage	M333L-2	OB-16+Lub	28.8-29.2	4.2	0.0093	121.2	1265	21.6	14,937	90	303	9,950	10,262	312	1.95	11,028	12,100	361,957
Deep 32	1	Crab Orch.	M333-2	OB-16+Alt	3.2- 3.6	3.9	0.0087	108.7	582	10	9,981	90	301	10,028	10,266	237	1.47	11,000	12,097	179,430
Deep 32	2	Crab Orch.	M333-2	OB-16+Alt	4.0- 4.5	5.2	0.0115	111.1	1140	19.5	14,914	90	301	10,022	10,263	241	1.5	11,004	12,109	263,604
Deep 32	3	Crab Orch.	M333-2	OB-16+Alt	5.1- 5.4	6.9	0.0154	113.2	1633	27.9	19,983	90	301	10,026	10,278	252	1.57	11,002	12,042	284,707
Deep 32	4	Crab Orch.	M333-2	OB-16+Alt	6.2- 7.0	10.2	0.0226	114.7	2188	37.6	24,988	90	301	10,023	10,256	233	1.45	11,015	12,060	258,296
Deep 32	5	Crab Orch.	M333-2	OB-16+Alt	7.6- 8.1	5	0.0111	117	1137	19.6	15,114	91	301	10,031	10,269	238	1.48	11,001	12,058	276,447
Deep 32	6	Crab Orch.	M333-2	OB-16+Alt	9.2- 9.8	6.7	0.0149	119.5	1620	27.9	20,054	90	301	10,027	10,283	256	1.59	10,999	12,082	290,859
Deep 33	1	Mancos	M333-2	OB-16+Alt	3.1- 3.9	21.8	0.0482	104.8	1717	29.6	10,152	91	302	10,006	10,239	234	1.46	10,958	12,005	95,923
Deep 33	2	Mancos	M333-2	OB-16+Alt	4.5- 6.7	27.6	0.0612	106.4	2428	41.7	14,793	90	302	9,943	10,166	223	1.39	10,982	12,008	106,088
Deep 33	3	Mancos	M333-2	OB-16+Alt	9.0- 9.4	31.6	0.0701	108.4	3116	53.4	19,684	90	302	10,058	10,273	215	1.34	10,945	11,976	119,025
Deep 33	4	Mancos	M333-2	OB-16+Alt	13.2-14.6	29.5	0.0654	109.9	3103	53.4	25,831	90	301	9,955	10,356	401	2.49	10,963	12,007	127,137
Deep 33	5	Mancos	M333-2	OB-16+Alt	15.0-15.4	22.1	0.0487	110.7	1966	34	15,235	91	301	9,996	10,364	368	2.29	10,964	11,982	108,476
Deep 33	6	Mancos	M333-2	OB-16+Alt	16.8-17.5	13.5	0.0299	112.1	2217	38.1	20,844	90	301	10,012	10,373	361	2.25	10,961	12,020	197,804
Deep 33	7	Carthage	M333-2	OB-16+Alt	20.3-20.4	1.8	0.0039	120.6	687	11.9	10,029	91	301	10,003	10,232	229	1.43	10,967	12,003	463,444
Deep 33	8	Carthage	M333-2	OB-16+Alt	20.6-21.1	7.1	0.0158	121.8	1582	27.1	15,388	90	301	10,000	10,230	230	1.43	10,964	12,012	267,925
Deep 33	9	Carthage	M333-2	OB-16+Alt	21.4-22.3	13.8	0.0307	122.8	2426	41.5	20,238	90	301	10,010	10,231	221	1.37	10,973	12,028	211,672
Deep 33	10	Carthage	M333-2	OB-16+Alt	23.0-24.5	24.1	0.0537	124.1	3410	58.3	25,091	90	301	10,007	10,224	217	1.35	10,967	12,036	170,680
Deep 33	11	Carthage	M333-2	OB-16+Alt	25.8-26.3	6.5	0.0144	125.1	1426	24.6	14,976	91	301	10,017	10,236	218	1.36	10,969	12,024	266,716
Deep 33	12	Carthage	M333-2	OB-16+Alt	27.1-27.8	15.1	0.0339	125.3	2499	42.5	20,001	89	301	10,027	10,241	214	1.33	10,962	12,032	197,097
Deep 34	1	Crab Orch.	M333-2	OB-16+Mn	2.9- 3.3	5.8	0.0129	107	461	7.9	9,782	90	300	9,993	10,315	323	2	10,990	12,012	95,725
Deep 34	2	Crab Orch.	M333-2	OB-16+Mn	5.3- 5.7	9.8	0.0218	111.4	1160	19.9	15,009	90	300	9,993	10,314	321	1.99	10,978	12,017	142,572
Deep 34	3	Crab Orch.	M333-2	OB-16+Mn	7.6- 8.9	15.2	0.0337	114.1	1879	32.2	20,017	90	300	10,003	10,318	315	1.95	10,995	12,039	149,050
Deep 34	4	Crab Orch.	M333-2	OB-16+Mn	10.9-12.9	24.7	0.0551	116.2	2829	48.4	25,169	90	300	9,992	10,310	318	1.97	10,982	12,044	138,331
Deep 34	5	Crab Orch.	M333-2	OB-16+Mn	13.8-14.8	10.2	0.0225	118.3	1100	19	15,051	91	300	9,989	10,286	297	1.84	10,982	12,040	131,382
Deep 35	1	Mancos	M333-2	OB-16+Mn	3.5- 3.8	10.6	0.0235	102.5	1230	21.2	10,199	90	301	9,991	10,304	313	1.95	11,005	12,014	139,606
Deep 35	2	Mancos	M333-2	OB-16+Mn	4.8- 5.3	18.2	0.0406	103.8	1981	33.9	15,224	90	301	9,992	10,301	308	1.92	10,985	12,004	131,154
Deep 35	3	Mancos	M333-2	OB-16+Mn	7.4- 8.8	39.2	0.0874	105.3	3028	51.7	20,047	90	301	9,992	10,466	474	2.94	10,971	12,007	93,403
Deep 35	4	Mancos	M333-2	OB-16+Mn	10.4-12.2	36.5	0.0813	106.9	3324	56.8	25,408	90	301	9,994	10,536	542	3.37	10,986	12,042	110,181
Deep 35	5	Mancos	M333-2	OB-16+Mn	13.1-14.1	18.3	0.0404	108.3	1643	28.3	14,862	90	301	10,023	10,542	519	3.22	10,992	12,011	108,263

Table A-1 (continued). Data from all Deep Trek tests, averaged over the interval of "constant" test parameter settings.

Test Number	Data Point . No.	Rock[1]	Drill Bit[2]	Drilling Fluid[3]	Drilled Interval in	ROP[4] ft/hr	ROP in/rev	Temp °F	Torque ft-lb	Hyd. Horse-power[5] HP	Weight on Bit lb	Rotary Speed rpm	Flow Rate gpm	Bore Press. psi	Swivel Mud Press. psi	Bit Press. Drop psi	HSI Horse-power[6] HP/in²	Conf. Stress psi	Over-burden Stress psi	Mech. Specific Energy psi
Deep 35	6	Carthage	M333-2	OB-16+Mn	20.3-20.5	3	0.0067	118.2	401	6.9	9,840	90	301	9,996	10,522	526	3.27	10,990	12,022	160,748
Deep 35	7	Carthage	M333-2	OB-16+Mn	21.0-21.5	7.5	0.0166	120.2	1189	20.4	15,156	90	301	9,997	10,500	502	3.12	10,992	12,036	190,776
Deep 35	8	Carthage	M333-2	OB-16+Mn	22.5-23.4	17.3	0.0385	121.8	2252	38.4	20,110	90	301	10,000	10,527	527	3.27	10,986	12,047	156,919
Deep 35	9	Carthage	M333-2	OB-16+Mn	24.1-25.4	26.5	0.059	122.8	3085	52.6	25,158	90	301	10,008	10,565	557	3.46	10,989	12,062	140,588
Deep 35	10	Carthage	M333-2	OB-16+Mn	25.9-26.4	8.3	0.0183	123.8	1169	20.1	15,201	90	301	9,992	10,517	526	3.26	10,990	12,045	169,550
Deep 36	1	Mancos	M233-2	OB-16+Mn	3.3- 3.6	5.9	0.0131	100.2	1001	17.3	9,940	91	301	9,973	10,303	330	2.05	10,987	12,081	206,207
Deep 36	2	Mancos	M233-2	OB-16+Mn	4.0- 4.7	19.9	0.0442	100.9	2293	39.3	15,577	90	301	10,004	10,324	320	1.99	10,985	12,078	138,822
Deep 36	3	Mancos	M233-2	OB-16+Mn	5.1- 6.6	25.6	0.0569	102	2802	48	20,221	90	301	9,991	10,305	314	1.95	10,988	12,075	132,059
Deep 36	4	Mancos	M233-2	OB-16+Mn	8.0- 8.9	15.2	0.0338	103.7	2262	38.9	25,330	90	301	9,983	10,460	477	2.96	10,991	12,068	179,475
Deep 36	5	Mancos	M233-2	OB-16+Mn	10.7-11.2	8.7	0.0193	106.1	1532	26.5	15,403	91	301	9,974	10,455	481	2.99	10,986	12,048	214,203
Deep 36	6	Mancos	M233-2	OB-16+Mn	12.4-13.2	13.2	0.0291	108	1930	33.3	20,183	91	301	9,979	10,488	509	3.16	10,991	12,045	178,118
Deep 36	7	Carthage	M233-2	OB-16+Mn	20.4-20.6	3	0.0067	115.8	613	10.6	10,001	91	301	9,981	10,455	474	2.94	10,988	12,023	248,278
Deep 36	8	Carthage	M233-2	OB-16+Mn	20.8-21.2	8	0.0177	116.9	1391	23.8	15,043	90	301	9,990	10,476	486	3.01	11,011	12,042	209,182
Deep 36	9	Carthage	M233-2	OB-16+Mn	22.7-23.5	11.3	0.0251	118.8	1975	33.8	20,023	90	301	9,981	10,474	493	3.06	11,004	12,052	210,443
Deep 36	10	Carthage	M233-2	OB-16+Mn	24.6-25.9	19.1	0.0425	119.9	2755	47.2	24,873	90	301	9,995	10,485	490	3.04	11,002	12,067	173,969
Deep 36	11	Carthage	M233-2	OB-16+Mn	26.4-27.0	7.9	0.0174	121	1289	22.3	15,156	91	301	9,973	10,459	486	3.02	10,999	12,063	198,509
Deep 36	12	Carthage	M233-2	OB-16+Mn	27.6-28.3	10.4	0.0231	122	1897	32.6	20,158	90	301	9,983	10,462	479	2.97	10,999	12,070	219,598
Deep 37	1	Mancos	M333-2	OB-16+Lub	4.1- 4.6	9.5	0.0208	105.2	1400	24.2	10,275	91	301	9,989	10,353	364	2.26	11,002	12,020	179,170
Deep 37	2	Mancos	M333-2	OB-16+Lub	6.0- 7.5	31.8	0.0706	106.9	2909	49.9	15,042	90	301	9,991	10,379	388	2.41	11,015	12,059	110,306
Deep 37	3	Mancos	M333-2	OB-16+Lub	8.9- 9.5	24.5	0.0544	108.3	2958	50.8	20,234	90	301	9,977	10,341	364	2.26	11,012	12,051	145,597
Deep 37	4	Carthage	M333-2	OB-16+Lub	19.9-20.0	0.7	0.0014	114.6	532	9.2	10,051	91	301	9,984	10,344	360	2.23	11,002	12,019	922,489
Deep 37	5	Carthage	M333-2	OB-16+Lub	20.3-20.6	4.3	0.0097	116.5	1347	23	14,912	90	301	9,976	10,340	363	2.25	11,007	12,033	376,434
Deep 37	6	Carthage	M333-2	OB-16+Lub	21.1-21.9	15.1	0.0337	117.4	2594	44.3	19,986	90	301	9,991	10,375	384	2.38	11,004	12,043	206,853
Deep 37	7	Carthage	M333-2	OB-16+Lub	22.2-24.1	24.3	0.0541	118.1	3576	61.2	24,946	90	301	10,008	10,380	371	2.3	11,010	12,058	177,475
Deep 37	8	Carthage	M333-2	OB-16+Lub	24.4-24.6	3.4	0.0075	119.1	1263	21.8	15,038	91	301	9,982	10,332	350	2.17	11,000	12,040	451,250
Deep 37	9	Carthage	M333-2	OB-16+Lub	25.4-26.1	16	0.0354	120.4	2650	45.5	20,115	90	301	9,968	10,329	361	2.24	11,004	12,054	199,461

Table A-1 (continued). Data from all Deep Trek tests, averaged over the interval of "constant" test parameter settings.

Test Number	Data Point. No.	Rock[1]	Drill Bit[2]	Drilling Fluid[3]	Drilled Interval in	ROP[4] ft/hr	ROP in/rev	Temp °F	Torque ft-lb	Hyd. Horse-power[5] HP	Weight on Bit lb	Rotary Speed rpm	Flow Rate gpm	Bore Press. psi	Swivel Mud Press. psi	Bit Press. Drop psi	HSI Horse-power[6] HP/in^2	Conf. Stress psi	Over-burden Stress psi	Mech. Specific Energy psi

[1]Rock types tested: Carthage marble, Crab Orchard sandstone, and Mancos shale.
[2]Bits types ase per IADC designations with the numerical extension referring to the testing phase. The bit types include: 737—tungsten carbide insert roller cone, M121—four-bladed PDC, M233—four-bladed PDC, M333—7-bladed PDC, and M841—diamond impregnated.
[3]Drilling fluids included: Water—water, WB-11—11 ppg water-based, Base Oil—mineral oil base without additives, OB-12—12 ppg oil-based, OB-16—16 ppg oil-based without special additives, CF-16—cesium formate brine, CF-16+--cesium formate brine with simulated drill solids, OB-16+Lub—16 ppg oil-based with lubricity additives, OB-16+Alt—16 ppg oil-based with surfactant added, OB-16+Mn—16 ppg oil-based with manganese tetroxide weighting material.
[4]ROP—rate of penetration.
[5]Hydro. Horsepower is the hydraulic horsepower across the bit.
[6]HSI Horsepower is the hydraulic horsepower per square inch of bit face.

APPENDIX B
DeepTrek Phase 2 Test Procedures

The following procedure will be followed for each trial.

Test Setup and Routine Maintenance

1. Check all equipment for wear, fluid levels, and proper lubrication.
2. Check out test sample. Ensure that rods extend no more than ½ inch below the nut on the bottom endcap.
3. Check the length of the drilling assembly.
4. Make up the drilling assembly. Check the rotary table transmission to make certain it is in 3rd gear.
5. Install the rock sample assembly in the pressure vessel.
6. Make up the vessel.
7. Apply 200 psi confining and 300 psi ram pressures (if sample is to be sitting overnight).
8. Make up the drill string.
9. Tie down the rig.
10. Raise the drill string 2 inches above the rock.
11. Check seal oiler air line.

Pretest Procedures

1. Take a sample of the mud.
2. Determine standard mud properties.
3. Start the engine of the Hughes mud pump.
4. Check calibration of instruments.
5. Set up the data acquisition system while referring to the listed parameters.
6. Turn on the TerraTek mud pump.

Safety Meeting/Lessons Learned/Trial Parameters

1. Discuss safety issues related to the testing.
2. Ensure that all have proper safety gear.
3. Review shut down procedures.
4. Review evacuation procedures.
5. Discuss incidents from previous trials.
6. Discuss the test coming up and issues from previous trials.
7. Discuss the parameters and sequence for the upcoming trial.
8. Post the test sequence.

Test Procedures

1. Triple check all mud system valves.
2. Start data acquisition.
3. Bring up the ram pressure to 400 psi and the confining pressure to 200 psi.
4. Start mud system centrifugal pumps.
5. Turn to the right at about 10 rpm.

6. Bring up the ram, confining, and bore pressures to the test pressure with a differential of 200 psi greater ram than confining pressure and 200 psi greater confining than bore pressure.
7. Bring the ram, confining, and bore pressures to respectively, 12,000 psi, 11,000 psi, and 10,000 psi.
8. Make certain pressure effects are zeroed out and take off-bottom torque measurements at rotational speeds to be used in the trial.
9. Bring up the rotary speed to the initial designated speed and slowly bring the bit in contact with the rock and spud while applying increasing WOB until the designated depth is reached. The WOB should be at the level designated for Data #1.
10. Follow the outlined test matrix at the designated rotational speed, WOB, and depth (or drill until adequate data is acquired).
11. Take high rate data after the parameters are stabilized.
12. After completing the trial sequence, bring the string up 3 inches.
13. Lower rotary speed to 10 rpm.
14. Reduce ram, confining, and bore pressure using the differentials listed in step 7 until bore pressure is zero, the confining pressure is 150 psi, and the ram pressure is 250 psi.
15. Blow out the mud system. Remove the air pressure from the mud system.
16. Break out the drill string and back the rig off the vessel.
17. Bring confining and ram pressures to zero.
18. Remove the cuttings basket while spraying drill cuttings.
19. Remove the drilled sample from the vessel.

Post Test Procedures

1. Remove the top endcap and drill string assembly and check and note the bit condition and balling.
2. Note the condition of bit and photograph.
3. Clean, examine, photograph, and freeze drill cuttings.
4. Examine and photograph the bottom of the borehole.
5. Cut the rock sample 4 inches above the bottom of the borehole. Take one core plug from the side/bottom of the borehole and one from the bottom of the borehole. Label and freeze the plugs.
6. Measure and record the top and bottom of the borehole at two locations each (at right angles to each other).

APPENDIX C
Supplemental Graphs

LIST OF FIGURES

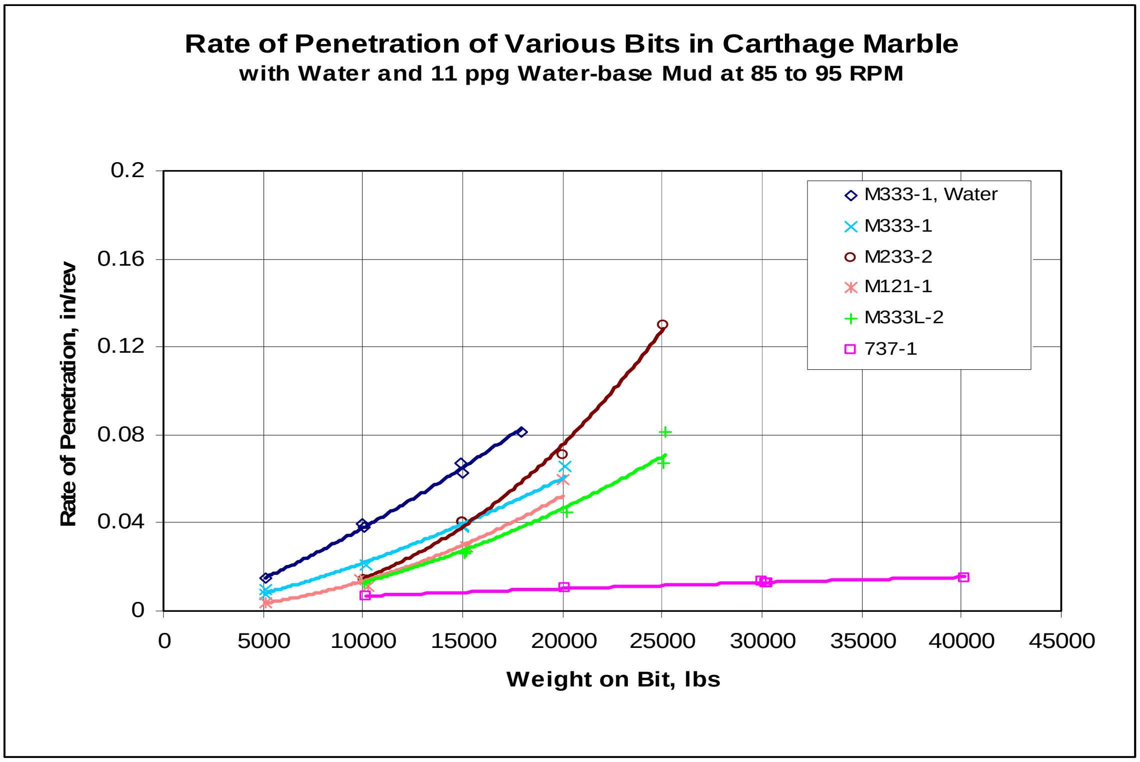

Figure C-1. Rate of penetration comparison of various drill bits in Carthage marble with water and 11 ppg water-based drilling fluids.

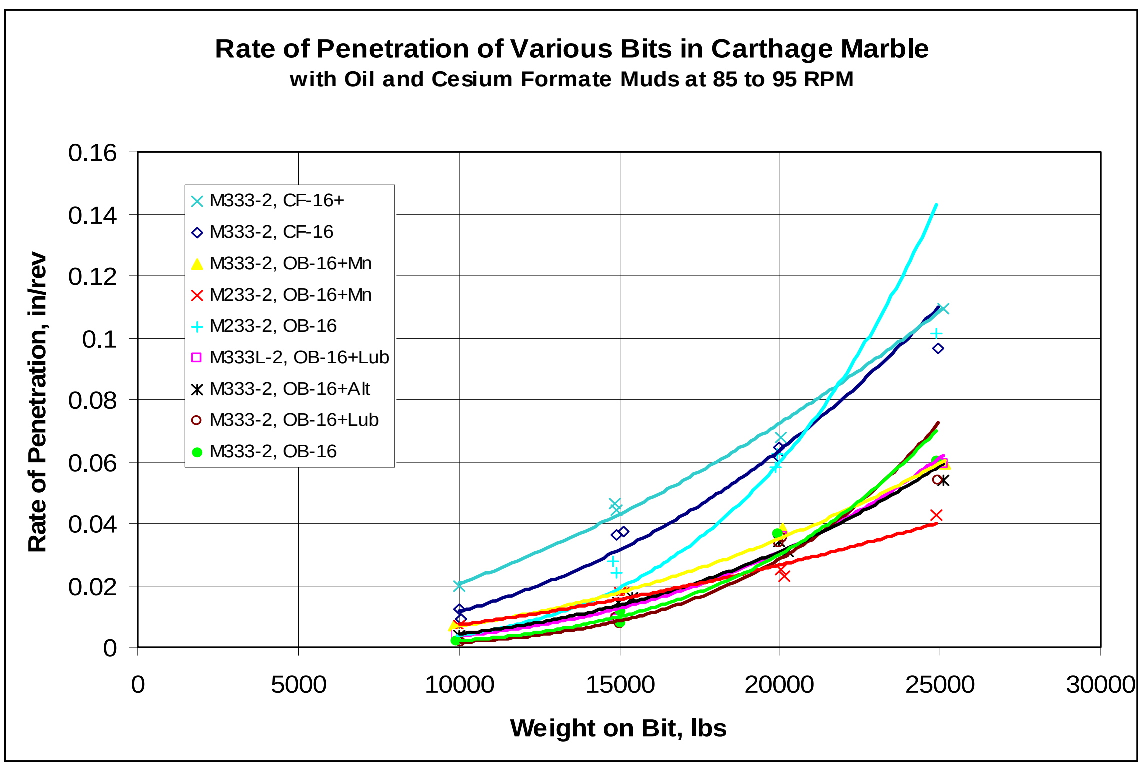

Figure C-2. Rate of penetration comparison of various drill bits in Carthage marble with 16 ppg oil-based and cesium formate drilling fluids.

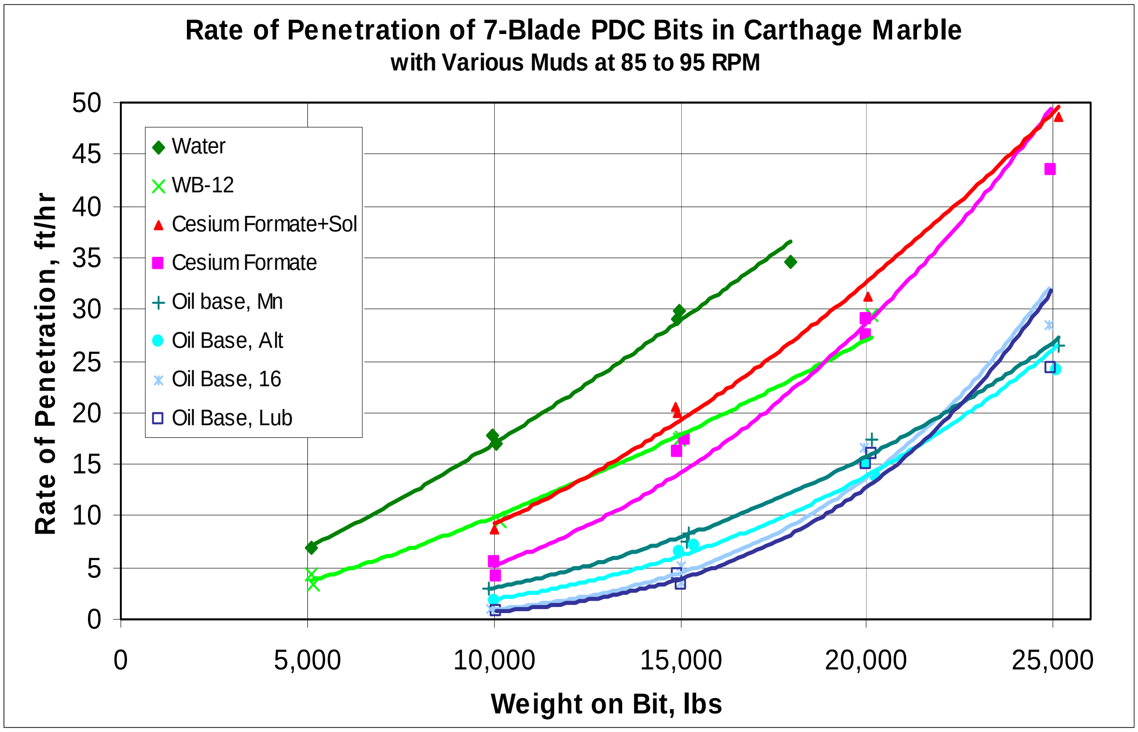

Figure C-3. Rate of penetration of 7-bladed PDC drill bits in Carthage marble with various drilling fluids.

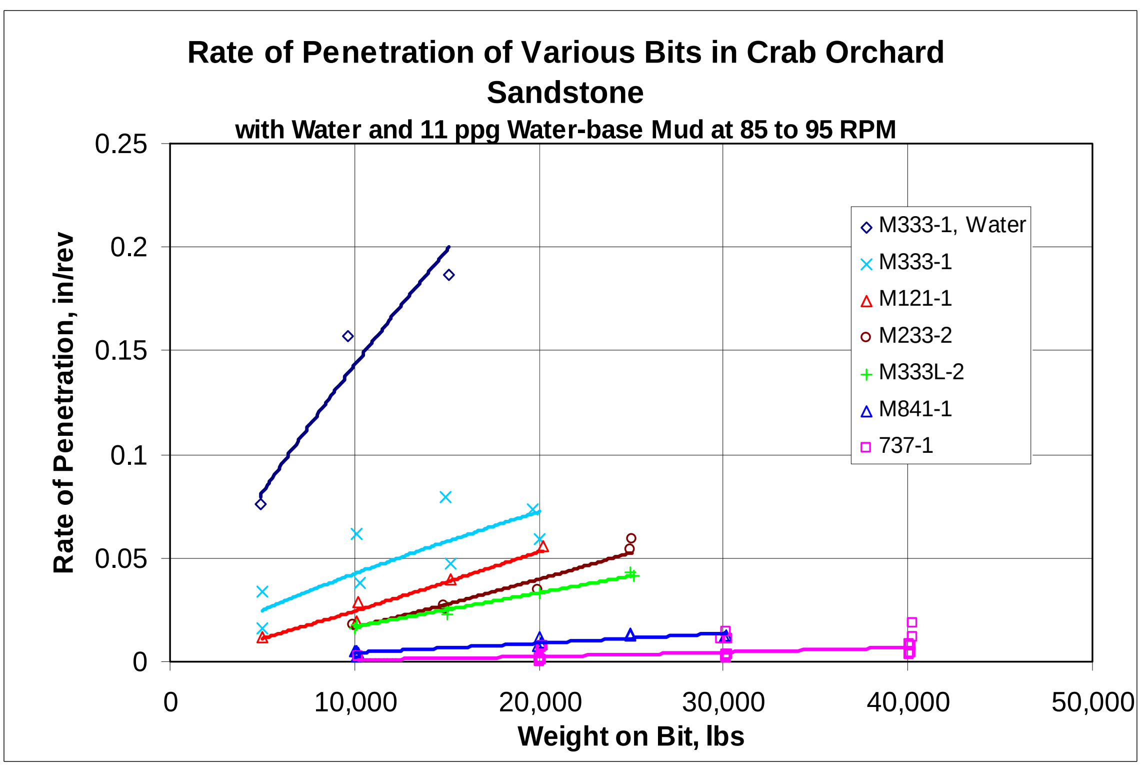

Figure C-4. Rate of penetration comparison of various drill bits in Crab Orchard sandstone with water and 11 ppg water-based drilling fluids.

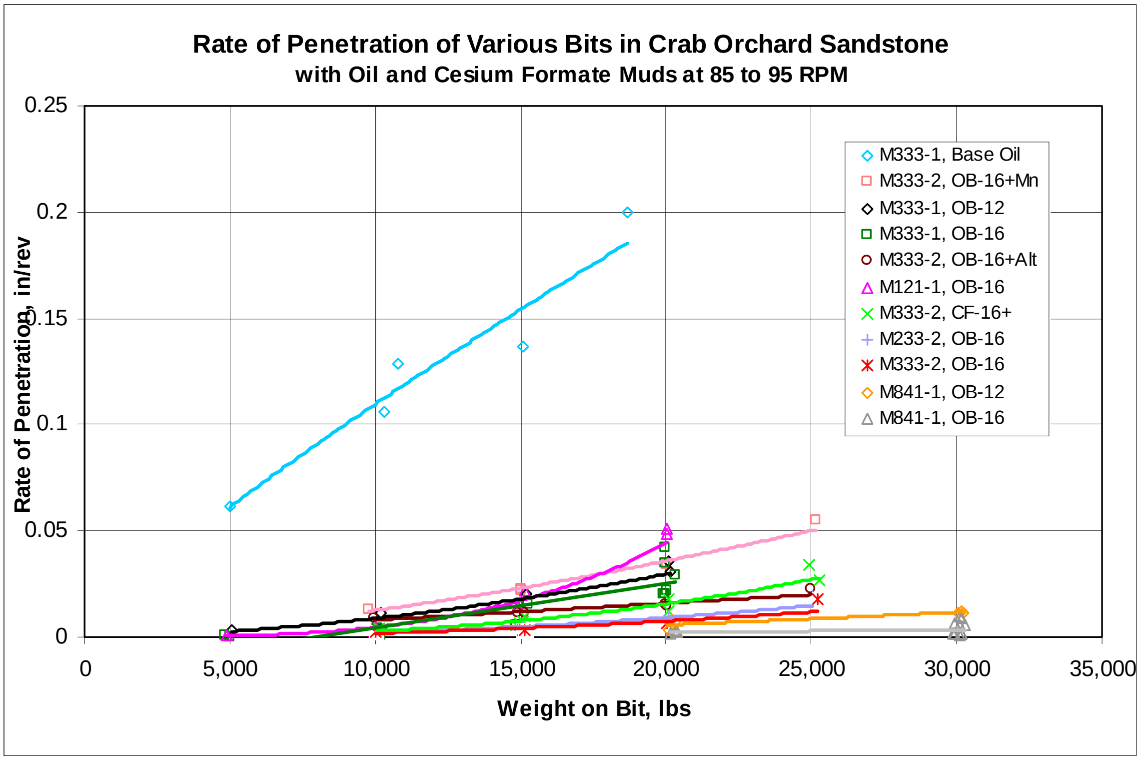

Figure C-5. Rate of penetration comparison of various drill bits in Crab Orchard sandstone with 16 ppg oil-based and cesium formate drilling fluids.

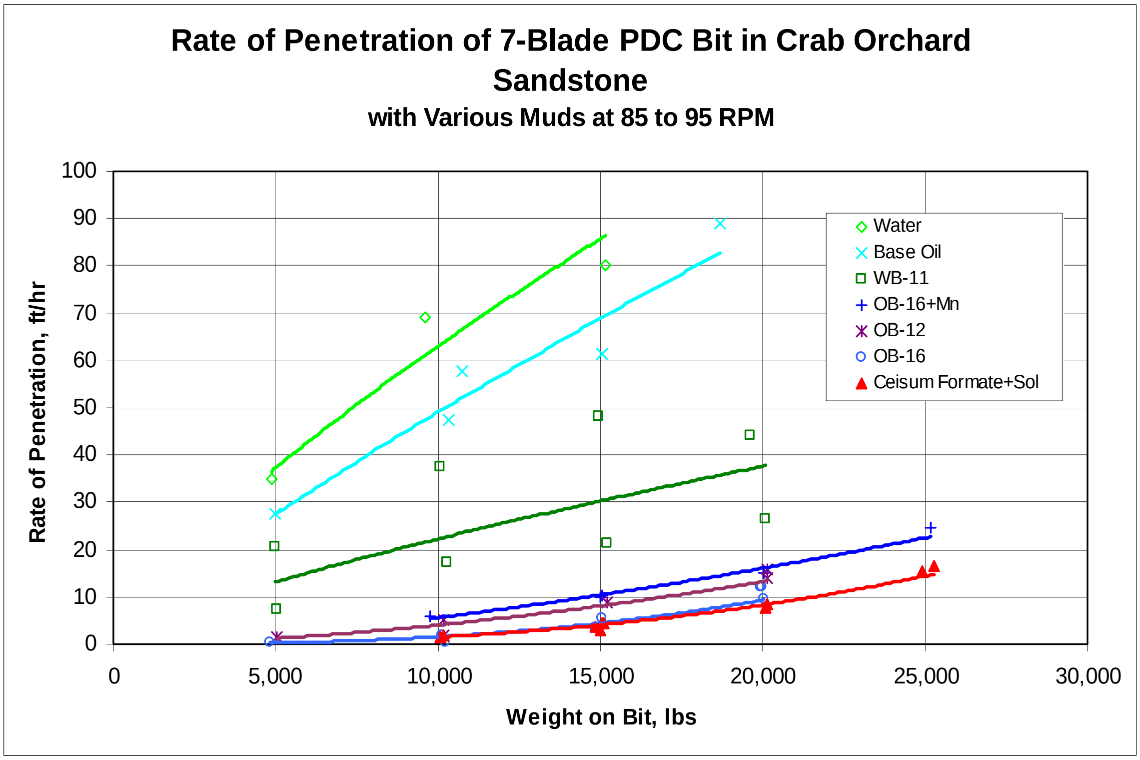

Figure C-6. Rate of penetration of 7-bladed PDC drill bits in Crab Orchard sandstone with various drilling fluids.

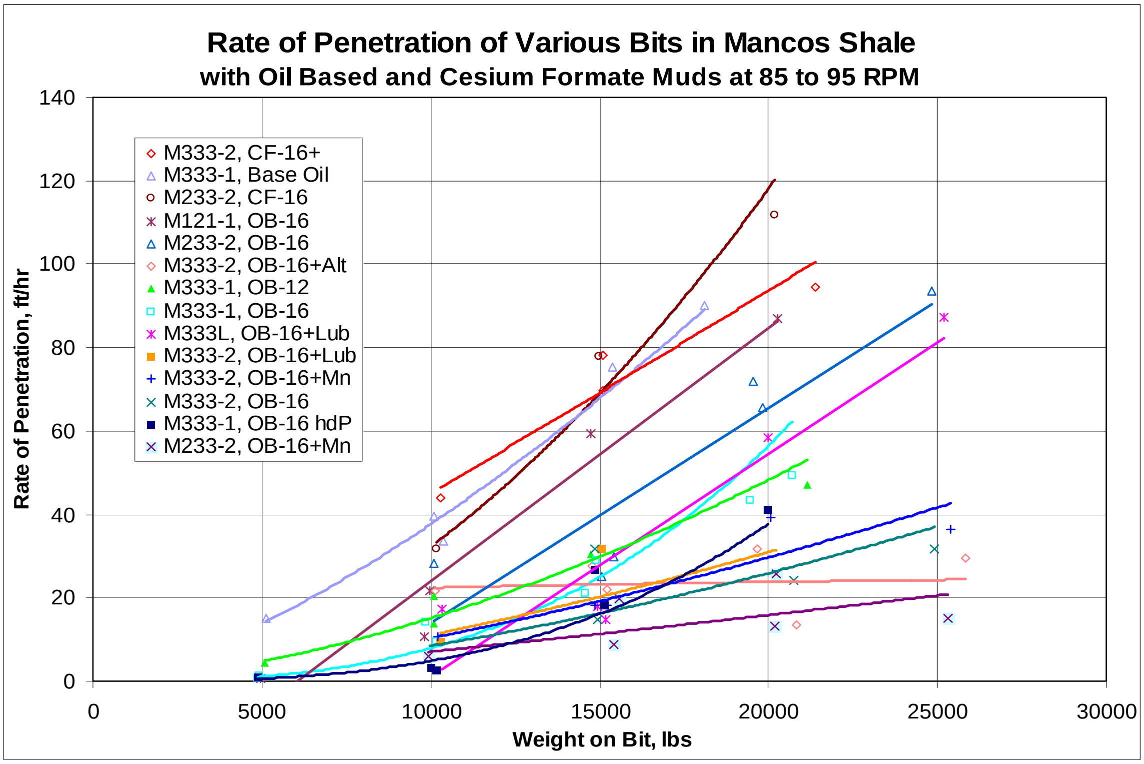

Figure C-7. Rate of penetration comparison of various drill bits in Mancos shale with 16 ppg oil-based and cesium formate drilling fluids.

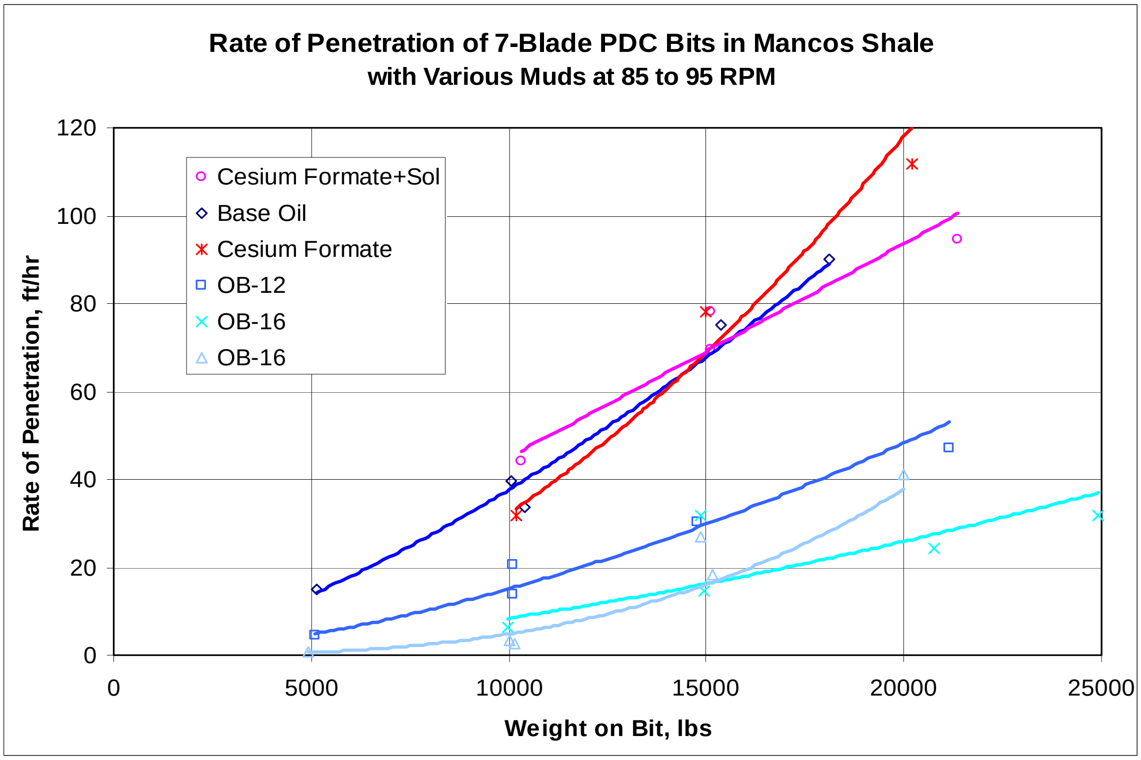

Figure C-8. Rate of penetration of 7-bladed PDC drill bits in Mancos shale with various drilling fluids.

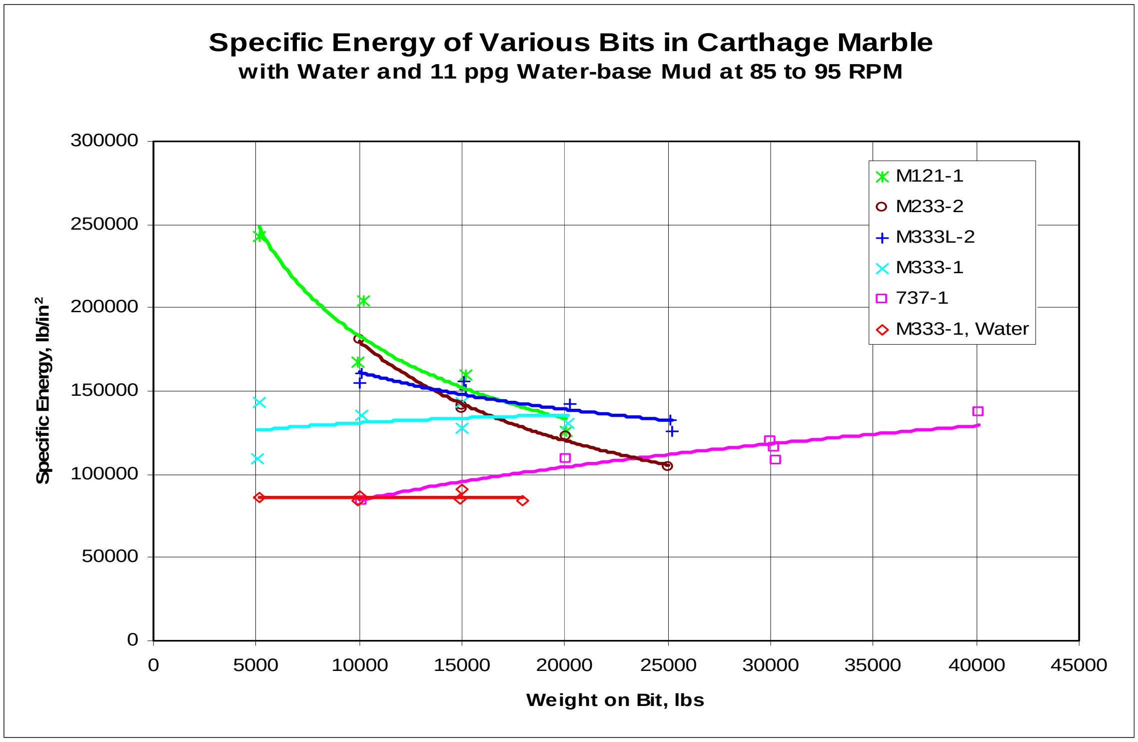

Figure C-9. Mechanical specific energy comparisons of various drill bits in Carthage marble with water and 11 ppg water-based drilling fluids.

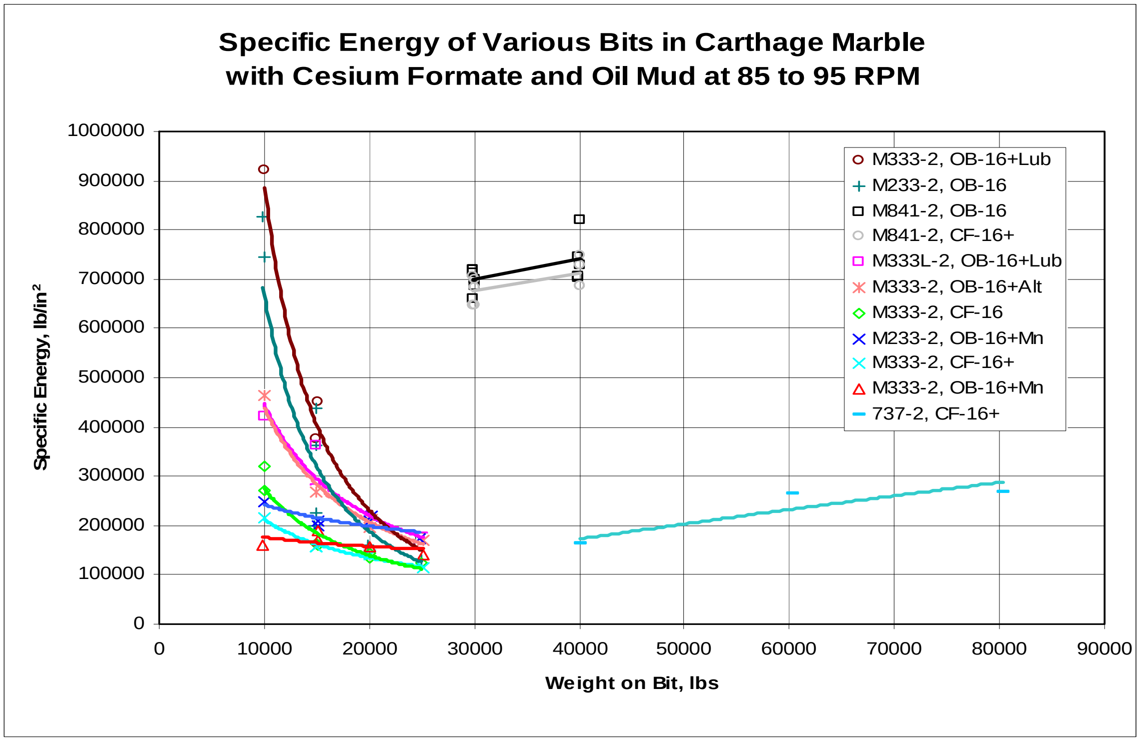

Figure C-10. Mechanical specific energy comparison of various drill bits in Carthage marble with 16 ppg oil-based and cesium formate drilling fluids.

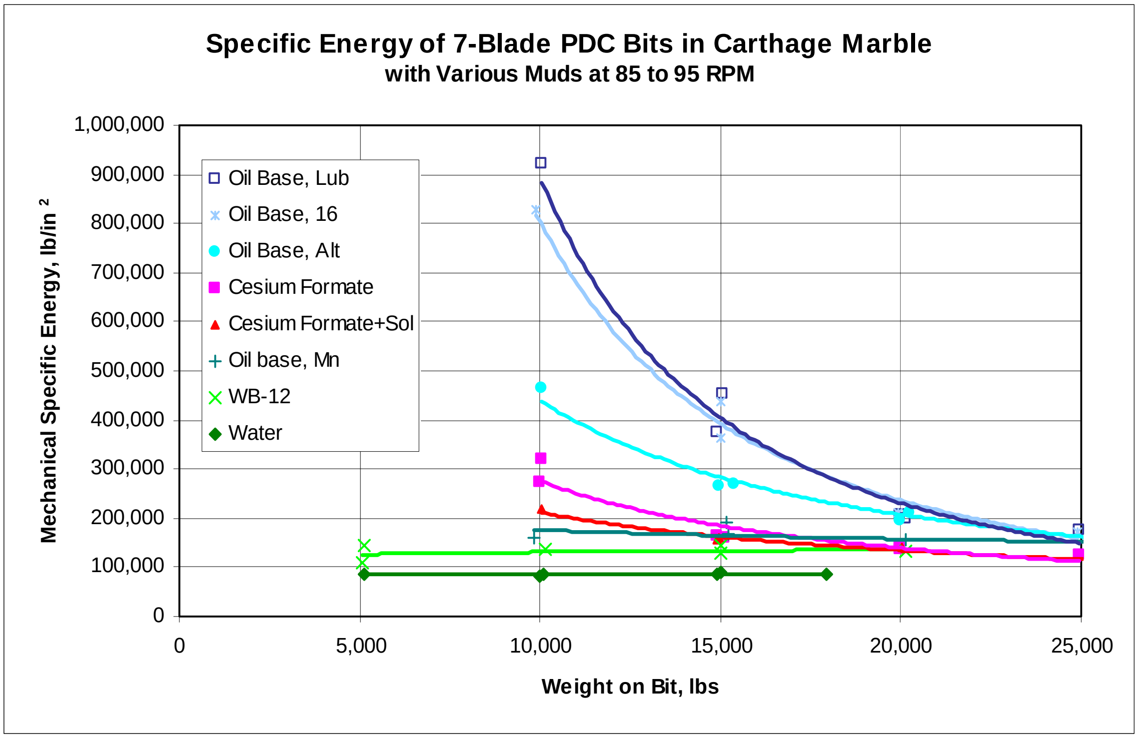

Figure C-11. Mechanical specific energy of 7-bladed PDC drill bits in Carthage marble with various drilling fluids.

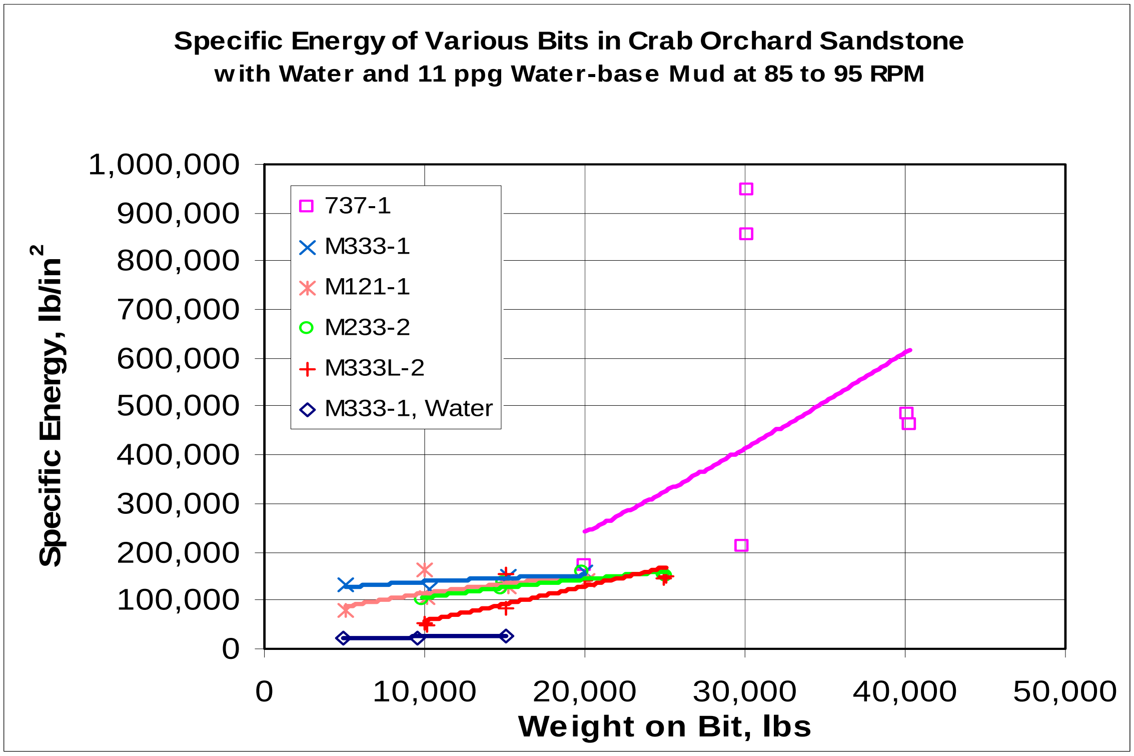

Figure C-12. Mechanical specific energy comparison of various drill bits in Crab Orchard sandstone with water and 11 ppg water-based drilling fluids.

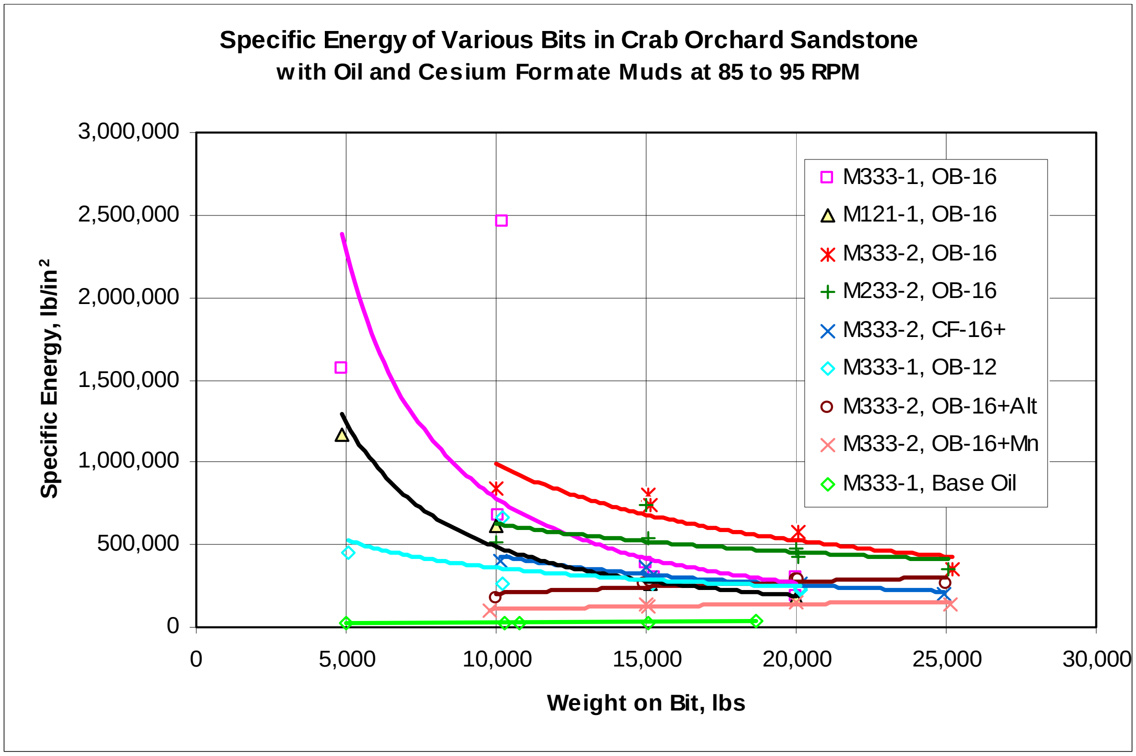

Figure C-13. Mechanical specific energy comparison of various drill bits in Crab Orchard sandstone with 16 ppg oil-based and cesium formate drilling fluids.

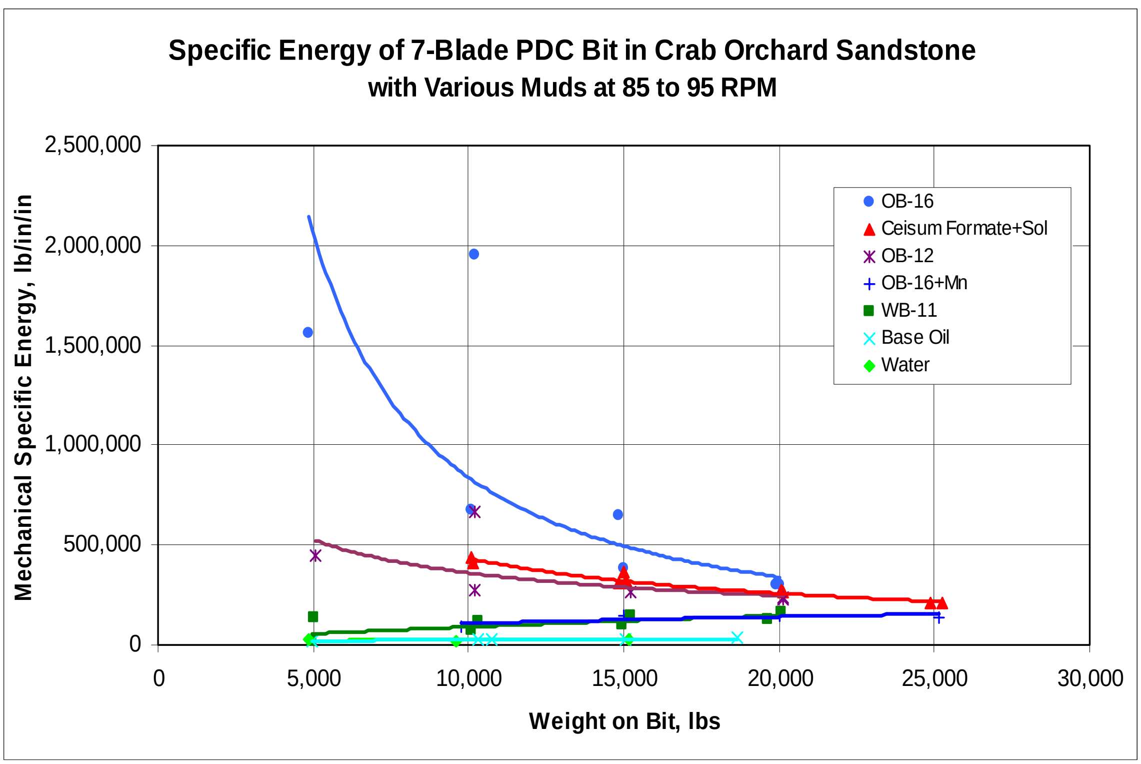

Figure C-14. Mechanical specific energy of 7-bladed PDC drill bits in Crab Orchard sandstone with various drilling fluids.

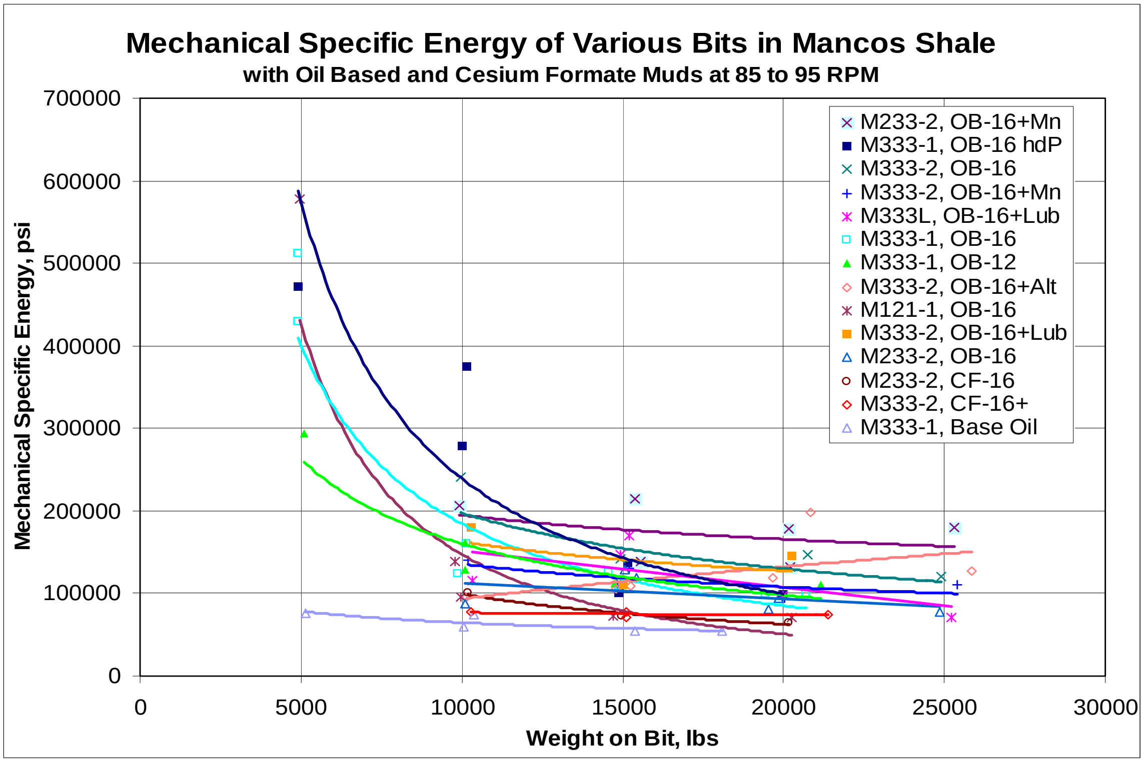

Figure C-15. Mechanical specific energy comparison of various drill bits in Mancos shale with 16 ppg oil-based and cesium formate drilling fluids.

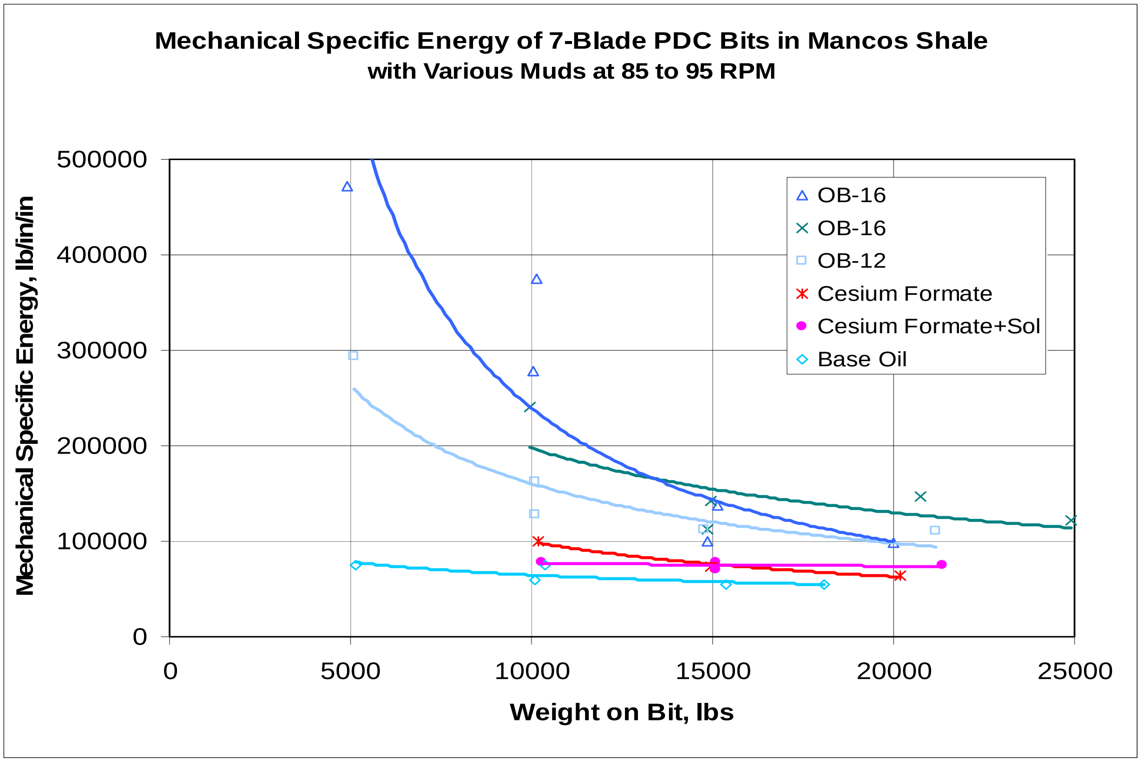

Figure C-16. Mechanical specific energy of 7-bladed PDC drill bits in Mancos shale with various drilling fluids.

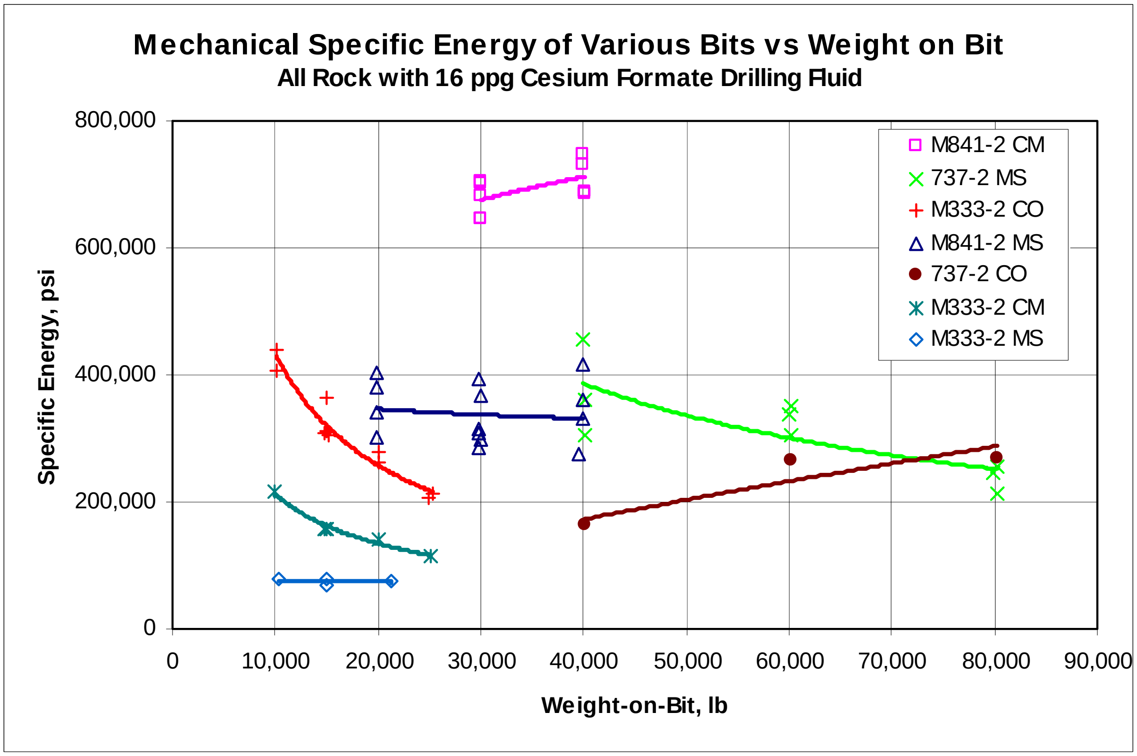

Figure C-17. Mechanical specific energy of various drill bits in all rock types with 16 ppg cesium formate drilling fluid.

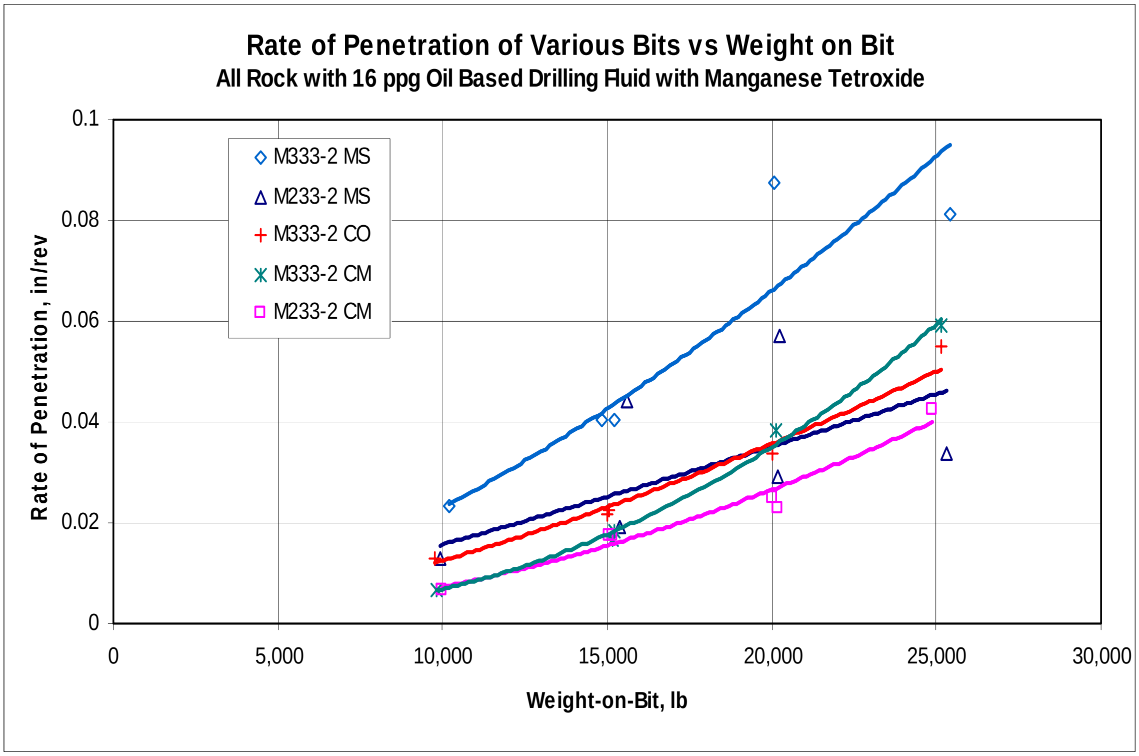

Figure C-18. Rate of penetration comparison of various drill bits in all rock types with 16 ppg oil-based drilling fluid with manganese tetroxide weighting material.

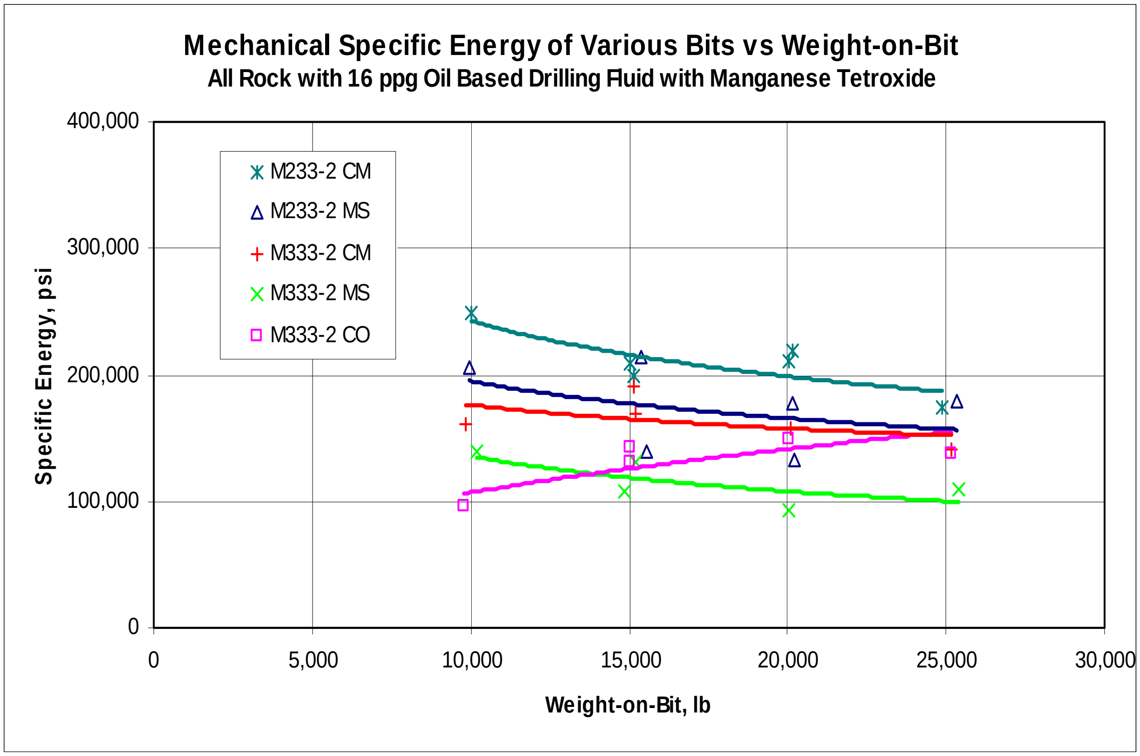

Figure C-19. Mechanical specific energy comparison of various drill bits in all rock types with 16 ppg oil-based drilling fluid with manganese tetroxide weighting material.

APPENDIX D
Cuttings Analysis

Table D-1. Cutting size distribution for all tests.

Test #	Mud/Weight[1]	Drill Bit[2]	Rock Type[3]	Cuttings Size Distribution, mm		
				D10	D50	D90
1	Water	M333-1	CO/CM	2.2	2.8	4.0
2	WB-11	737-1	CM	2.4	3.7	6.1
3	WB-11	737-1	CO	2.2	3.3	5.3
4	WB-11	M333-1	CM	2.6	3.6	4.9
5	WB-11	M333-1	CO	2.6	4.3	7.0
6	WB-11	M841-1	CM	3.9	8.4	14.1
7	WB-11	M841-1	CO	2.6	3.4	9.9
8	WB-11	M121-1	CO/CM	2.9	4.7	7.2
9	Base Oil	M333-1	CO/MS			
10	OB-12	M333-1	CO/MS	4.3	9.4	14.3
11	OB-12	M841-1	CO/MS	2.3	4.3	11.8
12	OB-16	M841-1	CO/MS			
13	OB-16	M333-1	CO/MS			
14	OB-16	M333-1	CO/MS			
15	OB-16	M121-1	CO/MS			
16	OB-16	M333-1	CO/MS			
17A	WB-11	M841-2	MS	3.2	11.4	2.7
17B	WB-11	M841-2	CM	2.8	6.0	13.5
18	WB-11	M233-2	CM/CO	3.1	5.8	8.1
19	WB-11	M333L-2	CM/CO	2.6	3.9	5.8
20	WB-11	737-2	MS/CM/CO	2.7	7.0	23.0
21	CF-16	M333-2	MS/CM	2.7	5.8	16.2
22a	CF-16+sol	M841-2	MS/CM			
22b	CF-16+sol	M841-2	CM			
23	CF-16+sol	M333-2	MS/CM	3.6	12.4	26.2
24	CF-16+sol	M333-2	CO	2.4	3.2	5.7
25	CF-16+sol	737-2	MS/CM/CO	2.8	4.7	11.4
26	OB-16	M841-2	MS/CM	3.2	10.3	25.0
27	OB-16	M233-2	CO	3.6	6.3	8.4
28	OB-16	M233-2	MS/CM	4.8	10.8	17.0
29	OB-16	M333-2	CO	3.0	5.1	7.6
30	OB-16	M333-2	MS/CM	4.5	10.0	16.9
31	OB-16+lub	M333L-2	MS/CM	3.8	8.2	15.3
32	OB-16+sur	M333-2	CO	2.8	4.2	9.2
33	OB-16+sur	M333-2	MS/CM	4.7	9.8	18.1
34	OB-16+Mn	M333-2	CO	2.4	5.1	7.5
35	OB-16+Mn	M333-2	MS/CM	5.6	12.5	17.5
36	OB-16+Mn	M233-2	MS/CM	3.8	9.2	17.9
37	OB-16+lub	M333-2	MS/CM	4.0	9.1	15.6

[1]Mud/Weight: WB-11—11 ppg water-based, OB-12—12 ppg oil-based, OB-16—16 ppg oil-based, CF-16—16 ppg cesium formate brine, CF-16+sol—cesium formate brine with simulated drill solids, OB-16+lub—16 ppg oil-based with lubricity additives, OB-16-sur—16 ppg oil-based with surfactant added, OB-16+Mn—16 ppg oil-

based with manganese tetroxide weighting material.

[2]Drill Bits are listed according to the IADC designation as such: M333—7-blade PDC, 737—tungsten carbide insert roller cone, M841—diamond impregnated, M121—four-bladed PDC, M233—four-bladed PDC.

[3]Rock Type: CO—Crab Orchard sandstone, CM—Carthage marble, MS—Mancos shale.

APPENDIX E
Abbreviations

API	American Petroleum Institute
IADC	Association of Drilling Contractors
HSI	hydraulic horsepower per square inch
MSE	mechanical specific energy
PDC	polycrystalline diamond compact
ROP	rate of penetration
TCI	tungsten carbide insert
DOE	U.S. Department of Energy
WOB	weight on bit