TECHNOLOGY ASSESSMENT FOR

Optimization of Deep Drilling Performance; Development and Benchmark Testing of Advanced Diamond Product Bits and High Pressure/High Temperature Fluids to Significantly Improve Rates of Penetration

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Introduction: Current State of Technology

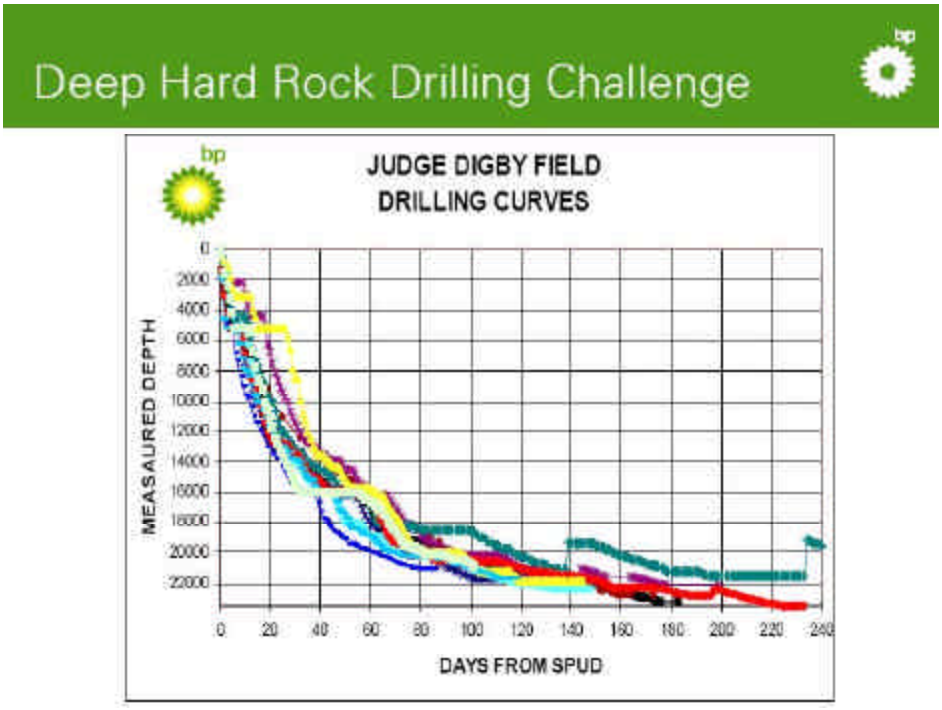
Background and context

For domestic operations involving hard rock and deep oil and gas plays, improvements in drilling penetration rates are an opportunity to reduce well costs and make viable certain field developments. These regions include the Rocky Mountains, Tuscaloosa trend, Anadarko basin, and several other areas. An estimate of North American hard rock drilling costs is in excess of $1,200 MM. Thus potential savings of $200 MM to $600 MM are possible if penetration rates are doubled [and assuming bit life is reasonable]. The net result for operators is improved profit margin as well as an improved position on reserves.

Some of the challenges of drilling in deep and hard formations include;

- Rock strength increases with increased depth. Also seen are increased shale plasticity and bit balling tendencies.
- High overbalance (Borehole - Pore Pressure) resulting in chip hold down.
- High mud solids, high density, increased viscosity, lower spurt-loss fluids in Deep Wells
- Rig and operational limitations i.e. low hydraulics, bit wear, friction losses, differential sticking, lost circulation, etc.

Figure below shows example time - depth curves for example Tuscaloosa wells presented by BP's John Shaughnessy to the Department of Energy, 2001 (times below 18,000 ft Measured Depth are long)

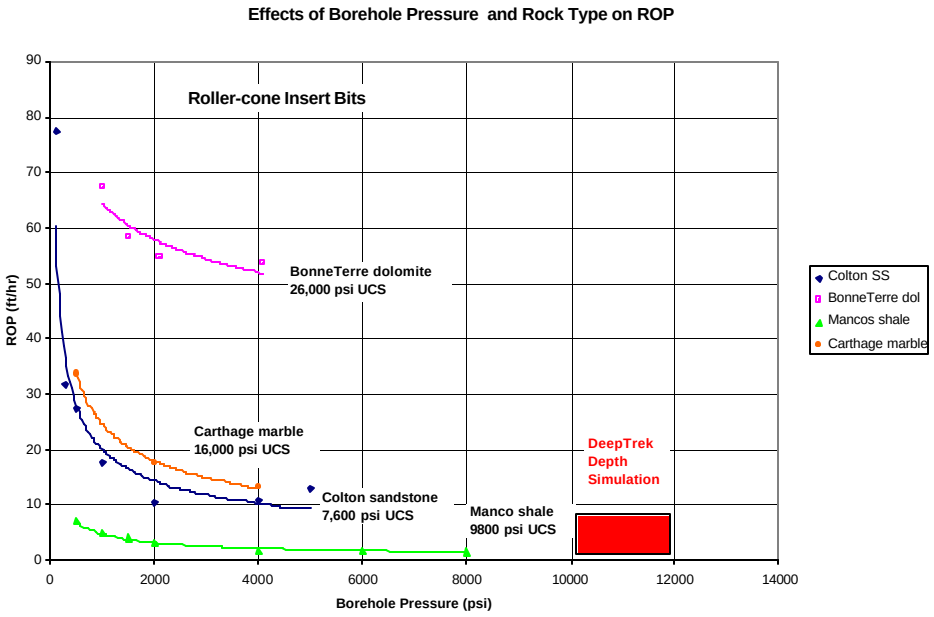


Technologies and tools being used

Large-scale testing has accelerated the knowledge of factors affecting drilling rates in various rock types. As early as 1959, A. Garnier and R. Feenstra, Shell, published articles about drilling

rates at depth and jetting of 'impermeable' rocks, respectively. Over more recent years, the conditions at which tests have been conducted simulated greater and greater depths. TerraTek's Drilling Engineering Association Project Number 90 on 'Drilling Shale at Great Depth' has advanced PDC bit and water based fluid additive technology significantly, yet the tested 9,000 psi pressures still limit certain analyses for depths the Department of Energy anticipates in future domestic plays. Roller cone and fixed cutter bits are used at depths in excess of 16,000 feet at which point drilling costs escalate tremendously due in part to tripping requirements and also the inability to maintain sufficiently large hole sizes. Aggressive impregnated bits have received rather modest attention yet have the potential for increasing rates of penetration. Percussion tools, particularly fluid hammers, have recently demonstrated good success in another DOE project, yet at high borehole pressures performance improvements deteriorate. Motors and turbines are currently available in some applications but the requirements of high temperature stators in positive displacement motors for example can limit life and their effectiveness. TerraTek demonstrated the innovative features of ultra-high speed rotary drilling to NASA's MARS Drilling Program at the Jet Propulsion Laboratory. In this program, the ability to design diamond product bits for harder rocks was noted. Other techniques to drill deep and yet retain reasonable performance have come through improvements in materials technology (e.g. high strength drill pipe), higher horsepower pumps, and high temperature electronics for a variety of measurement-while-drilling and other downhole tools. Enhancements to deep drilling via novel drill bits and fluid technologies complement developments in directional drilling and other advanced techniques.

DeepTrek – Achieving the next level in ROP performance



Benefits and pitfalls of current technology

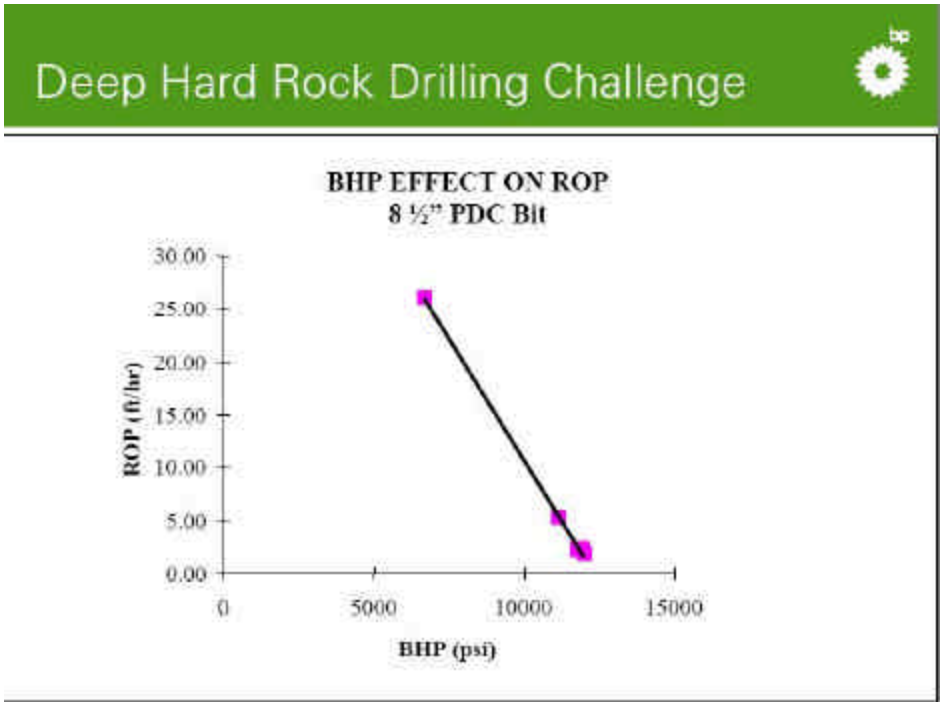
Operators working in the United States have articulated the need for deep drilling performance improvements for such areas as Tuscaloosa trend, Western Oklahoma, and Anadarko Basin. Looking ahead to some deep gas exploration plays, challenges include Rates of Penetration (ROP), hydraulics limitations at great depth, and dynamics – problems such as 'slip-stick'. Operators and suppliers expressed such concerns at the Department of Energy Deep Trek

Workshop in March 2001. There some of the significant ROP problems were addressed; i.e. rock strength can be high and variable, there is a lack of aggressive drag bits, persistent low ROPs are viewed as serious non-productive time, ROP increases can justify development costs of new downhole tools, rock variability often requires 'smarter bits' capable of drilling with a consistently higher ROP, and bit vibration can induce failures. The fundamentals of rock mechanics and cutting mechanisms at great depth are obvious avenues of more research.

Rich Reiley, formerly BP America, also advised the DOE that –

PDC bits drill too slow and dull too fast (see figure below)
Electronics can cook in HPHT environments
Drilling fluids are hard to pump, have high ECD, and can trap gas

Figure below shows average ROP vs. bottomhole pressure; presented by BP's Richard H. Reiley to the Department of Energy, 2002



Discussion: Development Strategies

New technology and research

TerraTek is benchmarking tool performance at conditions not possible in other laboratory environments and not practical in expensive field trials. One solution to hard rock drilling ROP is not likely another impregnated matrix and/or diamond change but a re-examination of the mechanics of cutting using impregnated and PDC cutting structures. High speed cutting with new impregnated bits and designs for low stress / high load cutting are two options being investigated in the first phase of the program. TerraTek's ability to develop novel technologies for drilling is exemplified by it's innovative 'ultra-high speed' coring technique being evaluated for NASA's Jet Propulsion Laboratory 'Drilling on Mars' program. Through testing and development of novel impregnated and advanced PDC bits, the proposed work will minimize the risks of troublesome

vibrations and improve ROPs significantly. Faster penetration rates can affect asset or application economics through lower development drilling costs and reduced drilling time. Coupled with HP/HT fluids and new ROP enhancers, the delivery of a proven *'smart drilling bit-fluid system'* capable of drilling various deep rock formations is crucial.

The drilling of certain deep formations at high borehole pressures has proven difficult particularly under high overbalanced conditions. Understandably, the proposed work will focus first on developing optimum bit cutting characteristics and test these innovations at TerraTek's large-scale drilling laboratory. Drilling Engineering Association (DEA) Project 90 "Drilling Plastic Shale at Great Depth" is an example joint industry program carried out by TerraTek that resulted in significant advances and innovations both in PDC bits and fluid additives that have already had economic benefit to operators drilling in the United States.

TerraTek will test innovative bits and new products in its 'Wellbore Simulator'. Confining and overburden stresses are applied to selected rock samples and borehole pressures / hydraulics can be controlled. Weight-on-bit is applied with a servo-controlled system and rotary speed is controlled with variable speed direct drive motors, 5-speed transmission and standard oil-field rotary table. High-pressure fluid ends on the mud pump will facilitate drilling at pressures in excess of 10,000 psi. The bit supplier to develop and design features important to the improvement of ROP at great depths will use computer aided engineering practices. The work proposes to benchmark performance and provide bit developments first for a 6 to 8-1/2" diameter range. John Shaughnessy, BP's Senior Drilling Engineering for the Tuscaloosa trend, noted at the March 2001 Deep Trek Workshop that "over 50% of rig time is spent in the last 10% of the hole" and the operator has "high interest in improving ROP deep".

Problems to be addressed in the research project

The greatest potential for problems in the described work program includes 1) supply of sufficient hydraulics for high pressure drilling tests, 2) supply of innovative bit and drilling fluid systems which will achieve significant improvements of performance at depth conditions, and 3) marketplace acceptance of deep drilling technologies during business cycles of variable rig activity.

Industry partners will assist with sufficient pumping capacity to ensure that the state-of-the art bits and fluids are properly evaluated. Rolf Pessier, Hughes Christensen, has publicly stated that ROP is indeed highly dependent on flow rate and HSI [and Rolf] suspects the hydraulics become even more important at higher bottomhole pressure and higher mud weight; i.e. those evaluated in the DeepTrek program.

Assurance of the delivery of novel bits and fluids is to occur via Baker-Hughes substantial 'in-kind' contributions to the proposed program. The business model used for this project potentially enhances the supplier role of Hughes Christensen and INTEQ Drilling Fluids with the operators keen to develop deep fields. While interest in deep drilling plays may fluctuate during oil and gas activity cycles, the long term needs of a domestic gas supply clearly indicate a trend to deeper formations.

Deliverables

1. Characterization of applications – Determination of the specific performance issues with roller cone, impregnated and/or PDC bits in the operators' areas of interest.

2. Benchmarking performance of emerging products – Full scale drilling tests will be performed in TerraTek's Drilling and Completions Laboratory. In the Wellbore Simulator, drilling tests at high pressures in hard rock and others as appropriate can reveal deficiencies and design features required for a next level of performance.
3. With the Industry Team, develop and supply new aggressive impregnated and PDC bit prototypes and HP/HT drilling fluids addressing ROP challenges. Improved ROPs in a variety of rock types is the goal for these deep applications. TerraTek will test, evaluate, and document the performance of these innovative diamond products and drilling fluids.
4. Commercialization and Field Deployment - Field-testing of the prototype developments will precede the commercialization of *'smart bit – fluid systems'* that perform up to operator expectations.

Conclusion: The Future

Impact on the petroleum industry

The DeepTrek work will be a driving force in progressing improved deep drilling performance and ultimately commercialization. Field testing on expensive wells (>$100,000 /day) can negatively impact the development of robust drilling bits and 'smart' drilling fluids due to high initial costs. Large-scale testing under high-pressure conditions offers an economical alternative to high day rates and can prove or disprove the viability of a particular design or system.

Novel technologies such as percussion tools, impregnated bits, and deep drilling fluid ROP enhancers are 'tools' that can directly affect drilling performance. The net results for operators are improved profit margins and an improved position on reserves. Given the size of the problem, suppliers are willing to commercialize innovative designs, yet need assurance of marketplace volume. The larger operators in particular have regularly articulated publicly the need for such advances. Developments from this program will also have the capability to improve deep directional drilling performance thus will provide even more incentive for commercialization.

For operators faster penetration rates deep can positively affect asset or application economics. TerraTek has assembled a strong team, selecting a bit company and drilling fluid developer that has both the capability and willingness to develop new technology and reach a practical commercialization point. Hughes Christensen notes that the proposed work "has the potential to make a positive impact on the performance of drilling products to reduce exploration and development costs" for these deep applications. Applications for deep and oftentimes hard rock applications exist worldwide, thus making attractive the deployment of bits and fluids at an accelerated pace.

Tools, methods, instrumentation, products

For the future it is likely that the DeepTrek project will result in the commercialization of new diamond product bits achieving superior performance at depth. Perhaps more important will be an increased shift to marketplace delivery of drilling bit and *'smart-fluid'* combinations capable of even better drilling rates of penetration performance. Operators' expectations of access to such products will be met, though only in earnest when performance is demonstrated for deep plays by the prototype products. We fully expect the diamond product drilling bits and application specific *'smart-fluids'* to complement other equipment developments; examples include materials for tubulars and downhole tools, high temperature electronics, and the deployment of other reliable tools.

A. Judzis, Executive Vice President, TerraTek, November, 2004