EVALUATION OF THE MICRO-CORE QUALITY USING DRILLING MECHANICS DATA

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ABSTRACT
Micro-cores of formations during conventional drilling operations (from 10 to 40 mm diameter depending upon application) can be continuously generated using specific drill bit. However, micro-core sample conditions may be adversely affected during the drilling and circulation process. The efficient recovery of micro-cores depends on many engineering factors such as drilling depth, wellbore conditions, formation hardness and cutting structure of the bit, etc. Field tests were conducted with a newly developed micro-core bit (MCB) in a shallow hole in order to eliminate the influence of core damage during the circulation process to the surface. Instrumented drilling was carried out to record and monitor the drilling mechanics data such as weight-on-bit (WOB) in order to study their influence on micro-core recovery and quality. After drilling tests, the micro-cores were recovered at the exit of the hydraulic system. Manual screening of the mud allowed recovery of the cores along with the larger cuttings generated by the MCB. The key to successful coring lies in optimizing the parameters affecting overall bit/rock interactions and control of the cutting mechanisms. Prior to any field operations, initial tests were carried out to assess the performance of the MCB. Drilling mechanics data such as rate of penetration (ROP), WOB, torque and rotary speed of drill-pipe, flow rate, pump pressure were acquired along with the drilling depths. Although core recovery was sufficient in the initial tests, the micro-core samples were partially damaged under various drilling mechanical settings. Here, we will provide an overview of our tests and propose an evaluation method using the micro-core quality index.

INTRODUCTION
Core is the principal product for formation evaluation in both scientific drilling and the exploration of oil and gas resources. However, typically, core sampling requires significant operational time with either a conventional core barrel or wire-line retrievable type coring system or even sidewall coring. Logging-while-drilling (LWD) is particularly important in evaluating formations prior to coring by *in-situ* measurements and analysis of the physical properties. If the downhole conditions (HPHT) exceed the LWD specifications, accessing critical geological information will necessarily require a challenging coring job, dramatically increasing the operations time and thus the cost of the well. In order to solve these problems, a micro-core bit (MCB) developed by major

oil company has been employed in several field tests as well as deep-sea drilling operations. This MCB can cut small cores (approx. 1 inch in size depending on application) continuously while drilling, and lift these core samples to the surface while discarding cuttings into the annulus between the BHA and borehole, thus preventing bit clogging. The cores obtained with this MCB do not require the pulling of a whole string as with conventional methods. This has been the first deployment of this MCB technology in Japan and we are now carrying out field tests to test its effectiveness.

OVERVIEW OF MICRO-CORE BIT

Figure 1 shows a typical MCB concept (Deschamps, et al., 2008, Desmette, et al., 2008, Shinmoto, et al., 2011). The micro-core is generated in the center of the bit where the cutting-structure is interrupted. [1] The micro-core is cut at the center of the polycrystalline diamond compact (PDC) cutters. [2] Advancing to its nominal size, it may reach a resistant material (PDC stop). Lateral force is applied on the core, inducing shearing. [3] The micro-core is then led to the annulus via the slot (evacuation area). This area is larger and deeper than a conventional hydraulic waterway. Keeping this transit area open prevents any risk of balling to the cutting structure.

Figure 2 shows an 8-1/2" size PDC drill bit with specific MCB adaptations. The new MCB uses an enlarged slot between the two front blades to channel the core into the borehole annulus. This slot remains open, preventing any risk of bit plugging. Moreover, the slot with the dedicated central hydraulic nozzle does not become clogged and can maintain a sufficiently clean area. In the present example of a 8-1/2" bit, the standard core sample dimension is 25 mm in diameter by 50 mm in length for transit into the annulus between the bottom hole assembly (BHA) (5 ~ 6") and borehole (8-1/2").

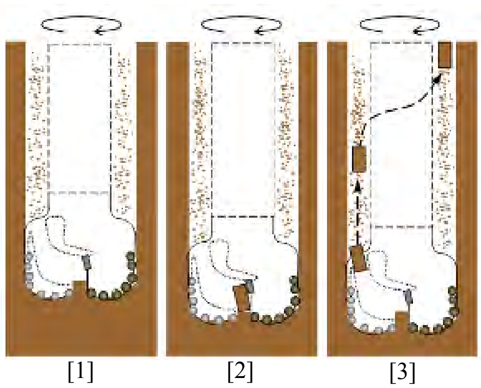

Figure 1: Schematic drawing of the MCB concept

Figure 2: 8-1/2" Micro-core bit (PDC type)

EXPERIMENTAL EQUIPMENT

Tests were carried out to optimize the parameters affecting bit/rock interactions and control of the cutting mechanisms as well as to assess the MCB performance. Field tests were conducted with the new MCB at a drilling site of the drilling equipment manufacturer, NLC, Ltd., in Hitachi-Omiya City, Ibaraki Prefecture, Japan. **Figure 3** shows the system for the field tests. Several rock samples were selected and installed in a cage and set at the bottom of a 1 m diameter borehole (approx. 11 m from ground level). The height of the rock sample was approx. 1.5 m with a width of 70 cm. The kelly-driven drilling machine (**Figure 4**) has a maximum axial thrust capacity of 80 kN and rotation speed of 400 revolutions per minute (RPM). A 5-1/2" liner in the mud pump was set at a maximum flow rate of 1,400 liters per minute (LPM) and maximum pump pressure of 15 MPa. The field tests were conducted with instrumented drilling to record and monitor the drilling parameters (i.e., weight-on-bit, etc.), then to study their influence on micro-core recovery and quality. The unit housed a computer as well as data logger. The data scan rate was 1 point per 100 msec. KCL polymer mud was used and the mud weight was 10.0 ~ 11.6 ppg (specific gravity 1.2 ~ 1.4). A 10" inner diameter (ID) size casing was mounted at the top of the rock sample to efficiently return drilling fluid and micro-cores to the surface. **Figure 5** shows the mud return line at the surface. A steel screen was set to catch the micro-cores before gathering to the shale shaker. Since the grain size of the cuttings was very fine (less than 0.1~5 mm), most of cuttings could pass through the mud screen (7 mm).

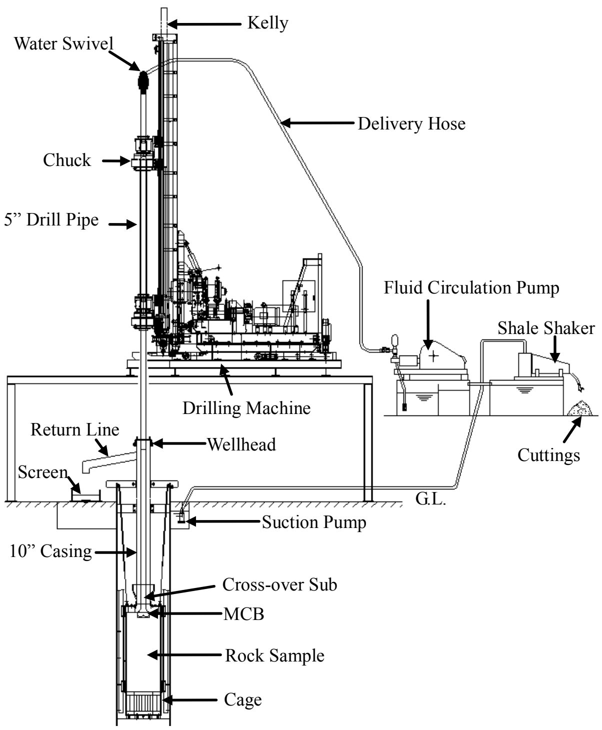

Figure 3: Schematic of field test equipment

Figure 4: Drilling system for field tests

Figure 5: Mud return line to retrieve Micro-cores

ANALYSIS OF THE MICRO-CORE QUALITY

Experimental Results

During the field tests, a total of 8 micro-core samples were successfully obtained by the 8-1/2" PDC type MCB. **Table 1** shows the experimental cases and results such as core recovery. For Case #7, during drilling, the bottom fell out of the Oya-tuff rock sample so that several micro-core samples could not be tested.

The primary rock samples properties of Ashino-andesite [dry bulk density: 1.9 g/cm^3, Unconfined Compressive Strength (UCS): 14 MPa], white marble (dry bulk density: 2.6 g/cm^3, USC: 122 MPa), and Oya Tuff (dry bulk density: 1.4 g/cm^3, UCS: 7.0 MPa) were measured by a conventional geotechnical method based on Japanese Industrial Standards (JIS). The BHA above the MCB was changed to run an industry standard 6-3/4” Drill Collar (DC) with two 8-1/4” stabilizers for 8-1/2” hole section drilling. Although efficiency in the MCB is an important factor, high core sample recovery and quality can be considered the most essential points in our deep-sea drilling operations.

Table 1: Experimental results using a 8-1/2” PDC type Micro-core bit (MCB)

Case#	Rock sample	Mud Weight (ppg)	BHA above MCB	Micro-core recovery (%)
1	Ashino-andesite	10	5-1/2” Drill pipe Slick	Nearly 100
2	Ashino-andesite	11.6	5-1/2” Drill pipe Slick	Nearly 100
3	Ashino-andesite	11.6	6-3/4” DC with 8-1/4” stabilizers (x 2)	Nearly 100
4	White marble	11.6	5-1/2” Drill pipe Slick	Nearly 100
5	Ashino-andesite	11.7	5-1/2” Drill pipe Slick	86
6	Ashino-andesite	11.7	6-3/4” DC with 8-1/4” stabilizers (x 2)	Nearly 100
7	Oya-tuff	11.7	6-3/4” DC slick	78 (The bottom fell out of the rock sample)
8	Oya-tuff	11.7	5-1/2” Drill pipe Slick	91

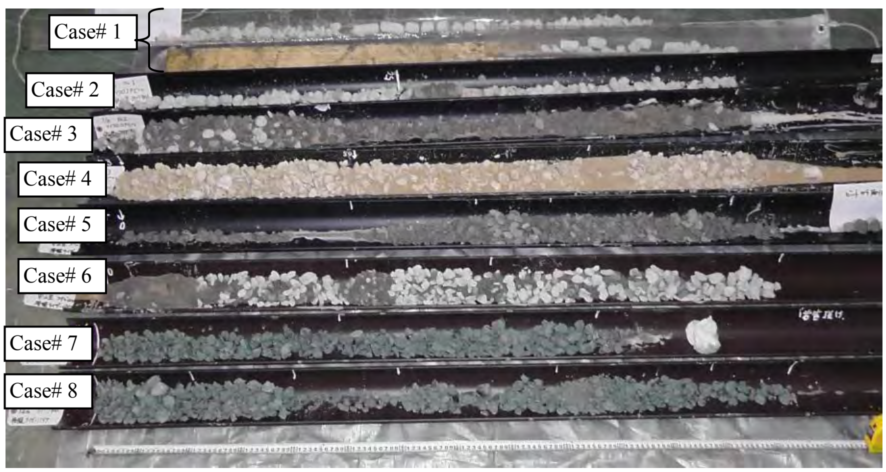

Figure 6: Micro-core samples from experiments (From top to bottom, Case # 1~8 in Table 1)

Drilling Parameters

Figure 7 shows drilling parameters such as rate of penetration (ROP), weight-on-bit (WOB), torque and rotary speed of drill-pipe, flow rate, pump pressure (PP) and the micro-core samples (Case #1) along with the drilling depths. Core recovery (versus 1.4 m cored length) was sufficient for the initial tests. However, the conditions of the micro-core samples were partially damaged under various drilling parameter settings.

At a depth of 0.78 m, the core quality suddenly decreased with the slightly higher ROP. The flow rate was lowered to 1100 LPM to prevent any annulus turbulence damage to the cores. The micro-core quality improved slightly and the half length of the specifications were recovered. However, at a depth of around 1 m, the ROP decreased suddenly and there was almost no progress in the drilling (0.1 m/hr), possibly due to broken micro-cores jamming in the tip of the MCB. Since drilling was no longer in progress, the rotary speed was reduced (25 RPM) and WOB increased (30 kN). Drilling was then resumed and the ROP was also increased to 3 m/hr. After changes in the drilling parameters (WOB, rotary speed, flow rate), micro-core recovery and quality were greatly improved. After a depth of 1.2 m, the rotary speed was increased again to 40 RPM. ROP decreased since the torque-on-bit was insufficient for efficient coring. The micro-core quality had deteriorated by the end of drilling.

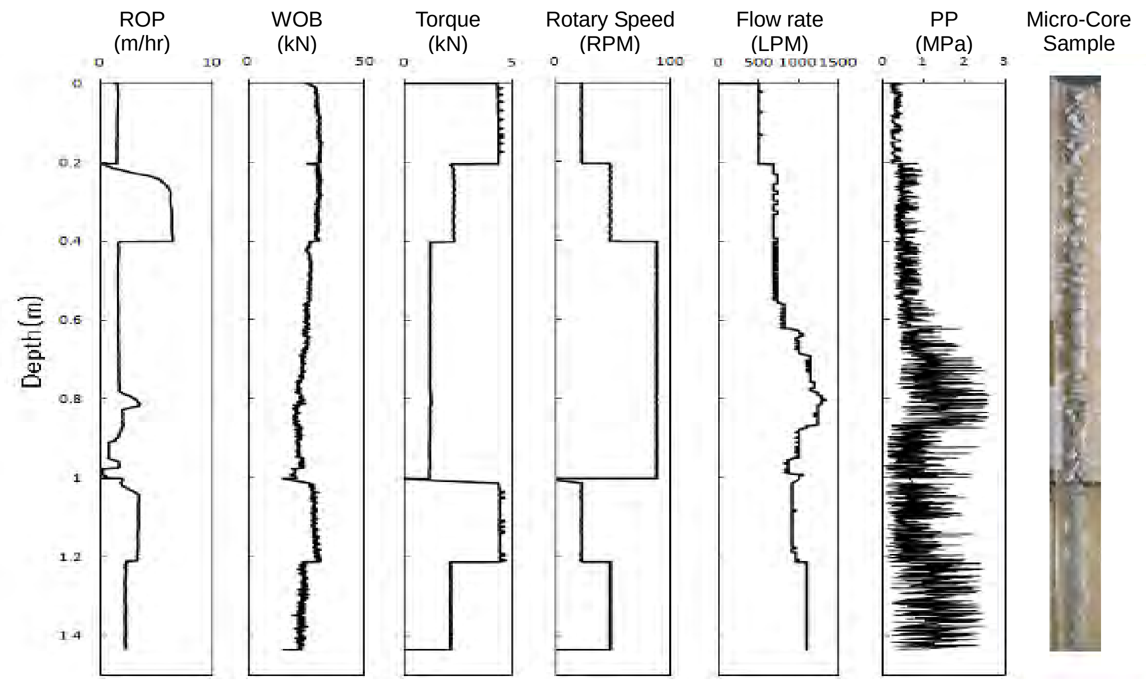

Figure 7: Drilling Parameters for Micro-Core Samples (Case #1)

Evaluation Method Proposal for the Micro-core Quality

In order to analyze the micro-core quality, an evaluation method was established to determine the micro core quality. The micro-core samples were cut in a cylindrical shape (2-inch length, 1-inch diameter for a 8-1/2" PDC type MCB). Grain size analysis was carried out to identify damage of the micro-core shape during drilling and lifting. Each micro-core sample was investigated one by one with a sieve (size 0.5 ~ 6 cm in 0.5 cm/per step) and slide caliper to identify the actual minimum and maximum size of the micro-core. **Figure 8 (top)** shows the micro-core samples along with the drilling depth acquired for Case #1. **Figure 8 (middle)** shows the minimum and maximum diameter of the micro-core sample along with the drilling depth. The long side may be more damaged during drilling and the core length reduced. An equation to calculate the micro-core quality index (MCQI) and value of the MCQI along with the drilling depth is proposed for Case #1, as shown in **Fig. 8 (bottom)**:

$$MCQI = \frac{(d\,\text{max}/\,50) + (d\,\text{min}/\,25)}{2}$$

d_{max}: maximum dia. of the micro-core (mm), d_{min}: minimum dia. of the micro-core (mm).

High MCQI is observed at the depth from 40 to 70 cm as well as 120 ~ 135 cm, which was similar to our view from the picture.

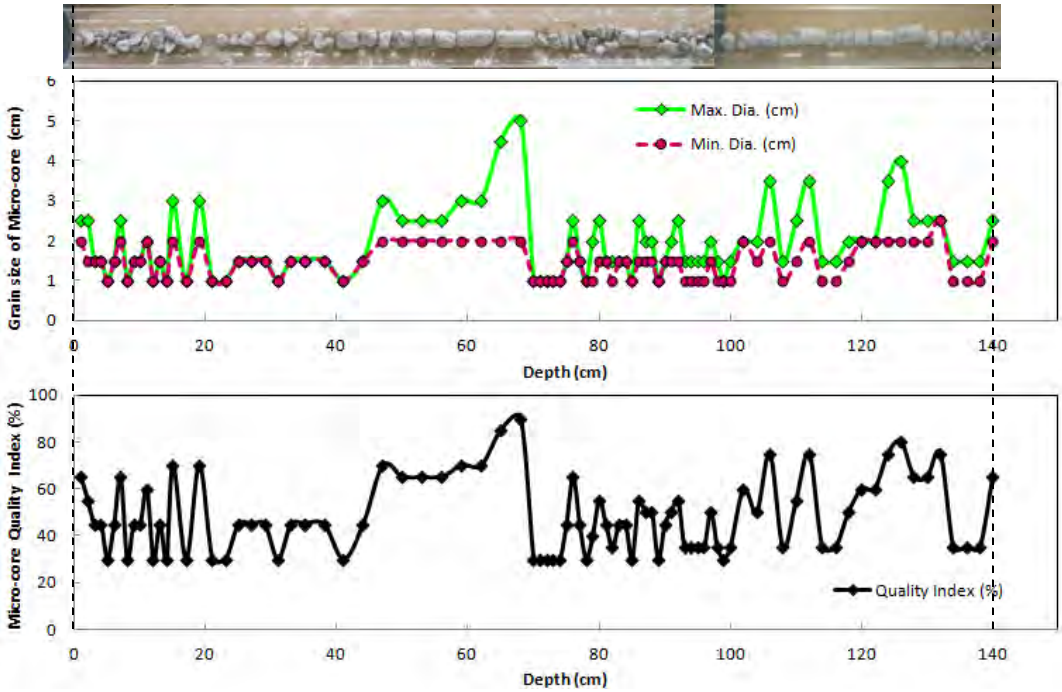

Figure 8: Grain size (Max., Min.) and Quality Index for Micro-core samples for case #1

CONCLUSIONS

This paper demonstrates an overview of the MCB from field test results. This study evaluates the drilling parameters along with the micro-core samples and proposes an evaluation method to determine the micro-core quality. Experimental results showed the potential for improvement in such operational areas as drilling, lifting capability and geological evaluation with higher micro-core quality. Deeper investigations are currently in progress with the MCQI in relation to the drilling parameters (WOB, ROP etc.). In field operations, definition of specific drilling practices, including bit and BHA design, operational parameter monitoring and specific adaptations at the shale shakers are required to optimize micro-core recovery.

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