

## **Characterization of Fractured-Rock Aquifers Using Drilling Parameters**

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### **Abstract**

Identifying fractures in contaminated rock from simple borehole investigations is an integral part of the USEPA-funded Bedrock Bioremediation Center project being conducted in southeastern New Hampshire. Characterization of underlying folded and dike-injected metasandstone and metashale of the Silurian Kittery Formation has been performed by drilling a series of cored 4-inch boreholes.

As part of bedrock characterization, a drilling parameter recorder (DPR) system provided continuous monitoring of the drilling advance and helped evaluate natural fractures. Drilling parameter recorders are computerized systems which monitor a series of transducers installed on conventional drilling equipment to collect data automatically on advance rate, downthrust and pull-up pressures, rod torque, rotation rate, mud/water pressure and flow, depth, and time. The data are displayed in real time in digital form and as hard copy and are stored on an electronic medium for further analysis.

Carefully logged cores summarize lithologic variability, fracture attitude, spacing, and fracture surface types, and provide the basis for comparison with the DPR logs, acoustic televiewer and video logs. Comparisons help determine how these methods can be used most effectively, separately or in combination, to maximize information about lithology and fracture patterns in a bedrock aquifer. Data collected by the DPR significantly enhance the quality of information obtained from the boreholes and have the potential to lead to improvements to drilling equipment and techniques. Such advances can increase efficiency, productivity, control of the drilling process and improve rock recovery.

The DPR system provides real-time geological profiling and the preliminary results clearly show that it can accurately detect fracture frequency and opening. DPR protocols are currently being developed that will provide in situ characterization rapidly and more cost-effectively, thus limiting the need for coring during rock investigations.

### **Introduction**

Successful application of in situ bioremediation techniques to fractured rock aquifers is highly dependent on our ability to characterize geological deposits accurately and economically. An ongoing bedrock bioremediation project, funded by the USEPA, has allowed researchers from the University of New Hampshire Bedrock Bioremediation Center (BBC) to evaluate and develop innovative methods to detect fracture patterns and direction of groundwater flow in a metamorphic rock formation in southern New Hampshire. A test site located at the Pease International Tradeport in Portsmouth, New Hampshire, has been selected for this study. The site, formerly part of the Pease Air Force Base, is contaminated with TCE (trichloroethylene) resulting from degreasing operations during equipment maintenance. Those contaminants migrated downward into the groundwater eventually finding their way to the weathered and competent bedrock. While TCE is the primary contaminant, other degradation products (dichloroethylene, DCE and vinyl chloride, VC) are present at different concentrations within the geologic profile. For this project, sets of paired boreholes approximately 30 feet apart and 200 feet deep are needed to develop protocols for bioremediation. Identification of connecting fractures between the pairs of boreholes will allow monitoring of groundwater and evaluation of the effectiveness of the bioremediation techniques. This paper briefly presents an innovative site characterization technique based on the recording of drilling parameters during the advance of each borehole.

## ***Site Geology***

The subsurface conditions at the test site consist of approximately 30 to 70 feet of Pleistocene glaciofluvial deposits overlying a relatively thin weathered bedrock zone followed by competent bedrock. Southeastern New Hampshire is underlain by Silurian and older metasedimentary rocks that are variably metamorphosed, tightly folded and faulted, and intruded by Paleozoic and Mesozoic igneous rocks. The bedrock in the area of Great Bay consists of biotite grade metasediments and metashales of the Kittery and Eliot formations. The Kittery Formation is typically comprised of alternating beds of calcareous feldspathic metasediment, some with well-preserved primary structures, and thin metashale intercalations. The Eliot Formation is a typically finer grained alternation of calcareous metasediment and metashale. Both units are tightly folded into asymmetric, northeast plunging anticlines and synclines overturned to the southeast. Abundant Jurassic diabase dikes occur throughout southeastern New Hampshire and are well exposed in the Great Bay area. Although rarely seen in the few outcrops at the Pease International Tradeport site, they have been encountered in all of the BBC boreholes drilled thus far. They maintain a dominant northeast-southwest strike with steep dips to the northwest or southeast.

## ***Drilling Parameters***

Thousands of miles of drilling occur annually in the United States. Unfortunately, very little useful information is retrieved from these borings because the majority are for water wells, monitoring wells and instrumentations. For soil exploration, the boreholes typically yield discrete information at 5 feet depth interval, while in rock, the profiling often relies on cuttings. A system known as drilling parameter recorders (also known in the oil exploration industry as measurements while drilling, MWD) can provide continuous characterization of the subsurface while drilling any borehole. The DPR consists of a computerized system which monitors a series of transducers installed on conventional drilling rigs. These various sensors collect data on all aspects of drilling, in real time, without interfering with the drilling process. The measurements recorded include advance rate, downthrust and pull-up pressures, rod torque, rotation rate, mud/water pressure, mud/water flow, depth and time. The data from the different parameters are acquired automatically by simply pushing a button on a recorder operated by the driller or the drill inspector. The data are displayed in real time on a strip chart and on an LCD screen and all information is stored on electronic medium for further analysis. The system is compact, portable, waterproof and rugged. Installation of the sensors for pressure measurements simply requires tee-connectors onto the appropriate hydraulic or water/mud lines. For the rotation speed, an electromagnetic sensor uses the bolt pattern on the rotating head to determine the revolutions per minute. The depth is measured using a pulley system mounted on the mast and attached to the drill head. For this project, water flow is measured using two flowmeters. One flowmeter measures the inflow while the second flowmeter intercepts the return water using a tee-connection as it exits the borehole. A typical concatenated output from borehole BBC-4 is shown in Figure 1 for depths of 100 to 122 feet. The parameters are recorded as a function of depth rather than time. The recording depth interval is 0.2 inch. Figure 1 shows all recorded parameters in English units (the system can handle both SI and English units). The delta flow column is a calculated value and represents the difference between the inflow and the outflow.

Drilling parameters can be used to achieve multiple objectives. Applications include improvement in drilling efficiency, management of drilling operations from the ground surface to the final depth of the boring, detection of voids, fissures or other anomalies and, evaluation of properties of soils and rocks. The application of the DPR technology to the BBC project is significant. Measurements have allowed the driller to make real-time adjustments to improve the rock core drilling in terms of quality and recovery. Real-time geologic profiling has helped determine transitions between weathered and competent bedrock. Of interest is the detection of fractures and the recorded drilling parameters are currently being analyzed to develop a procedure for identifying fractures. Using individual DPR measurements, fractures may be identified by observing a sudden increase in advance rate depending of the fracture aperture and orientation, and/or a sudden decrease in water/mud pressure as well as an increase in water inflow and an associated decrease in return flow. Nevertheless, variations in the drilling parameters are interpreted to indicate the presence of fractures, changes in lithology, and competency of

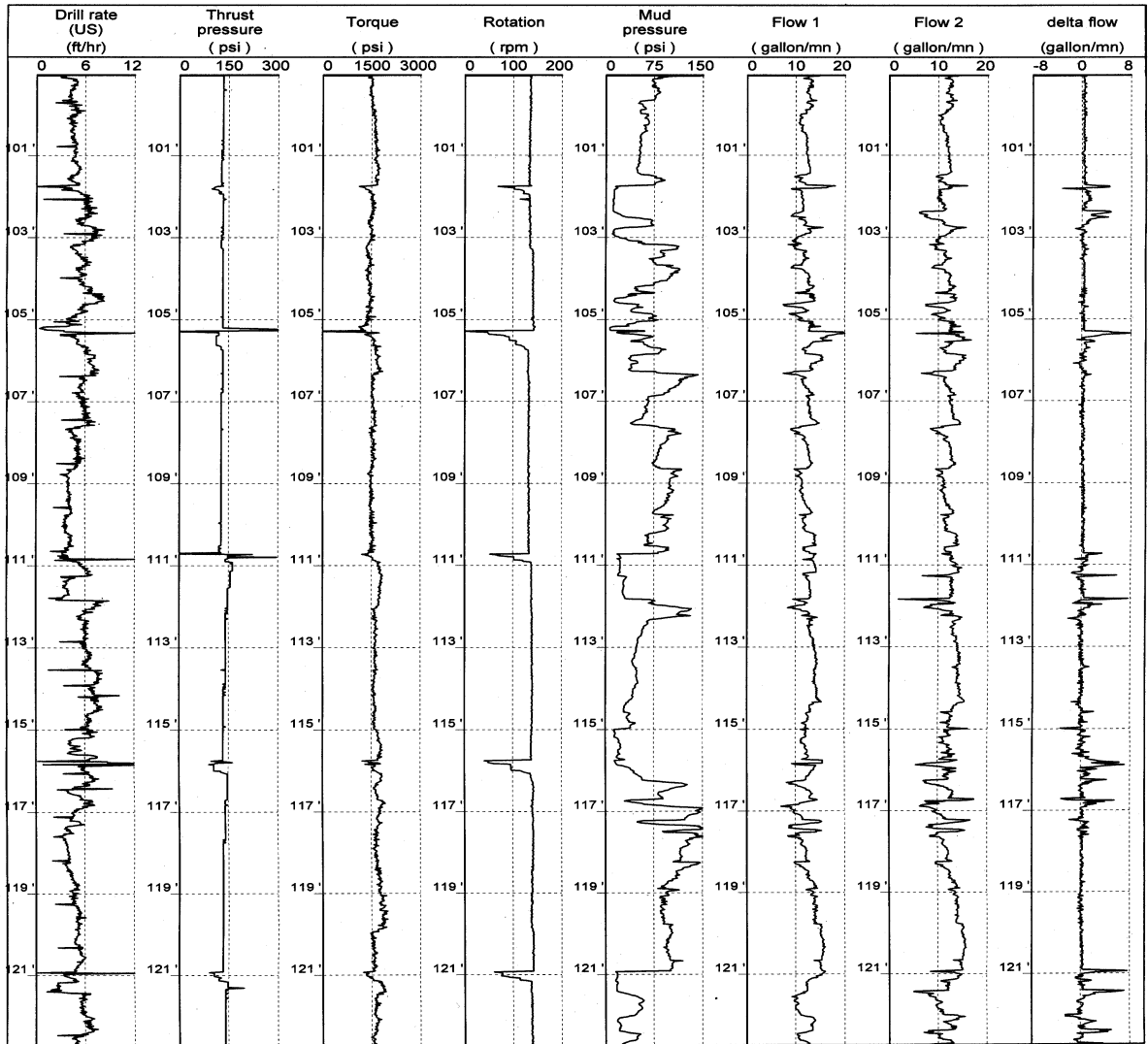


Figure 1: Typical Drilling Parameter Recorder Log

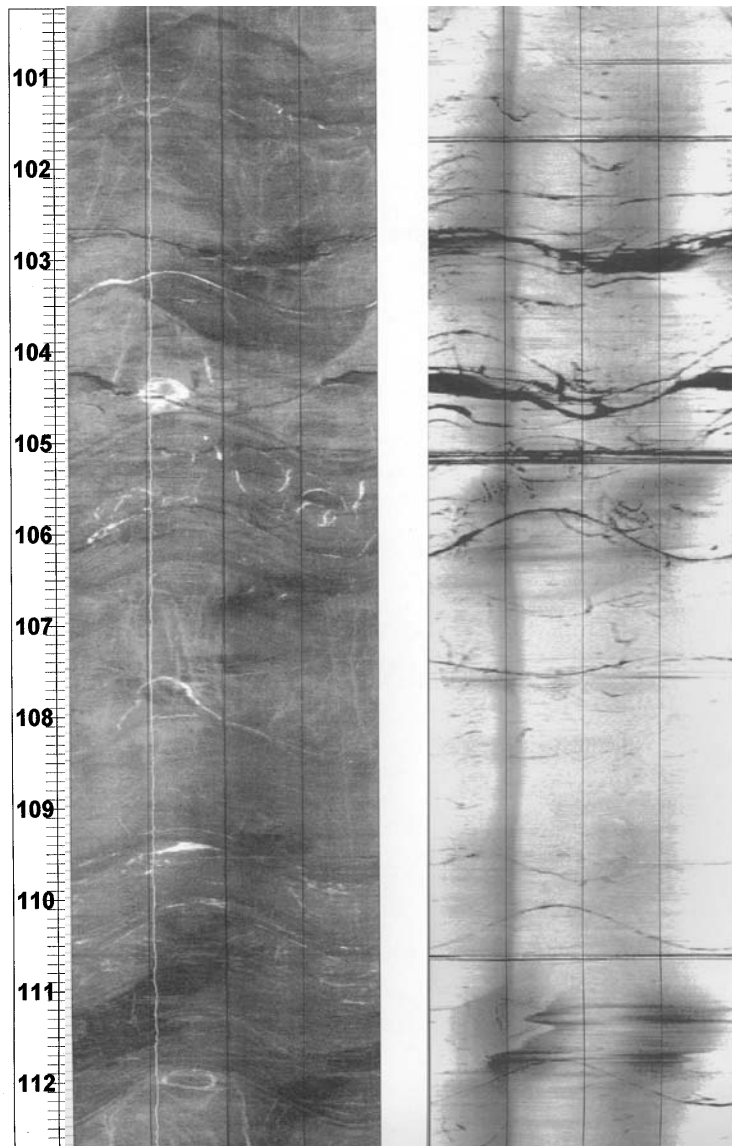
the bedrock. Several methods of interpretation have also been developed using compound parameters. Those compound parameters simply combine individual parameters into expressions of energy or empirical indices reflecting the resistance of the geological material to drilling. As an example, Pfister (1985) presents the following energy parameter ( $W$ ) formulation:

$$W = \frac{c \omega}{V} \text{ or } c \omega D_t$$

where:

- $c$  = rotation torque
- $\omega$  = rotation speed
- $V$  = instantaneous penetration rate
- $D_t$  = time needed to drill a layer 5 mm thick

Current formulations being used on the BBC DPR data do not include inflow and mud/water pressure parameters. Efforts to develop new compound parameters that would include these parameters are being investigated. DPR results are also being compared to measurements from geophysical methods such as videologging and acoustic televiewer monitoring as well as with direct physical evaluation of the rock cores in an effort to better predict, in situ, the location and frequency of fractures in the bedrock. The rotation profile



on the partial DPR log in Figure 1 clearly shows the starting and stopping points of each core run. For example, depths of 101.8 and 105.4 feet are starting depths for the five-foot core runs. Figure 2 shows the optical and acoustic televiewer logs obtained from BBC-4 following borehole completion. These logs provide a view of the wall cavity. The optical and acoustic logs at depths of 102.6 to 103.1 feet and 104.2 to 104.6 feet clearly indicate the presence of fractures and for those features the DPR shows a decrease in mud pressure along with a corresponding increase in flow. The drill rate also shows an increase at the same depth. DPR systems are not typically used when advancing a core barrel and thus at this point the data interpretation is in the early stages. As the triple core barrel (includes a Lexan liner) advances into the rock, the water inflow and pressure may vary if clogging occurs within the barrel system. Since the return flow (flow 2) is recorded at the same depth as the inflow (flow 1) but represents different time events (the water inflow is measured before entering the hole while water return is measured after exiting the borehole), it is difficult to predict clogging and fractures based solely on water pressure and flow measurements.

## Conclusions

The use of drilling parameters measurements can potentially provide a significantly improved subsurface characterization at a modest investment of time and cost. For the BBC project in New Hampshire, the DPR has already helped improve the drilling and reduce the amount of fluid being introduced and lost into the aquifer. From the results of this investigation, a protocol for drilling and for the use of the DPR will be developed for future sites and for other geological conditions.

## Acknowledgements

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## Reference

Pfister, P. (1985) *Drilling Parameters Recording in Soil Engineering*, Ground Engineering, April.

Figure 2: Optical and Acoustic Televiewer Log